Shabbir A. Shahid
Mahmoud A. Abdelfattah
Faisal K. Taha
Editors

Developments in Soil Salinity Assessment and Reclamation

Innovative Thinking and Use of Marginal Soil and Water Resources in Irrigated Agriculture

Environment Agency - ABU DHABI
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Environment Agency - ABU DHABI

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Foreword

Productive and fertile soils are a scarce resource in the arid and especially in the hyperarid desert environments. Most often, these areas suffer from scarce fresh water resources which necessitate the use of marginal quality water for agriculture. The improper use of marginal quality water and poor management of soil and water resources can lead to soil salinization, which in addition to causing reduction in crop yield has been identified as the major land degradation process in many countries. It is therefore essential to understand the salinity hazard spatially and temporally for proper management to enhance soil services for many uses.

Nearly 10% of the total land surface (over 1 billion ha) is covered with different types of salt-affected soils. The process of soil salinization is dynamic, and soil salinity is widespread and distributed over 100 countries, and no continent on the globe is free from such soils. Saline soils are not only common in desert and semidesert regions but also frequently occur in fertile alluvial plains. There exist conventional and modern techniques to assess soil salinity from farm to national and regional levels.

Recognizing this need, the idea emerged to organize an international conference and invite top-level experts in soil science and related disciplines to discuss the recent developments in soil salinity assessment and monitoring, as well as optimum use of marginal quality water for agriculture for better agricultural and environmental outcomes in the future. Enhanced agriculture production and more sustainable outcomes are critical to improve food security.

The international conference, "Soil Classification and Reclamation of Degraded Lands in Arid Environments," was held under the patronage of H.H. Sheikh Hamdan bin Zayed Al Nahyan (Ruler's Representative in the Western Region Abu Dhabi and Chairman of Environment Agency–Abu Dhabi (EAD)) in 17–19 May 2010. It proved to be the ideal forum to share and discuss latest developments in soil salinity assessment and use of marginal quality water in agriculture.

During the conference, broad issues related to the high-tech in soil salinity assessment, salinity management and reclamation, biosaline agriculture and salt-tolerant mechanisms in plants, and opportunities and challenges in using marginal water were raised. It is these topics which are presented in this book to assist in a better understanding of saline soil and water resources to ensure sustainable environmental and agricultural use.

I wish to thank H.E Mohammed Al-Bowardi (managing director EAD), H.E Majid Al Mansouri, then secretary general EAD, and Her Excellency Ms Razan Al-Mubarak (secretary general EAD) for their inspiration and respective endeavors to ensure the success of the conference and subsequent publication of its proceedings.

Director General, International Center for Biosaline Agriculture
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Shawki Barghouti

Preface

This book is the outcome of an International Conference on Soil Classification and Reclamation of Degraded Lands in Arid Environments held during 17–19 May 2010 in Abu Dhabi, United Arab Emirates. The Environment Agency – Abu Dhabi (EAD) and Dubai-based International Center for Biosaline Agriculture (ICBA) jointly organized the conference. The main objective of the conference was to bring renowned scientists, educators, and policy makers to share and discuss conference technical themes in broader perspectives.

We received overwhelming response to the call for papers, and over 250 abstracts were received from over 35 countries. The abstracts were reviewed, and those suitable were accepted for the submission of full manuscripts. The diversity of the conference themes made it necessary to publish these papers into two independent books. Prior to publication of the papers, all preselected papers went through rigorous technical review and through an iterative review process with authors before finalization for publication.

The papers published in this book "Developments in Soil Salinity Assessment and Reclamation: Innovative Thinking and Use of Marginal Soil and Water Resources in Irrigated Agriculture" represent part of the conference proceedings. The rest of the papers are published in a separate book, "Developments in Soil Classification, Land Use Planning and Policy Implications-Innovative Thinking of Soil Inventory for Land Use Planning and Management of Land Resources (Shahid SA, Taha FK and Abdelfattah MA (eds))."

In this book, papers pertaining to high tech in soil salinity mapping and monitoring, management and reclamation of salt-affected soils, use of marginal quality water for crop production, salt-tolerance mechanisms in plants, biosaline agriculture and agroforestry, microbiological interventions for marginal soils, opportunities and challenges in using marginal waters, and soil and water management in irrigated agriculture are presented in eight parts divided into 52 chapters.

Part I deals with advanced technologies in soil salinity assessment and monitoring using remote sensing, geographical information system, modeling, and geostatistics, and examples from Egypt, India, Iran, Morocco, South Africa, Spain, Thailand, UAE, USA, and Uzbekistan are presented. The experience of management and reclamation of soils from China, India, Oman and Pakistan, is presented in Part II. The research on the use of marginal quality water for crop production in Australia, Bangladesh, Egypt, Italy, Morocco, Tunisia, UAE, and USA is included in Part III. Mechanism of salt tolerance in plants is discussed in Part IV including work from Germany and Morocco, whereas in Part V the work from various countries (Egypt, India, Italy, and Uzbekistan) on biosaline agriculture and agroforestry is detailed. A paper on microbiological interventions on marginal soils from Pakistan is included in Part VI. Opportunity and challenges in using marginal waters are presented in Part VII (Egypt, sub-Saharan Africa), and work on soil and water management in irrigated agriculture (Algeria, Egypt, Iran, Morocco, Pakistan, and UAE) are included in Part VIII.

We hope the book will be an excellent addition and contribution to the science and knowledge of soil salinity assessment and monitoring using advanced techniques and use of marginal soil and water resources in irrigated agriculture. We believe the adoption of relevant technologies in specific areas may ultimately lead to optimize crop production in developing countries of arid, semiarid, and desert environments, the regions highly vulnerable to the impact of climate change and food insecurity.

Shabbir A. Shahid
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About the Editors

Shabbir A. Shahid is salinity management scientist at Dubai-based International Center for Biosaline Agriculture (ICBA). He earned his Ph.D. degree from the University of Wales, Bangor, UK, in 1989 and B.Sc. Hons and M.Sc. Hons (soil science) from University of Agriculture, Faisalabad (UAF), Pakistan, in 1977 and 1980, respectively. He joined ICBA in 2004 and has over 30 years experience (Pakistan, the UK, Australia, Kuwait, and United Arab Emirates) in soil-related RD and E activities. He has held positions: associate professor soils (University of Agriculture Faisalabad, Pakistan); associate research scientist in Kuwait Institute for Scientific Research, Kuwait; and manager of soil resources department, Environment Agency – Abu Dhabi, UAE. He is a prolific author of over 150 publications in peer-reviewed refereed journals, proceedings, books, and manuals. He is life member and current councilor of the World Association of Soil and Water Conservation. Dr. Shahid is recipient of Sir William Roberts and David A. Jenkins Awards.

Mahmoud A. Abdelfattah an Egyptian national, earned M.Sc. degree in Soil Survey and Land Evaluation from ITC, the Netherlands (1998), and Ph.D. in soil science from Cairo University, Egypt (2002). He joined UAE University in 2000, and in 2002 he joined the Environment Agency–Abu Dhabi, as soil scientist. He was seconded to ICBA as deputy technical coordinator for Soil Survey of Abu Dhabi Project (2004–2009). Dr. Abdelfattah is currently a deputy manager, Soil and Land Use Management section, at EAD and managing Soil Survey of the Northern Emirates Project; he is also an associate professor at Fayoum University, Egypt. He has over 20 years experience in teaching and research. He participated in a number of international conferences, managed number of technical projects, and is author or co-author of over 50 published scientific papers.

Faisal K. Taha is director of technical programs at Dubai-based International Center for Biosaline Agriculture (ICBA). He earned Ph.D. degree from the University of Wyoming and has over 30 years of professional experience in research and development in the USA, Canada, Kuwait, and the United Arab Emirates. He has held key positions as project leader, program manager, department manager, chairman, professor, and technical program director at the Kuwait Institute for Scientific Research, Canada's Agriculture Development Fund, UAE University, and ICBA. Dr. Taha is an accomplished researcher and scientist with over 100 publications in refereed journals, proceedings, technical reports, and scientific books. He is also the winner of various regional and international awards in agricultural research and development.

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I would like to express my thanks and appreciation for the assistance received from the management of the Environment Agency – Abu Dhabi (EAD) and the International Center for Biosaline Agriculture (ICBA) in organizing the conference and publication of this book. I would like to thank H. E Majid Al Mansouri, the secretary general of EAD at the time and the chairman of the conference, for his support, guidance, and encouragement. The staff from EAD and ICBA was instrumental in the planning and organizing of the conference and deserve recognition and special thanks. The contribution of members of both steering and technical committees is greatly appreciated.

Special thanks go to Dr. Shawki Barghouti, director general of ICBA, for his kind support and approval of funds to publish the proceedings of the conference. H.E Razan Khalifa AlMubarak, secretary general of EAD, endorsed this publication, and we extend our thanks to her. Also special thanks to H. E Dr. Jaber Eidha Al Jaberi, deputy secretary general of the Environment Agency – Abu Dhabi for his support. My sincere acknowledgements go to the editors of this book, as well as to Dr. Henda Mahmoudi, visiting scientist, and Ghazi Jawad Al-Jabri, communications coordinator, whose professionalism, dedication, and careful review facilitated the printing. The Springer Publishing House deserve "thank you" for taking the challenging task of publishing this book and assisting with its distribution.

Last but not least, thanks to all the competent scientists and partners for their invaluable contributions that made it possible to produce these proceedings.

Chairman — Faisal K. Taha
Technical Committee
International Conference on Soil Classification and
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Part I
High-tech in Soil Salinity Mapping and Monitoring

Chapter 1
Developments in Soil Salinity Assessment, Modeling, Mapping, and Monitoring from Regional to Submicroscopic Scales

Shabbir A. Shahid

Abstract Soil salinity spreads in more than 100 countries, and no continent is completely free from salinity. The level of salinity problem varies trans-country and even within the country at different locations, landforms, and irrigated agriculture regions to farmers' fields. Local climatic, environmental, and management conditions determine the salinity problem. Current global estimates reveal over one billion ha area affected to various degrees of soil salinization. Soil salinization in the coastal areas due to seawater intrusion developed very strongly saline soils called sabkha. Human-induced salinization occurs in irrigated agriculture farms due to poor management of soil and water resources, high water table, poor drainage conditions, and the use of saline-brackish water for irrigation with less emphasis on leaching fraction. There have been significant innovative advancements in technologies to assess, map, and monitor soil salinization spatially and temporally, from regional, national, to farm levels and submicroscopic scales. In this chapter, a comprehensive array of routine and modern techniques to address salinity issues at various scales using remote sensing and GIS, geophysical methods, and modeling are presented to guide stakeholders for the selection of appropriate technology to suit their needs and budget. A comprehensive review of such technologies and their applications has been included in this chapter, and salinity diagnostic procedures from regional to submicroscopic levels with relevant examples are described. Soil salinity classification systems used in various countries such as Australia, China, FAO-UNESCO, Russia, the USA, and Vietnam have been described. The chapter also presents global distribution of salt-affected soils.

Keywords Geophysical • GIS • Soil salinity • Submicroscopic • Thin section

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1.1 Introduction

Soil salinity and humanity live beside each other since centuries. There is evidence in Mesopotamia that early civilizations flourished and then failed due to human-induced salinization. Parallel to population growth, such as for the last four decades, it has been doubled, by 2050 it will increase to 9 and 11 billion by 2100. In 1997, 4.8 billion of the world's 5.8 billion people (83%) were living in developing countries (FAO 1997). Soil salinization is also increasing around the world, especially in poor developing countries. The main reason of salinity increase is due to forced intensification of agriculture for short-term benefits, ignoring long-term consequences for soil services to meet food demand, and poor management of soil and water resources. Soil salinization has been identified as the major cause of land degradation. It is, therefore, very important to understand the salinity hazard spatially and temporally.

The soil salinity is dynamic, globally spreading over more than 100 countries, and no continent, even Antarctica (originally thought to be free from salinity but glaciers), is not completely free from salinity. It is a global-regional-national-ecosystem-farm level concern to all of us. It is projected that soil salinization is likely to be increased with future climate change scenarios like sea level rise and impact on coastal areas and rise in temperature that will subsequently increase evaporation and salinization. Salinization can affect ecosystem to a level where it cannot provide environmental services to its full potential.

In agriculture regions, soil salinity varies widely vertically, horizontally, and temporally, depending on such conditions as variation in soil texture, plant growth, quality of irrigation water, hydraulic conductivity, irrigation system in place. In general, salinity mapping and monitoring plan must be a part of any project dealing with the use of irrigation water with salinity/sodicity component. In agricultural farms, an effective salinity monitoring plan must be prepared to trace salinity changes particularly in the root zone to oversee the impact of management options used to overcome or reduce salinity effects and to assure that root zone salinity does not increase above crop threshold level to avoid yield losses. At the regional and national level, such monitoring program helps identify the problem and areas at risk for salinization and, hence, helps policymakers to take necessary and timely action to tackle the issue to avoid spreading to other areas that may have significant impact on national economies through degrading soil resources.

The knowledge and data gained from remote sensing of saline soils is used heavily in agricultural uses all over the world. The RS images taken over a period of time are used to (1) monitor the progress of the reclamation projects to insure the processes are being carried out accordingly and that the soil is being returned to its original condition and (2) predict areas at risk. Salinity monitoring of agricultural fields and salt-affected soils as well as sodium-bearing minerals (halite NaCl) is important to manage agriculture fields for better production. By knowing soil salinity, salt-tolerant crops, whose salinity threshold values are matching to salinity zones, can be selected to assure better behavior of crops. This is particularly important in impoverished regions where agriculture is at high risk and food shortages are a reality. The knowledge gained from the new monitoring techniques, along with that generated by decades of painstaking field research, is offering many insights to the causes of salinization. Such monitoring program, aids scientists to predict sites most at risk of waterlogging and salinization so that preventative measures such as where to establish plantation eliminate waterlogging "through biodrainage" at the areas of risk.

Monitoring determines periodic changes in soil salinity. Soil salinity mapping at the regional, national, and farm levels is becoming increasingly important for decision making and managing these resources. It is important where salinity occurs, to generate soil salinity information to determine extent and further risk of salinity, of which salinity assessment, mapping, and regular monitoring have a great role to play. Various researchers (FAO 2009) have assessed and monitored salt-affected soils at national and regional scales, for example, irrigated Arab agriculture (Abdelgawad 2009), India (Singh and Mandal 2009), Thailand (Im-Erb and Sukchan 2009), Iran (Cheraghi et al. 2009), Egypt (Gomaa 2009), China (Yang 2009), and Sudan (El-Mubarak 2009). The aim of soil salinity mapping is to know temporal subtle salinity differences in the landscape and to develop salinity zones to help design management plan for sustainable use of soil resources. Managing saline soils is highly site specific and depends on factors such as nature of soils, soluble salts, and local hydrological conditions.

In this chapter, significant efforts have been made to present review of technological advancements and their application in soil salinity assessment, mapping, and monitoring, such as remote sensing, geographical information system, modeling, geophysical, field to submicroscopic levels, and routine procedures, by giving appropriate examples, suitable to address the needs of various stakeholders at various levels (farm-national-regional scales).

1.1.1 Salinity and Sodicity Conception

To soil scientists, the concept of salinity and sodicity is crystal clear as they studied it from prep of soil science to postgraduate levels; however, experience shows that non-soil scientists many times consider salinity and sodicity of similar meaning. Definitions of both are simple and straightforward, but to clarify at all levels, they are briefly defined here.

Salinity is a measure of the concentration of all the soluble salts in soil or water as electrical conductivity (EC). From saline soil definition point of view, when EC of soil extract from saturated paste equals or exceeds 4 dS m^{-1} at 25°C, the soil is said to be saline (US Salinity Lab Staff 1954); this definition is still part of the latest glossary of soil science in the USA.

The salinity (EC) is measured as millimhos cm^{-1} (mmhos cm^{-1}), the old unit which is now obsolete. Currently used standard international (SI) units are milli-Siemens per cm (mS cm^{-1}) or deci-Siemens per meter (dS m^{-1}). The use of dS m^{-1} is preferred over the unit mmhos cm^{-1}. The units can be presented as 1 d

S m^{-1} = 1 mmho cm^{-1} = 1 mS cm^{-1} = 1,000 micro-Siemens per cm (1,000 μS cm^{-1}). Readings are usually taken and reported at a standard temperature of 25°C. For accurate results, EC meters should be checked with 0.01-N KCl solution, which should give a reading of 1.413 dS m^{-1} at 25°C.

In agricultural fields, the irrigation through flood irrigation and modern irrigation systems (drips and sprinklers) is unlikely be applied uniformly; therefore, the behavior of salinity development would be heterogeneous at the farm level. Recently Shahid et al. (2010) have hypothesized salinity development cycle to describe the sequence of soil salinity development, including various facets, such as leaching, seepage from system, water movement restriction, capillary rise, and evaporation to salts crystallization.

Sodicity is a measure of sodium ions in soil or water relative to calcium and magnesium ions. It is expressed either as sodium adsorption ratio (SAR) or as exchangeable sodium percentage (ESP). If the SAR of the soil equals or is greater than 13 (mmoles $L^{-1})^{0.5}$ or ESP equals or is greater than 15, the soil is termed sodic (Richards 1954). The SAR is calculated by the relationship $SAR = Na/[(Ca + Mg)/2]^{0.5}$, where the concentrations of Na^{+} and $Ca^{2+} + Mg^{2+}$ are in milliequivalents per liter (meq L^{-1}) in soil extract from saturated paste, and SAR is expressed as (mmoles $L^{-1})^{0.5}$.

1.1.2 Global Identification of Salinity Problem

The planet Earth presents world land surface to about 13.2×10^{9} ha, and within this total land, only 7×10^{9} ha is arable and only 1.5×10^{9} ha of which is cultivated (Massoud 1981). Of the cultivated lands, about 0.34×10^{9} ha (23%) are saline and another 0.56×10^{9} (37%) are sodic. Worldwide, the area of cultivated land has increased by less than 6% in the last 25 years. Older estimate (Szabolcs 1989) presents 10% of the total arable land to be affected by salinity and sodicity and extends over more than 100 countries and almost all continents. One billion ha of the 13.2×10^{9} ha land on Earth is covered with saline and/or sodic soils, and between 25 and 30% of irrigated lands are salt-affected and commercially unproductive. In Southwest USA and Mexico, about 200×10^{6} ha land is affected by salinity. In Spain, Portugal, Greece, and Italy, saltwater intrusion into aquifers is significant, and in Spain more than 20% of land area is desert or seriously degraded and nonproductive. In the Middle East 20×10^{6} ha area is affected by increased groundwater and soil salinity, reasons being irrigation practices, high evaporation rates, growth of sabkhas (salt scalds), and increase in groundwater salinity. In addition, the irrigated lands of Euphrates (Syria, Iraq) are seriously constrained by salinity. In Iran 14.2% of the total area is salt-affected (Pazira 1999). In Egypt 1×10^{6} ha cultivable land along the Nile is salt-affected; salt accumulation in Jordan River basin adversely affected agricultural production in Syria and Jordan. In Iran 25×10^{6} ha land is unproductive due to salinity. In Africa 80×10^{6} ha is saline, sodic, or saline/sodic, of which Sahel, West Africa, is most affected; in Asia, for example, in India, 20% of cultivable land is affected and distributed mainly in Rajasthan, coastal Gujarat, and Indo-Gangetic

Table 1.1 Distribution of salt-affected soils (Kovda and Szabolcs 1979; cf. Pessarakli and Szabolcs 2011)

Continent	Area (Million ha)
North America	15.7
Mexico and Central America	2.0
South America	129.2
Africa	80.5
South Asia	87.6
North and Central Asia	211.7
South-East Asia	20.0
Australasia	357.3
Europe	50.8
Total	954.8

plains. In Pakistan 10×10^6 ha is affected; about 5–10 ha per hour is lost to salinity and waterlogging in inland coastal regions and irrigated Indus basin. In Bangladesh 3×10^6 ha is unproductive due to salinity. In Thailand 3.58×10^6 ha is salt-affected (3.0 and 0.58×10^6 ha inland and coastal saline soils, respectively). In China 26×10^6 ha total land area is salt-affected (Inner Mongolia, Yellow River basin, tidal coastal regions), and in Australia the extent of saline soils is 357×10^6 ha.

Table 1.1 shows global distribution of salt-affected soils (Kovda and Szabolcs 1979). They are distributed in desert and semidesert regions and frequently occur in fertile alluvial plains, river valleys, coastal area, and irrigation districts. The countries where significant salinity problems exist include but not limited to Australia, China, Egypt, India, Iran, Iraq, Mexico, Pakistan, the USSR, Syria, Turkey, and the United States. In Gulf States (Bahrain, Kuwait, Saudi Arabia, Qatar, Oman, and the United Arab Emirates), saline soils mainly occur in coastal lands (due to seawater intrusion) and agriculture farms irrigated with saline-brackish water.

1.1.3 Classification of Salt-Affected Soils

Many classification systems of salt-affected soils are available in the published soil literature; the most common one is of the US Salinity Laboratory Staff (1954). Classifications most commonly used are recently described by Shahid and Rahman (2011). In this section, they are introduced briefly, with addition of saline soil classification from Australia, China, and Vietnam.

1.1.3.1 US Salinity Laboratory Staff Classification (Richards 1954)

Saline: the soil with $ECe \geq 4$ dS m^{-1} and $ESP < 15$
Saline-sodic: the soil with $ECe \geq 4$ dS m^{-1} and $ESP \geq 15$
Sodic: the soil with $ECe \leq 4$ dS m^{-1} and $ESP \geq 15$

The high ECe flocculates soils and causes physiological drought in plants, while high ESP disperses soil aggregates and affects soil permeability through structure degradation.

1.1.3.2 FAO-UNESCO Classification (FAO-UNESCO 1974)

Salt-affected soils (halomorphic soils) are also indicated on the soil map of the world (1:5,000,000) by FAO-UNESCO (1974) as solonchaks and solonetz (Russian names). Solonchaks are soils with high salinity (ECe > 15 dS m^{-1}) within 125 cm of the soil surface. The FAO-UNESCO (1974) divided solonchaks into four mapping units:

- *Orthic solonchaks* – the most common solonchaks
- *Gleyic solonchaks* – with groundwater influencing the upper 50 cm
- *Takyric solonchaks* – solonchaks in cracking clay soils
- *Mollic solonchaks* – solonchaks dark-colored surface layer, often high in organic matter

Soils with ECe between 4 and 15 dS m^{-1} are mapped as "saline phase" of other units.

The FAO-UNESCO (1974) divided solonetz (>15 ESP) into three mapping units:

- *Orthic solonetz* – the most common solonetz
- *Gleyic solonetz* – groundwater influence in the upper 50 cm
- *Mollic solonetz* – dark-colored surface layer, often high in organic matter

Soils with ESP between 6 and 15 are mapped as a "sodic phase" of other soil units.

1.1.3.3 Australian Salinity Classification (Isbell 1998)

Highly saline – soils having EC > 2 dS m^{-1} (1:5 H_2O) are considered highly saline.
Sodic – since the review by Northcote and Skene (1972), an ESP of six has been widely used in Australia as a critical limit for the adverse effects of sodicity.

1.1.3.4 Russian Salinity Classification

- *External solonchaks* – soluble salts throughout whole soil
- *Internal solonchaks* – soluble salts in subsoil or substratum only
- *Due to composition of salts* – nitrate, nitrate-chloride, chloride, chloride-sulphate, sulphate-chloride, sulphate-soda, soda, and borate
- *The external solonchaks* – flooded, puffed, sabkha
- *Origin of salts* – closed basin, marine, allochthonous air blown, anthropic

1.1.3.5 Soil Survey Staff (2010)

In the US Soil Taxonomy, true saline soils belong to the order "Aridisols" and suborder salids (equivalent to solonchak), divided into two great groups (aquisalids and haplosalids). Salids are soils which have a salic horizon within 100 cm of the soil surface.

Salic horizon – a horizon of accumulation of salts that are more soluble than gypsum in cold water

- Is 15 cm or more thick and has, 90 consecutive days or more in normal years:

  1. An electrical conductivity (EC) equal to or greater than 30 dS m^{-1} in the water extracted from a saturated paste
  2. A product of the EC, in dS m^{-1}, and thickness, in cm, equal to 900 or more

Aquisalids – soils that are saturated with water in one or more layers within 100 cm of the mineral soil surface for 1 month or more in normal years and also have a salic horizon within 100 cm of the soil surface

Aquisalids are divided into the following subgroups based on the presence of diagnostic horizon within upper 100 cm of the soil surface:

- *Gypsic aquisalids* – gypsic or petrogypsic horizon within 100 cm of the soil surface
- *Calic aquisalids* – calcic or petrocalcic horizon within 100 cm of the soil surface
- **Anhydritic aquisalids* – anhydritic horizon within 100 cm of the soil surface
- *Typic aquisalids* – which do not have characteristics of the above subgroups

*Anhydritic aquisalids subgroup has recently been identified by Shahid et al. (2007) and is currently under consideration by USDA for a change in USDA Soil Taxonomy (EAD-ICBA 2012).

Haplosalids – soils that are not saturated with water (like aquisalids) but has a salic horizon within 100 cm of the soil surface

Haplosalids are divided into five subgroups based on the presence of diagnostic horizon within upper 100 cm of the soil surface:

- *Duric haplosalids* – a duripan within 100 cm of the soil surface
- *Petrogypsic haplosalids* – a petrogypsic horizon within 100 cm of the soil surface
- *Gypsic haplosalids* – a gypsic horizon within 100 cm of the soil surface
- *Calcic haplosalids* – a calcic horizon within 100 cm of the soil surface
- *Typic haplosalids* – that do not have characteristics of the above-described haplosalids

Sodic soils are depicted at the great group level named Natrargids (argids that have natric horizon and do not have a petrocalcic horizon within 100 cm of the soil surface) which are argids (accumulation of clay) with a high ESP and are equivalent to solonetz (FAO-UNESCO 1974) or sodic soils.

1.1.3.6 Chinese Saline Soil Classification

Saline soils are classified as per weight of salts (g) per kilogram (g kg^{-1}) of soil, based on their occurrence in different landscapes and regions:

(a) *Coastal, semi-humid, semiarid, and arid regions*

- Light saline soil (1–2g kg^{-1})
- Moderate saline soil (2–4g kg^{-1})
- Severe saline soil (4–6g kg^{-1})
- Solonchaks (>6g kg^{-1})

(b) *Semidesert and desert regions*

- Light saline soils (2–3g kg^{-1})
- Moderate saline soil (3–5g kg^{-1})
- Severe saline soil (5–10g kg^{-1})
- Solonchaks (>10g kg^{-1})

In Chinese Soil Taxonomy (Chinese Academy of Sciences 2001), the following are identified:

Salic crust – has been identified as crustic epipedon with a thickness of 2 cm or more from the surface and has soluble salt contents of 100g kg^{-1} or more.
Salic horizon – accumulation of salts more soluble than gypsum and has thickness of 15 cm or more and salt content of (a) 20g kg^{-1} or more in Aridosols or Halosols of arid regions or EC (1:1) is 30 dS m^{-1} or more or (b) or 10g kg^{-1} or more in Halosols of other regions or EC (1:1) is 15 dS m^{-1} or more and product of thickness (cm) and salt content (g kg^{-1}) is 600 or more, or the product of EC (dS m^{-1}) and thickness (cm) is 900 or more.
Hypersalic horizon – a non-cemented horizon, with a thickness of 15 cm or more and salt content of 500 g kg^{-1} or more, and is loose and shows white, granular salt crystal or salt spot, when dry.
Salipan – cemented or indurated pan formed by soluble salts mainly composed of halite (NaCl). It has a thickness of 5 cm or more and soluble salt contents of 200 g kg^{-1} or more; shows platy or coarse blocky structure; and cannot be penetrated by spade or auger, when dry.

The lower limit of salt content in salic horizon is 5 g kg^{-1} (arid region) or 2 g kg^{-1} (other regions).

In Chinese Soil Taxonomy, saline soils are identified at the third level of order Aridosols:

Order – Aridosols
Suborder – Orthic Aridosols
Group – Sali-Orthic Aridosols (having a salic, hypersaline horizon or salipan, which has its upper boundary within 100 cm of the soil surface)
Subgroups – at Sali-Orthic Aridosols great group level; lithic, sodic, gypsi-panic, panic, gypsic, and typic (Sali-Orthic Aridosols) subgroups have been identified

1.1.3.7 Vietnam Saline Soil Classification

Saline soils are classified as per weight of salts (g) per kilogram (g kg^{-1}) of soil:

- Light saline soils (2.5–5 g kg^{-1})
- Moderate saline soil (5–10 g kg^{-1})
- Strong saline soil (>10 g kg^{-1})
- Solonchaks (>10 g kg^{-1})

1.1.4 Socioeconomic and Environmental Impacts of Saline Soils

(a) *Low Production and Socioeconomic Impacts*

- Farm abandonment reduces number of farmers and causes socioeconomic disturbance
- Low production due to low response to inputs leads to economic losses
- High cost for soil reclamation
- Loss of good quality soil (organic matter, nutrients) requires more input like fertilizer, financial pressure on farmer
- Compromised biosaline agriculture system that may give less cash returns compared to conventional crop production systems
- Farmers' migration to urban area

(b) *Environmental Impact*

- Ecosystem fragmentation
- Poor vegetation leads to soil degradation (erosion)
- Dust causes environmental issues
- Sand encroachment in productive areas
- Storage capacity of reservoirs reduced
- Contamination of groundwater

1.2 Salinity Diagnostics at Regional to Submicroscopic Levels: Scientific Antecedents

In the following section, a comprehensive review is given on currently used advanced technologies in soil salinity assessment, modeling, mapping, and monitoring. Salinity diagnostic procedures are also briefly described supported by examples.

1.2.1 Remote Sensing and Geographical Information System

Salinity mapping can be accomplished by various techniques integrating remote sensing (RS) and GIS at broad and small scales. Combining information on these and other factors could allow the prediction of sites vulnerable to the saline menace. This is where a geographic information system (GIS) can play a role. GIS is a computer application that involves the storage, analysis, retrieval, and display of data that are described in terms of their geographic location. The most familiar type of spatial data is a map – GIS is really a way of storing map information electronically. A GIS has a number of advantages over old-style maps, though; one is that because the data are stored electronically, they can be analyzed readily by computer. In the case of salinity, scientists can use data on rainfall, topography and soil type – indeed, any spatial information that is available electronically – to first determine the combinations most susceptible to salinization and then to predict similar regions that may be at risk. RS imagery is well suited to map the surface expression of salinity (Spies and Woodgate 2004), for example, poor vegetation cover could be an indication of salinity in the area, while depth to groundwater and associated vegetation cover is widely regarded as the most useful indicator for determining salinity trends and risks. The goal of such exercise is to assess and map soil salinity to understand the problem, provide information to take necessary action to prevent its temporal distribution, and to manage the improvement and sustainable use of land resources. Salinized and cropped areas can be identified with a salinity index based on greenness and brightness that indicates leaf moisture influenced by salinity, with classical false-color composites of separated bands or with a computer-assisted land-surface classification (Vincent et al. 1996). A brightness index detects brightness appearing at high levels of salinity. Satellite images can help in assessing the extent of saline areas and monitoring the changes in real time. Saline fields are often identified by the presence of spotty white patches of precipitated salts. Such precipitates usually occur in elevated or unvegetated areas, where water evaporates and leaves salt behind. Such salt crusts, which can be detected on satellite images, are not reliable evidence of high salinity in the root zone. Inadequate resolution of low-cost RS data in optical range limited the identification to surface salt encrustation; therefore, identification of subsurface salinity and waterlogging using optical RS data becomes difficult. Another limitation in salinity mapping with multispectral imagery is where saline soils support productive plant growth (Furby et al. 1995) such as biosaline agriculture, where plant cover obscured direct sensing of the soil, while salt-tolerant plants could not be differentiated from other cover, unless extensive ground truthing is made to correlate the information.

RS can provide useful information for large-area water and salt balances and identification of parameters such as evapotranspiration, rainfall distribution, interception losses, and crop types and intensities that can be used as indirect measures of salinity and waterlogging and as evidence for direct estimates (Ahmad 1999). Salinity mapping and monitoring through using remote sensing and GIS have been common in many countries; such procedures have recently been used in Kuwait and

Abu Dhabi Emirate as part of the National Soil Inventories (KISR 1999a, b; Shahid et al. 2004; EAD 2009; Abdelfattah et al. 2010). At the regional and national levels (Sukchani and Yamamoto 2005), RS and GIS for waterlogging and salinity monitoring (Asif and Ahmad 1999), RS technology for soil salinity mapping in the Middle East (Hussein 2001, 2003), mapping salt-affected soils using RS and GIS (Maher 1990), mapping salt-affected soils using Landsat satellite data (Joshi and Sahai 1993), soil salinity mapping using airborne remote sensing and spectroscopy (Bennett 1998), salinity assessment using RS techniques (Brena et al. 1995), salinity assessment by combined use of RS and GIS (Casas 1995), multispectral remote sensing of saline seeps (Chaturvedi et al. 1983), detecting saline soils with video imagery (Everitt et al. 1988), selection of the best possible Landsat TM band combination for the delineation of salt-affected soils (Dwivedi and Rao 1992), delineation of salt-affected soils through digital analyses of Landsat MSS data (Singh and Dwivedi 1989), application of multitemporal Landsat data for salinity identification (Farooq and Ud Din 1980; Makin 1986), salinity monitoring using RS and GIS (Goossens et al. 1993), use of remote sensing in salt marsh biomass and stress detection (Hardisk et al. 1983), RS study of salt-affected soils (Mougenot et al. 1993; Verma et al. 1994), Landsat imagery for mapping saline soils (Sharma and Bhargawa 1988), application of Landsat imagery for monitoring soil salinity trends (WAPDA 1984), integration of RS and conventional information (Zevenbergen 1990), and integration of RS/GIS and spatial statistics provided useful tools for modeling variability to diagnose pattern of characteristics (Kalkhan et al. 2000). Delineation of saline soils using RS/GIS has been proven efficient in recent studies (Sharma and Bhargawa 1988; Rao et al. 1991; Dwivedi 1992; Srivastava et al. 1997; Dwivedi and Sreenivas 1998; Khan and Sato 2001).

The TM bands 5 and 7 are frequently used to detect soil salinity or drainage anomalies (Mulders and Epema 1986; Menenti et al. 1986; Zuluaga 1990; Vincent et al. 1996); broadscale monitoring of salinity using satellite remote sensing (Dutkiewics and Lewis 2008). Metternicht and Zink (1996) have shown Landsat TM and JERS-ISAR data (visible and infrared regions) the best to distinguish saline, alkaline, and nonsaline soils, and Dwivedi (1992) used Landsat SMM and TM data for detailed mapping and monitoring of saline soils in India in the frame of the reconnaissance soil map.

Abdelfattah et al. (2009) developed a model that integrates remote sensing data with GIS technique to assess, characterize, and map the state and behavior of soil salinity. The coastal area of Abu Dhabi Emirate, where the issue of salinity is a major concern, has been used as a pilot study area. The development of the salinity model has been structured under four main phases: salinity detection using remote sensing data, site observations (ground truthing), correlation and verification (intersection between salinity map produced from visual interpretation of remotely sensed data and salinity map produced from site observations), and model validation. GIS was used to integrate the available data and information, to design the model, and to create different maps. A geodatabase was created and populated with data collected from observation points together with laboratory analyses data. The results of the study indicated that the correlation between the salinity maps developed from remote sensing data and site observations shows that 91.2% of the saline areas delineated using remote sensing data fit with those delineated using site observations data. The study confirmed that ground truthing coupled with RS data and GIS techniques are powerful tools in detecting salinity at different levels in hyperarid conditions and hence the model can be adopted elsewhere in similar areas that experience salinization problems.

1.2.2 Modeling

Salinity is dynamic and transient condition in saline soils. Chemical reactions in root zone (solubility, precipitation, cation-exchange reactions) in irrigated field affect soil salinity and sodicity and salt contribution to drainage water. Comphuter programs (Dutt and Tanji 1962; Dutt 1962) can predict composition of soil solutions. Others (Oster and Rhoades 1975; Rhoades and Suarez 1977) used models to evaluate salinity, sodicity, and environment hazards of drainage water that resulted from irrigation; others calculate the effect of chemical reactions in the soil solution composition for transient conditions within the root zone (Jury et al. 1978; Robbins et al. 1980) and for sodic soil reclamation (Dutt et al. 1972). There exist models to address salinity issues in agriculture fields and landscapes vulnerable to soil salinization and try to give answer to specific questions. Numerical models can be used as evaluation tools in predicting soil and water salinity-related-dependent variables that help in decision making. In addition, model results assist in evaluating possible scenario analysis. Models that incorporate all governing elements of nature such as soils, water, crops, and agrometeorology produce better results as they represent the nature to a large extent. One limitation of such holistic models is extensive data requirements. The potential numerical models, however, need to be locally calibrated and validated for reliable application of model outputs. Modeling soil-water-salt-plant relationships is important for the use of scaling and extension of technologies and decision support system. How models can be made to predict near to the actual field conditions is essential in modeling development. Since several factors beyond the problems considered in these models play significant deciding role in biological systems like agriculture, issues like climate change and its likely impacts in saltwater dynamics under actual condition should be considered (FAO 2009). In the First Expert Consultation on Advances in Assessment and Monitoring of Salinization for Managing Salt-Affected Habitats (FAO 2009), it was concluded that salinity models could be of limited use if they are not well designed and some models can be very vulnerable to particular parameters if not properly developed. Comparison of two models (SMSS2 and SMSS3) with reference to irrigation-induced soil and water quality parameters was presented from Morocco. The statistical results from the model outputs supported the reliable use of models. Soil physics character should be studied for reliable prediction models. It was recommended that SWAP model has been efficiently used and needs to be shared with network member countries. Limitation of using modeling under saline conditions is due to the dynamic nature of salinity problems which should be clearly understood by the model users. Physically based models simulating water and solute transport represent an essential tool for predicting soil salinity and/or sodicity. These models enable different options to be compared to develop strategies for sustainable irrigation in the short and in the long term. However, calibration and validation of these models against soil and crop field data is needed to check accuracy of the predicted values before these models can be used to develop reliable management scenarios.

Models could be simple or of great complexity. Major constraint to these models is mostly the lack of input data; many times, assumptions are made on different data to run these models (Ranatunga et al. 2008). Some models are simple, for example, Watsuit model (Rhoades and Merrill 1976) considers water composition, leaching fraction, and presence and dissolution and precipitation of minerals like calcite and gypsum in the root zone. The dissolution and precipitation of minerals can change water composition and quality; the relative magnitude of such effects can be evaluated by using Watsuit calculations; details of the assumptions and relations that comprise this model are given in Rhoades (1972, 1977, 1984, 1987, 1988) and Oster and Rhoades (1990).

Noncomputer version of Watsuit can be used where computer facilities are lacking in an analogous way to the computer-based Watsuit to predict the likelihood of soil water salinity-, sodicity-, and toxicity-related problems resulting from irrigation under steady-state conditions. However, these predictions are less accurate than computer-based Watsuit predictions. This can be achieved by multiplying the water EC with factors (fc) appropriate to leaching fraction and root zone salinity; these factors are described by Rhoades (1992). While considering Watsuit as a "production-function model," the effect of salinity on evapotranspiration (ET) is not taken into account, rather, it is assumed that there will be no yield loss, hence in ET, so long as the threshold level of ECe is not exceeded; thus, water suitability is simply predicted to learn whether the predicted salinity from irrigation will exceed ECe or not.

The models that consider water flow, water uptake by crops, and solution chemistry can allow more realistic simulation of the soil water status. There are very limited numbers of models that consider such aspects; among these models are the LEACHM (Hutson and Wagenet 1990) and UNSATCHEM (Suarez and Simunek 1997). A major limitation to the use of the LEACHM model is that it is not able to simulate sodic, alkaline conditions (Suarez and Dudley 1998). The UNSATCHEM 3.0 model (Suarez and Vaughan 2002) considers variably saturated water flow, heat flow, plant water uptake, and solution chemistry including cation exchange, precipitation-dissolution of mineral phases, and boron adsorption.

Models that can be used for a variety of irrigation systems, soil types, soil stratification, crops and trees, water application strategies (blending or cyclic), leaching requirement, and water qualities are lacking. For that purpose, the SALTMED model has been developed (Ragab 2001). The model employed the well-known water and solute transport, evapotranspiration, and crop water uptake equations. The FAO-US Salinity Laboratory SWS (Suarez and Vaughan 2002) developed a model (soil/water quality model) to evaluate the suitability of water for irrigation, primarily in arid and semiarid regions. The suitability of water is evaluated in terms of its utility for crop growth. The FAO-US Salinity Laboratory soil water quality model is a modification of the UNSATCHEM model (Suarez and Simunek 1997; Simunek and Suarez 1997b). The modifications include additions to the plant module, nitrate transport and provision for calculation of ETc, upgrade to 32 bit, and a user-friendly Windows 95 interface, including default parameters and catalogue menu. The complexity of the UNSATCHEM model, which was developed as a research tool, is greatly reduced in the FAO-US Salinity Laboratory model by means of the default parameters, set by the interface and thus hidden from the user. The UNSATCHEM model in turn is based on the SOILCO2 model (Simunek and Suarez 1997a) with addition of a chemical specification routine (Suarez 1977), calculation of exchangeable cations as described in Robbins et al. (1980), and calculation of osmotic activity coefficient using the Pitzer routines of GMIN (Felmy 1990).

Some workers compared steady-state models with transient models (Corwin et al. 2007) to optimize LF under salinity risk. A comprehensive review of models emphasizing irrigation management using saline waters has been made by Bastiaanssen et al. (2007). Batlle-Sales (2009) has given an overview of salinity modeling approaches at different spatial-temporal scales Batlle-Sales (2013). Recently Batlle-Sales (2013) described soil salinity models, approaches, and associated key issues.

1.2.3 Geostatistics

Geostatistics is used for mapping of surface features from limited sample data and the estimation of values at unsampled locations. Geostatistics is widely used in fields where "spatial" data is studied. Geostatistical estimation is a two-stage process: (1) studying the gathered data to establish the predictability of values from place to place in the study area, this study results in a graph known as a semi-variogram which models the difference between a value at one location and the value at another location according to the distance and direction between them, and (2) estimating values at those locations which have not been sampled. This process is known as "kriging." The basic technique, "ordinary kriging," uses a weighted average of neighboring samples to estimate the "unknown" value at a given location. Weights are optimized using the semi-variogram model, the location of the samples, and all the relevant interrelationships between known and unknown values. The technique also provides a "standard error" which may be used to quantify confidence levels.

In mining, geostatistics is extensively used in the field of mineral resource and reserve valuation – the estimation of grades and other parameters from a relatively small set of borehole or other samples. Geostatistics is now widely used in geological and geographical applications. However, the techniques are also used in such diverse fields as hydrology, ground water, soil salinity mapping, and weather prediction.

1.2.4 Electromagnetic Induction

The last 30 years has revolutionized soil salinity assessment. These revolutions have been in RS/GIS and development of a number of electromagnetic induction (EMI) instruments for providing reasonable in situ estimates of salinity (Corwin and Rhoades 1982; Slavich 1990). The apparent electrical conductivity (ECa) measured by EMI can be rapidly measured on a second-by-second basis; therefore, data population is relatively large, and landscape or farming land can be covered more comprehensively in short time than by conventional survey tools and methods. As larger volume of data is recorded at relatively larger spatial resolution, EMI surveys are considered as high-intensity surveys. Therefore, salinity maps prepared from ECa provide higher level resolution than those prepared from conventional surveys (Jaynes 1995), which further stated that ECa maps can be used as surrogates of soil maps. The ECa patterns in existing soil map can provide additional details (Hedley et al. 2004). A major contribution of EMI to soil surveys has been the identification and delineation of small included areas of dissimilar soils within the soil polygons (Fenton and Lauterbach 1999) and the general distribution of soils within fields (King et al. 2005). EMI has been successfully applied in high-intensity soil mapping in northern Illinois (Doolittle et al. 2009).

Spatial distribution of soil salinity on field (Cameron et al. 1981), agricultural farms (Norman et al. 1995a, b), district (Vaughan et al. 1995), and regional (Williams and Baker 1982) scales has been described. The risk of soil salinization in a vineyard at Sicilian was assessed using EM38 (Crescimanno et al. 2009), assessing salinity changes in natural landscapes and agricultural fields (Morales and Batlle-Sales 2009), integration of RS imagery and EMI was to assess soil salinity, drainage problems, and crop yield (Madrigal and Meraz 2009).

Baerends et al. (1990) used Geonics EM38 for a detailed salinity survey in an experimental area of 37 ha. The ECa is a weighted, average conductivity measurement to a specific soil depth (Greenhouse and Slaine 1983). The ECa is influenced by the type and concentration of ions in solution, the amount and type of clays, the volumetric water content, and the temperature and phase of the soil water (McNeill 1980); in general ECa increases with the increase of soluble salts and/or clay contents (Kachanoski et al. 1988; Rhoades et al. 1976). Baerends et al. (1990) found good agreement between the EM38 survey and the results of the visual agronomic salinity survey. However, they reported that the EM38 survey yields results with a better resolution; it is more sensitive to salinity changes and can be carried out at any time of the year. Rhoades (1995) reported a good agreement between the measured salinity levels and those predicted from the EM38 sensor on an average root zone (0–1.2 m) salinity levels (ECe) along the transact in the irrigated alfalfa. Williams and Baker (1982) recognized the possibility of using EM meters for reconnaissance surveys of soil salinity variation. The high values of apparent electrical conductivity (ECa) measured by the EM meters were correlated with increased amounts of salts in the soil. The correlation led to empirical relationships (Rhoades et al. 1989a, b; Cook et al. 1992; Acworth and Beasley 1998) that allow a prediction of soil salinity based on the measurement of the ECa. Presently, the devices are used regularly for soil salinity surveys in different parts of the world (Norman et al. 1989; Job et al. 1987; Williams and Hoey 1987). The main advantages of the EM method are the following: (1) measurements can be taken almost as fast as one can walk from one measurement location to another and (2) large volume of soil which is measured reduces the variability so that relatively few measurements yield a reliable estimate of the mean field salinity.

For the detection of vertical ECa changes in soil profiles from aboveground EM measurements, many investigators have used empirical relations (Cook and Walker 1992; Corwin and Rhoades 1982, 1984; Rhoades and Corwin 1981; Rhoades et al. 1989a, b) and, in one case, theoretical response functions for homogeneous profiles (Slavich 1990). All of these studies have been based on the assumption of linearity. Rhoades and Corwin (1981) and Slavich (1990) used multiple linear regressions to correlate EM ground conductivity meter readings with measured soil electrical conductivity profiles. The resulting coefficients could be used to predict soil electrical conductivity profiles at points where direct measurements were unavailable. Such regression models proved to be site specific. Hence, these relations yield reasonable results at the locations for which they have been developed or at locations with similar characteristics, but they cannot be extrapolated to sites with different characteristics without calibration. For reliable use, the instrument needs phasing and instrument zeroing using the manufacturer's standard calibration method after a warm-up period of 1 h. Calibration of the EM38 requires that the instrument in the V-VEM38 mode reads twice the ECa value of the instrument in the H-HEM38 mode when held 1.5 m above the Earth surface.

1.2.5 Micromorphological and Submicroscopic Investigations

According to Kubiena (1938), Nicol was the first to prepare thin sections of minerals in 1827. However, the method in general use today (Fitzpatrick 1984) was developed by Sorby in 1859. The concept of applying microscopic techniques in soil science was independently conceived by Kubiena (1931) and Harrison (1933). Soil thin section is an approach of studying undisturbed soil material with the aid of microscopic techniques (micromorphology). This permits study of different constituents and allows their natural relation in space and as far as possible in time to be studied. Consequently, it has become an important tool for investigations into the genesis, classification, and management of soils. Thin-section investigation by the optical microscope (OM) only provides two-dimensional (2D) information about the general soil fabric; its optical resolution imposes a limit at fine silt-sized material. The observation in the OM can be extended to clay-sized material where, for example, preferred orientation results in aggregate birefringence. The detailed micromorphology (2D) of arid and semiarid soils generally and of gypsum specifically has been presented by Stoops et al. (1978).

It has long been recognized that investigation of salt efflorescences/salt crusts from salt-affected soils has not been subjected to extensive studies (Stewart 1963) owing to their lack of economic significance and the reason that most of the salt minerals are dissolved during the process of thin-section preparation. Feofarova (1940, 1958) gave the first basic information on the salts in the soil. Driessen and Schoorl (1973) were the first to apply scanning electron microscopy (SEM) to identify minerals in salt efflorescences on saline soils. Some of the first SEM micrographs of halite were published by Driessen (1970) in his study on salt crusts from the Great Konya Basin, Turkey. In very few publications, such aspects have been studied in detail (Eswaran et al. 1980; Hanna and Stoops 1976; Barzanji and Stoops 1974; Shahid 1992; Shahid et al. 1990, 1992; Shahid and Jenkins 1994; Shahid and Mufti 1994). Braitsch (1962) brought the realization that salts occur as minerals during a large part of the year; which mineral forms and which vanishes during different seasons has been realized by Garrels and Christ (1965). Studies on evaporites (Stewart 1963) have clearly shown a salt succession which may be cyclic; some view (Kovda 1946) that the presence of salts depends on diurnal fluctuation. Muller and Irion (1969) reported a special growth structure of halite in salt sediments, salt flakes at the surface water layer of basin, large halite crystals on the bottom, and smaller ones on top of the discs. Gypsum, halite, aragonite, calcite, and huntite mineral assemblage has been reported in Tuz Golu in Turkey (Irion 1970). Review of Donar and Lynn (1971) on carbonate, halide, and sulfide minerals in soils gives the average of these salt crusts. Needle-shaped macroscopic thenardite (Na_2SO_4) crystals have been reported in puffed solonchaks (Buringh 1979) and thenardite efflorescences on polar desert soils of Prince Patrick Island (Tedrow 1966). Gumizzio et al. (1982) reported mineralogical composition of salt efflorescences in a typic salorthids. Stoops et al. (1978), using SEM, studied some authigenic sulfate minerals in soils. Different forms of gypsum have been reported by Stoops et al. (1978) and recently by Shahid and Abdelfattah (2009). While evaluating the salt morphologies by SEM (SEM and BSEI, SEM/EDXRA) and XRDA and chemical composition, Vergouwen (1980) observed that halite is forming smooth crust sealing the soil; trona, bloedite, and hexahydrite make the salt crust very fluffy.

A few micrographs of soluble minerals (gypsum and jarosite) have been published by Cheverry et al. (1972), and Eswaran and Barzanji (1974) reported gypsum micrographs. Shahid and Abdelfattah (2009) presented polymorphism of gypsum from coastline of Abu Dhabi Emirate. Hanna and Stoops (1976) have described halite cutans in saline soils from Egypt. Eswaran and Carrera (1980) used the XRD, SEM, and chemical analyses to evaluate salt profiles in two Aridisols in Peru. Eswaran et al. (1980) established halite morphologies in salt crusts using SEM. Shahid et al. (1992) by the very first time in the soil history of Pakistan revealed eight types of halite morphologies "polymorphism" using SEM and EDXRA techniques. Pioneer work on the salt-affected soils of Punjab, Pakistan, revealed dominance of thenardite minerals contrary to older hypothesis of halite dominance (Shahid 1988; Shahid et al. 1990; Shahid and Jenkins 1994). Further submicroscopic studies (SEM/EDXRA) on salt crusts from Pakistan confirmed the thenardite dominance (Shahid 1992; Shahid and Mufti 1994).

The very first in the history of soil research in Pakistan, a comprehensive study on the soil micromorphology of salt-affected soils from Punjab was completed

(Shahid 1988). The study was completed as a full requirement of a Ph.D. degree program at the School of Agricultural and Forest Sciences, University College of North Wales, Bangor, UK. Among many innovative findings, the most important and noble finding was the recognition that salt-affected soils of Punjab are dominant in thenardite (Na_2SO_4) and mirabilite ($Na_2SO_4.10H_2O$) salinity in contrast to old hypothesis of halite (NaCl) dominance. This gives new directions to researchers to focus screening of crops against Na_2SO_4 salinity to address the issues of salt-affected soils in Punjab, Pakistan. The new findings were a result of investigation of salt crusts collected from many areas of Punjab province of Pakistan using a combination of techniques including routine solution chemistry, description of thin section under optical microscopy, scanning electron microscope supplemented with energy dispersive x-ray analyses (EDXRA) for microchemical analyses, XRD, line scanning, and elemental mapping through electron probe microanalyses (EPMA). These findings also opened the door for using KCl fertilizer as source of K, rather than K_2SO_4; the latter is more expensive and largely imported in Pakistan and will enhance SO_4 toxicity in soils.

The literature on soil feature initially studied in thin section (2D) using optical microscope and further investigation by SEM (3D) through removing resin by low-temperature ashing is very scanty. The combination of OM and SEM evaluation of thin sections has attracted only limited attention (Jenkins 1980; Price and Jenkins 1980). These features can be inferred by the OM, but their 3D morphological details and their microchemical composition can only be possible at submicroscopic level. The SEM has become equally important in examining soil microfabrics (Jenkins 1980; Price and Jenkins 1980), where investigation of soil microfabrics is extended down to the submicroscopic level through low-temperature ashing (LTA) technique. The LTA is a technique whereby the impregnating resin from thin sections can be removed at low temperature through oxidation and volatilization. This technique permits features already studied under the optical microscope to be studied with the SEM at high magnification and their 3-dimensional (3D) morphology obtained. In addition, the features of interests can be analyzed with energy dispersive x-ray analyzer (EDXRA), thus giving a fairly comprehensive set of information about the feature of interest.

1.2.5.1 In Situ Elemental Mapping in Saline Features by Electron Probe Microanalyses (EPMA)

The electron microscope supplemented with energy dispersive x-ray analyses (EDXRA) or wavelength dispersive x-ray analyses (WDXRA) provides elemental composition in a soil feature at larger scale. The principle in such elemental composition is that the imaging and analytical functions of all microscopes are a direct consequence of the complex spectrum of events that always accompany the interaction of a stream of energetic electron with a solid sample. Electron-specimen interaction often yields different types of electrons and electromagnetic waves (of which x-rays are but one type) as a result of elastic or inelastic scattering events (Morgan 1985). The x-ray photons generated contain chemical information about the specimen. The x-ray mapping is a potentially useful means of qualitatively assessing the gross distribution of an element in a specimen (white dots). High-resolution x-ray dot maps can be obtained for different elements. These dots show the distribution of the elements in the feature, and their intensity is a measure of the concentration of the element. Saline soil features (highly polished thin section) can be investigated by EPMA using JEOL JXA 3A equipment (or latest models) operated at 20- and 10-kv accelerating voltage and about 0.15-μA specimen current and producing x-ray distribution pattern on a cathode ray oscilloscope (CRO) screen and photographed on a polaroid film.

1.3 Soil Salinity Diagnostic Procedural Matters: Regional to Submicroscopic Scales

Use of reliable methods for salinity diagnostics is essential to zone salinity at regional, national, farm, and even submicroscopic levels of investigation. This allows understanding of subtle difference for more precise management. Conventional soil salinity assessment requires geo-referenced field sampling and laboratory analysis where the electrical conductivity of soil saturation extract (ECe) is measured and, using GIS tool salinity zones, can be delineated. Other quicker methods have been developed such as use of RS imagery and geophysical methods (EM38) for salinity diagnostics. The EM38 is useful for agricultural salinity surveys. It is a rapid, mobile technique for measuring bulk soil electrical conductivity. It provides 1.5-m and 0.75-m depth of exploration of the vertical and horizontal dipole modes, respectively.

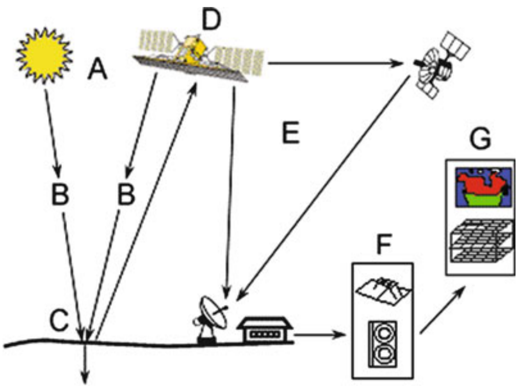
There are five basic tools for salinity assessment: (1) remote sensing and GIS, (2) conventional soil analyses, (3) geophysical methods, (4) salinity modeling, and (5) morphological and microchemical assessment from field to submicroscopic levels. The following section describes the technologies as well as their application in salinity aspects.

1.3.1 Remote Sensing

Remote sensing is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information. In much of remote sensing, the process involves an interaction between incident radiation and the targets of interest. This is exemplified (Shahid et al. 2010) by the use of imaging systems where the following seven elements are involved (Fig. 1.1):

1. Energy source or illumination (*A*) – the first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.
2. Radiation and the atmosphere (*B*) – as the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes

Fig. 1.1 Sequence of RS imaging system



through. This interaction may take place a second time as the energy travels from the target to the sensor.

3. Interaction with the target (*C*) – once the energy makes its way to the target through the atmosphere, it interacts with the target, depending on the properties of both the target and the radiation.
4. Recording of energy by the sensor (*D*) – after the energy has been scattered by or emitted from the target, it requires a sensor (remote – not in contact with the target) to collect and record the electromagnetic radiation.
5. Transmission, reception, and processing (*E*) – the energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital).
6. Interpretation and analysis (*F*) – the processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.
7. Application (*G*) – the final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information, or assist in solving a particular problem. These seven elements comprise the remote sensing process from beginning to end.

The RS imagery is then interpreted for both unsupervised classifications. It identifies natural grouping or structures within multispectral data. This can be accomplished by clustering methods defined with a clustering algorithm, which often uses all or many of the pixels in the input data file for its analysis. The cluster algorithm has no regard for the contiguity of the pixels that define each cluster. The ISODATA cluster method uses spectral distance as in the sequential method but iteratively classifies the pixel, redefines the criteria for each class, and classifies it again. Supervised classification is the process of using samples of known identity to classify pixels of unknown identity. Samples of known identity are those pixels located within training areas (the user selects pixels that represent recognized pattern or land cover features). The use of RS and GIS in salinity mapping has been very well described by Shahid et al. (2010), and global work is reviewed in earlier section.

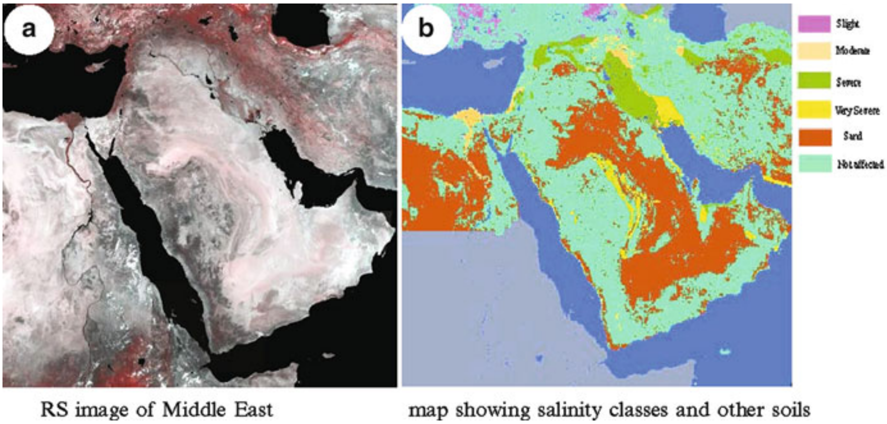


Fig. 1.2 RS image of Middle East (**a**), map showing salinity classes and other soils (**b**)

1.3.1.1 Case Study: Salinity Mapping at Regional Level (cf. Shahid et al. 2010)

As a part of more comprehensive investigation of the Middle East, Hussein (2001) investigated soil salinization in the region. He uses RS imagery and other parameters to develop soil salinization map of the Middle East (Fig. 1.2). The study focuses on the salinization affecting irrigated lands, so it is important to evaluate what is called the intensity of irrigation. For this evaluation, it is possible to use two interesting indicators. The FAO (1997) shows that in all countries, the rate of use of the equipped area for irrigation was greater than 50%.

To divide the salinization map into four classes or degrees of importance, it is necessary to establish threshold values; to achieve this task, reference is made to the existing information leading to the following threshold values. The analyses revealed 11.2% of the Middle East soils are affected by various levels of soil salinization (Table 1.2). Shahid et al. (2002) reported an area of about 12.1% to be affected to varying degrees of soil salinity in Kuwait, of which 4.37% of area is identified as inland salinity and the rest is coastal salinity.

1.3.2 Geophysical Method

Geophysical methods (especially electromagnetic induction) are gaining importance in agriculture salinity surveys. The EM38 measures salinity by transmitting an electric current through the soil; the resulting electromagnetic field is measured by a sensor in the device. This type of EC sensor works on the principle of electromagnetic induction (EMI). EMI does not contact the soil surface directly. The instrument is composed of a transmitter and a receiver coil usually installed at opposite ends of a nonconductive bar located at opposite ends of the instrument.

Table 1.2 Level of salinization and threshold values in Middle East (Hussein 2001; cf. Shahid et al. 2010)

Level of salinization	Threshold value	Area km^2	Area %
Non affected area	–	3,805,679	57.53
Slight salinization	0–25	113,814	1.72
Moderate salinization	25–75	109,148	1.65
Severe salinization	75–150	380,025	5.74
Very severe salinization	>150	138,204	2.09
Sand	–	2,068,092	31.26

EM38 works only with a fixed frequency and has an effective measurement depth of 1.5 m in vertical dipole mode or 0.75 m in horizontal dipole mode (Fig. 1.3a). The EM38 is designed to be particularly useful for salinity surveys in agricultural fields. It has gained acceptance due to its simplicity, reliability, rapidity, and reproducibility of the results. It is also a rapid, mobile instrumental technique for measuring bulk soil electrical conductivity as a function of spatial position on the landscape. Salinity maps help farmers to understand subtle difference in soil properties across their fields, allowing them to develop more precise management zones and, ultimately, potentially higher yields.

The conduction of electricity in soil takes place through the moisture-filled pores that occur between individual soil particles. Therefore, the EC of soil is determined by the following soil properties. The greater the soil porosity, the more easily electricity is conducted. Soil with high clay content has higher porosity than sandy soil. Compaction normally increases soil EC. Dry soil has much lower conductivity than moist soil. Increasing concentration of electrolytes (salts) in soil water will dramatically increase soil EC. Mineral soil containing high levels of organic matter (humus) and/or 2:1 clay minerals such as montmorillonite, illite, or vermiculite (high cation-exchange capacity) has a much higher ability to retain positively charged ions (such as Ca, Mg, K, Na, NH_4, or H) than soil lacking these constituents. The presence of these ions in the moisture-filled soil pores will enhance soil EC in the same way that salinity does. As soil temperature decreases toward the freezing point of water, soil EC decreases slightly. Below freezing, soil pores become increasingly insulated from each other, and overall soil EC declines rapidly. It should be remembered that EMI provides ECa (apparent EC); therefore, calibration of EM38 to generate different depth-wise predictive equations to convert ECa to ECe is required. Various regression equations are reported to convert ECa to ECe (Rhoades et al. 1989a, b; Im-Erb et al. 2005). Soils are heterogeneous, and thus, there is no universal relationship existing between ECe and ECa; in each study area, relationship is to be developed.

The EC value is a combined result of physical and chemical properties of soil. It has potential applications in agriculture for management decisions and the delineation of management zones. For agriculture applications, EC information works best when yields are primarily affected by factors that are best related to EC, for example, water holding capacity, salinity level, and depth of topsoil. As a result, it may

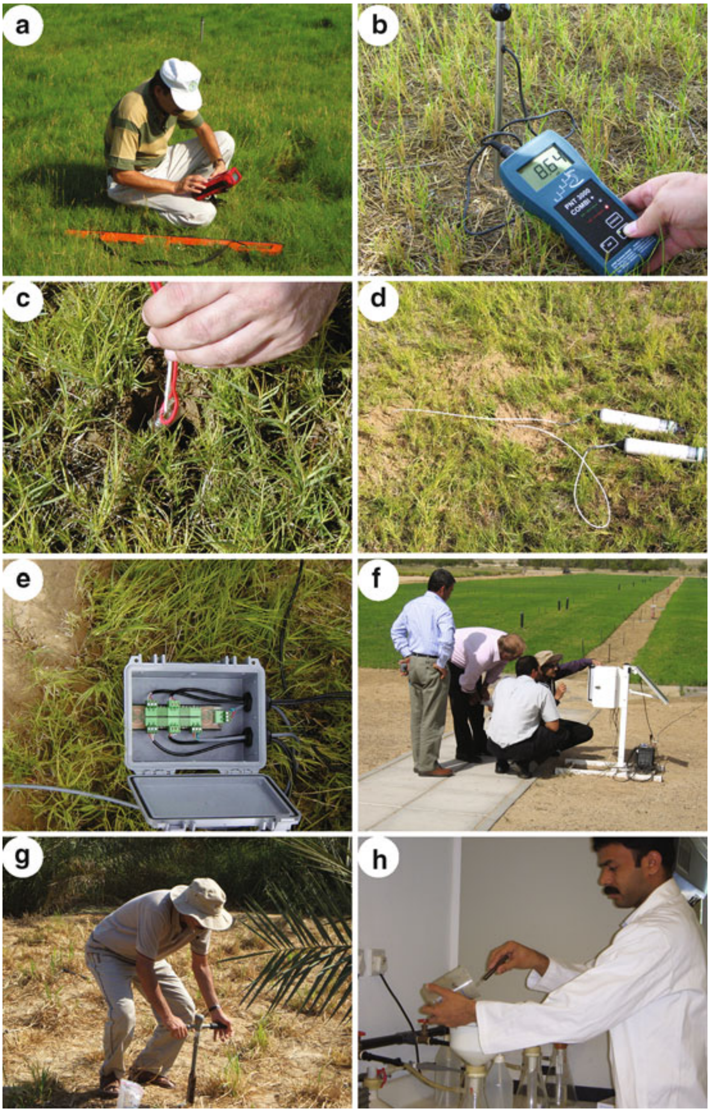


Fig. 1.3 Various views of salinity monitoring in irrigated agriculture field, (**a**) geophysical ECa assessment in a grassfield by EM38 in horizontal mode, (**b**) root zone ECa assessment in a grassfield by salinity probe, (**c**) placing salinity sensors at root zone, (**d**) smart interface connected with salinity sensors in root zone, (**e**) interface connected to databus leading to datalogger, (**f**) instant view of EC on datalogger, (**g**) field sampling for salinity monitoring and, (**h**) soil saturation extract collection in laboratory

not work well in areas when other factors (such as disease and pests) are more predominant. This has to be considered carefully while managing soils from salinity perspectives.

Salinity probes are handy equipment that are easy to use in open field (Fig. 1.3b) and pot experiments manually and give instant apparent salinity information (mS cm^{-1} and g L^{-1}) and avoid conducting soil sampling and preparation. At ICBA we use PNT 3000 COMBI+ model that brings together two important functions of salinity measurement: (1) the salinity measurement directly in soils or substrates (activity), taking into consideration the relevant soil properties, like temperature, soil moisture, and soil compaction, and (2) the EC measurement in solutions and suspensions. The PNT COMBI+ provides an extended EC-measuring range from 0 to 20 dS m^{-1} and from 20 to 200 dS m^{-1}.

In a recent study at ICBA field station, Shahid et al. (2010) developed correlation between ECa measured by salinity probe and ECe. These correlations provide baseline to convert ECa into ECe; the latter is internationally used to determine salt tolerance of plants.

1.3.3 Salinity Monitoring Through Real-Time Dynamic Automated Salinity Logging System (RTDASLS)

This is a modern in situ salinity logging system. Salinity sensors are to be buried at desired root zone depth (Fig. 1.3c) where salinity monitoring is required. A feature of the salinity logging system is that it does not require any knowledge of electronics or computer programming. To operate the salinity station, simply plug in a salinity sensor (Fig. 1.3c), and through smart interface (Fig. 1.3d) and databus (Fig. 1.3e), the Smart Logger (Fig. 1.3f) will then search the databus and automatically identify the number of salinity sensors connected and begin logging them at hourly intervals or any other time interval as programmed. For custom configuration of the Smart Logger or salinity sensors, a simple menu system can be accessed through HyperTerminal that provides complete control over each individual sensor's setup. Instantaneous readings from sensors can be viewed on the logger's display directly in the field without the need for a laptop (Fig. 1.3f). Data can also be accessed in the field by memory stick or remotely using a mobile phone modem. This data is then available for graphing and interpretation in Excel. The RTDASLS has been successfully used in grass field at ICBA field station (Shahid et al. 2008).

1.3.4 Rational for Saturated Soil Paste Extract EC (ECe)

The EC of solution extracted from a saturated soil paste (which has water content about double than at field capacity) has been correlated with the response of various crops. This measure, known as electrical conductivity of the soil saturation extract (ECe), is now the generally accepted standard measure of soil salinity even though the procedure is time-consuming and requires vacuum filtration. In order to collect soil extract from saturated paste, soil samples from representative sites are to be collected carefully using standard sampling tools (Fig. 1.3g).

The preparation of saturated soil paste is simple, where about 300 g of sieved <2-mm air-dried soil is used to prepare saturated soil paste. The deionized water (DIW) is gradually added until all the soil is moist, and then they are mixed with a spatula until a smooth paste is obtained. The paste should glisten and just flow when the container is tilted and have no free water on the surface but be in a condition whereby it slides cleanly off the spatula. Soil saturation extract can be obtained under vacuum (Fig. 1.3h) and ECe determined by standard EC meter.

It should be noted that EC measurement on extracts or suspensions of fixed soil: water ratio (commonly 1:1, 1:2.5, or 1:5) does not give a reliable correlation. Such extracts or wider ratio is more convenient where the soil sample is limited. This is because the amount of water held at a given tension varies from soil to soil, depending on texture, the type of clay mineral, and other factors. However, when regular salinity mapping is to be accomplished and results are required on a daily basis, then it is essential to develop relationships between ECe, and EC measured by field scout (salinity probe) and EC measured on different soil: water content suspensions.

1.3.4.1 Correlation Between EC measured by Salinity Probe and EC at Various Soil: Water Contents

For many reasons, laboratory analysis of soil saturation extract is still the most common technique for assessing soil salinity and other potential hazards. Salinity of the saturation extract is considered a standard procedure because the amount of water that a soil holds at saturation (saturation percentage) is related to a number of soil parameters, such as texture, surface area, clay content, and cation-exchange capacity. Lower soil water ratios, for example, (1:1; 1:2; 1:5), make extraction easier but, cautioned, less related to field moisture condition than the saturated paste. The choice of equipment/procedure depends upon the purpose of salinity determination, size of the area being evaluated, the depth of soil to be assessed, the number and frequency of measurements needed, the accuracy required, and the availability of resources. The standard way is salinity monitoring through collecting soil samples from the root zones over a period of time and their analyses in the laboratory on a soil saturation extract.

As a part of ICBA salinity monitoring program, the soil team collected many samples from experimental plots irrigated with different water salinity up to maximum of seawater. These samples were air-dried and processed to collect water extracts from 1:1, 1:2.5, and 1:5 (soil: water) suspensions as well as soil extract from saturated soil paste. In addition, we also measured field conductivity (ECa) in mS cm^{-1} using field scout (Fig. 1.3b). Simple statistical test was used (Table 1.3) to develop correlation and correlation coefficient (R^2) and derived factors to convert EC determined by various water contents and salinity probe (field scout) to ECe (Table 1.4).

The above correlations are developed for fine sand (Soil Survey Division Staff 1993) textural class (sand subfractions: very coarse 3%, coarse 3%, medium 4%,

Table 1.3 Correlation between EC measured by salinity probe vs 1:1, 1:2.5 and 1:5 EC (soil: water) EC with ECe

Correlation equation and coefficient	Definition of *x* and *y*
(a) Correlation between EC by field scout and various soil water contents	
$y=2.2936x+4.0177$; $R^2=0.8896$	x = EC by field scout and y = ECe
$y=0.7929x+0.8131$; $R^2=0.9449$	x = EC by field scout and y = EC (1:1)
$y=0.6057x+0.4763$; $R^2=0.9105$	x = EC by field scout and y = EC (1:2.5)
$y=0.4733x+0.3269$; $R^2=0.9023$	x = EC by field scout and y = EC (1:5)
(b) Correlation between EC at different water contents	
$y=0.3276x-0.4152$; $R^2=0.9539$	x = ECe and y = EC (1:1)
$y=0.2642x-0.4782$; $R^2=0.9688$	x = ECe and y = EC (1:2.5)
$y=0.1357x-0.1835$; $R^2=0.9137$	x = ECe and y = EC (1:5)
$y=0.5737x+0.1119$; $R^2=0.9786$	x = EC (1:2.5) and y = EC (1:5)

Table 1.4 Conversion factor for ECe determination from different soil: water ratio and field scout ECe values

EC (different methods) dS m^{-1}	Multiplied by (factor) to get ECe
Field scout (ECa)	ECa × 3.81
EC (1:1)	EC (1:1) × 3.35
EC (1:2.5)	EC (1:2.5) × 4.77
EC (1:5)	EC (1:5) × 7.31

fine 51%, very fine 37%), silt (coarse 0.5%, fine 0.5%), and clay (1%) at ICBA field station. The ICBA soil is very strongly calcareous (50–60% $CaCO_3$ equivalents), and according to US Soil Taxonomy, it is "Typic torripsamments, carbonatic hyperthermic" with saturation percentage (22–26). Different conversion factors may exist in other areas of different soil textures and composition of salts. Therefore, they are site specific and their direct use in other areas with different soils is cautioned. It is recommended to develop similar correlations at local conditions and then use confidently to obtain ECe, a prerequisite for crops growing in saline field for root zone salinity management. Such an initial development is useful; it saves time and provides on-site salinity information and eliminates soil sampling and laboratory analyses.

1.4 Soil Morphology

Soil morphology can be investigated at four levels:

– *Macromorphology* – field level investigation with naked eye
– *Mesomorphology* – when naked eye cannot resolve the details, then it is aided with hand lens or binocular

- *Micromorphology* – when optical aid is needed for the naked eye to resolve details at higher magnifications, for example, in soil thin sections as studied with, a polarizing microscope is considered as an extension to field morphological studies (Cady 1965)
- *Submicroscopic*- the resolution of details at submicroscopic level using electron microscopes (scanning and transmission). Bisdom (1980) coupled the optical microscopy with submicroscopic methods and later with contact microradiography (Drees and Wilding 1982)

1.4.1 Field Assessment (Macromorphology: Naked Eye Salinity Diagnostics)

Macromorphology can be established during field investigation on broader scale, and features of interest can be captured with digital camera (still or video). Such investigations provide rapid information about the area of interest. During a field study of the Abu Dhabi coastline, a number of features were captured showing salt crusts in different morphological forms (hexagonal, circular, pillars, cubic, massive, cracked, etc.); some of the features are shown in Fig. 1.4a–d. In agricultural farms, salinity also exists due to poor management of soil and water resources, for example, drip-irrigated Rhoades grass field in Madinat Zayed, Abu Dhabi (Fig. 1.4e) and furrow-irrigated barley field in Pakistan (Fig. 1.4f).

1.4.2 Mesomophology

Mesomorphological observations are made when naked eye cannot resolve the details of the features of interest. The naked eye is then aided with hand lens or binoculars at lower magnifications. Such observations can be made in the field (hand lens) or in laboratory using binoculars. Examples of such mineral features (nahcolite) from a salt crust developed through simulation in the laboratory are shown in Fig. 1.5a, b.

1.4.3 Micromorphology

Micromorphology – when optical aid is needed for the naked eye to resolve details at higher magnifications, for example, in soil thin sections as studied with, a polarizing microscope is considered as an extension to field morphological studies (Cady 1965). Examples of such observations are thenardite in soil matrix (Fig. 1.4g) in an Aridisol from Punjab, Pakistan, and lublinite calcite coating the voids (Fig. 1.4h) in Aridisols from Pakistan (revealing calcification soil forming process).

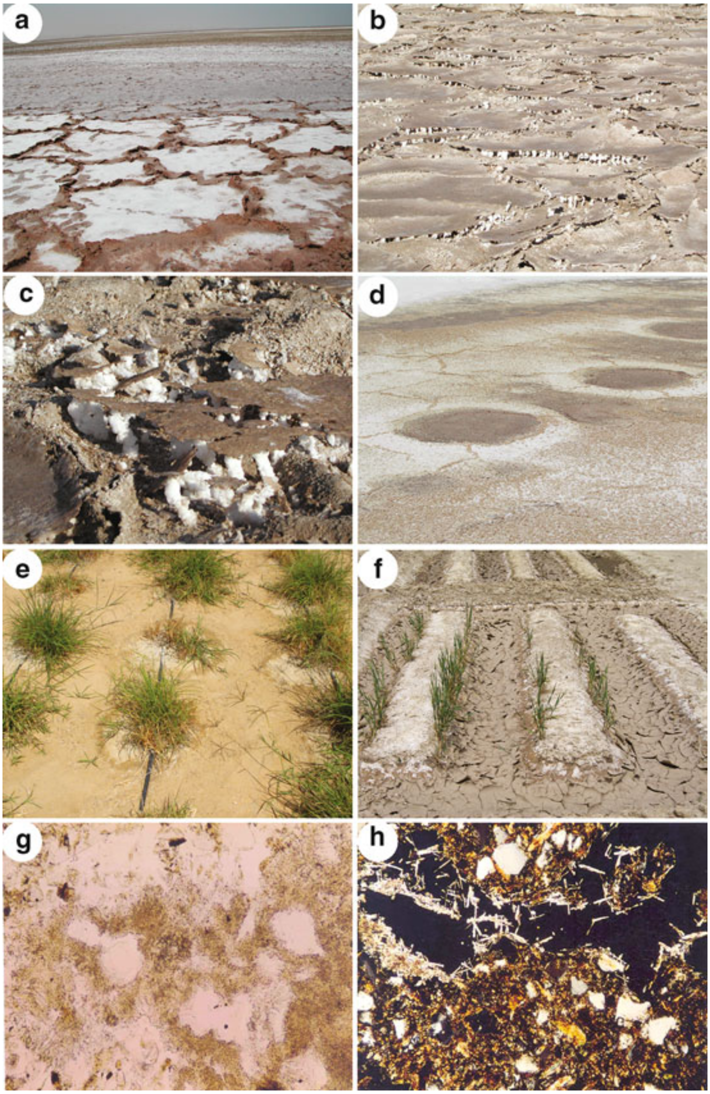


Fig. 1.4 Field observation of soil salinity at macro scale in Abu Dhabi Emirate, (**a**) hexagonal features, (**b–c**) surface cracking and salt pillars lifting surface crust, (**d**) circular salt features, (**e**) salinity in drip-irrigated Rhoades grass field, (**f**) salinity in furrow-irrigated barley field in Punjab Pakistan, (**g**) microscopic observation in thin section (Pakistan) showing thenardite in saline soil matrix, (**h**) lublinite crystals coating void surface (lublinitan), in a saline soil from Pakistan

1.4.4 Submicroscopic Observations by SEM

When morphological resolution of details is required at submicroscopic level, then features are investigated by electron microscopes (scanning and transmission). Bisdom (1980) coupled the optical microscopy with submicroscopic methods and

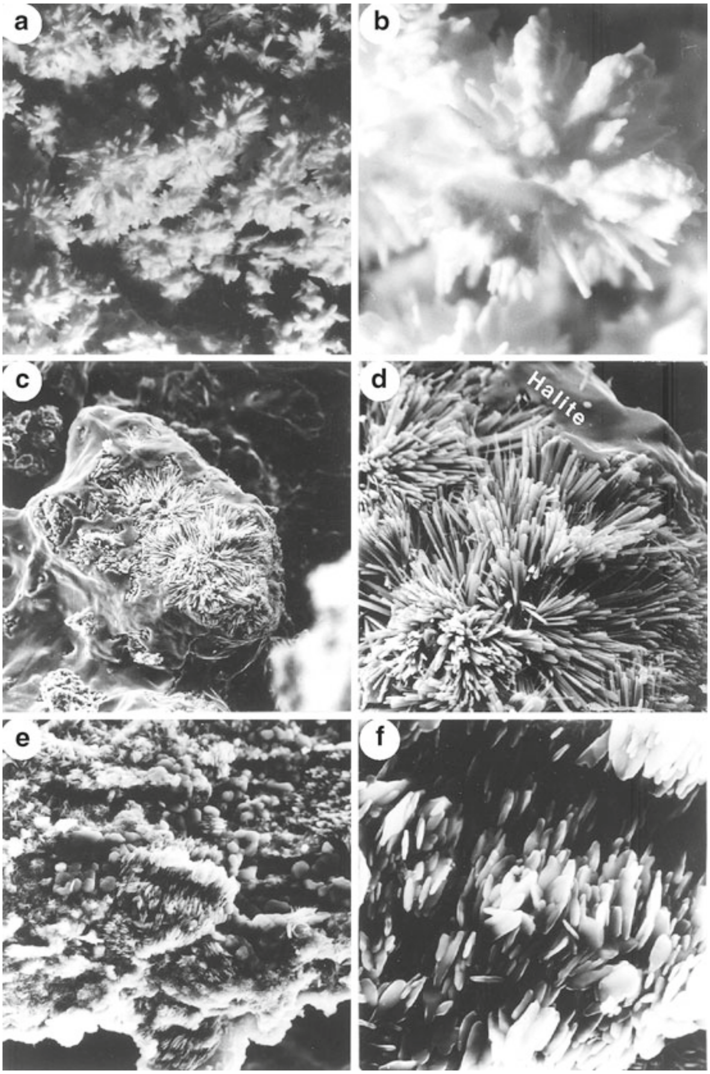


Fig. 1.5 (**a**) The nahcolite ($NaHCO_3$) efflorescence as seen under the binocular (width 1.1 mm), (**b**) selected part from (a) at higher magnification (width 0.28 mm), (**c**) SEM micrographs of lath-shaped glauberite [$Na_2Ca(SO_4)_2$] emerging from massive halite (NaCl) from Playa valley of Spain (width 160 μm), (**d**) glauberite at higher magnification (width 64 μm), (**e**) mixture of platy thenardite (Na_2SO_4), granular halite (NaCl) and lath-shaped trona [$Na_3H(CO_3)_2.2H_2O$] from saline soil Pakistan (width 80 μm), and (**f**) details of platy thenardite (width 16 μm)

later with contact microradiography (Drees and Wilding 1983). These electron microscopes are supplemented with microchemical analyzer (EDXRA, WDXRA), allowing in situ microchemical analyses (nondestructive). To study salt crusts at submicroscopic level, soil samples need coatings with gold-palladium (an alloy), or carbon on salt crusts is needed to make the sample conductor.

Figure 1.5 presents submicroscopic features of salt crust from Playa valley in Spain (Fig. 1.5c, d). The salt crusts were collected by the author during his visit to Spain and studied on SEM. The SEM micrographs (Fig. 1.5c, width 160 μm) show lath-shaped glauberite [$Na_2Ca(SO_4)_2$] emerging from massive halite (NaCl); the details of glauberite at higher magnification can be seen in Fig. 1.5d (width 64 μm). In another feature of a salt crust, mixture of platy thenardite (Na_2SO_4), granular halite, and lath-shaped trona [$Na_3H(CO_3)_2.2H_2O$] from saline soil Pakistan (width 80 μm) is evident (Fig. 1.5e), whereas Fig. 1.5f shows the details of platy thenardite (width 16 μm) at higher magnification. The mineral composition was confirmed using microchemical analyses (EDXRA) and the investigation of same feature with XRD.

1.4.4.1 Transition from 2D to 3D Information

The low-temperature ashing (LTA) is a technique of surface oxidation suitable for selective resin removal from thin sections. Basically, it involves the partial ionization of oxygen at low pressure by high-frequency (radio or microwave) excitation to produce a "nonequilibrium plasma" in which there is an abundance of free electrons accelerated to high velocities equivalent to temperature of several thousand degree centigrade, while the velocity of the abundant excited atoms and molecules is equivalent to temperature of a few hundred degree centigrade only. Such plasma can achieve controlled oxidation and volatilization of organic materials at relatively low temperature, the actual sample surface temperature depending on oxygen flow rate and RF power input but being of the order of 150–120°C (Thomas 1974). The LTA is operated at a frequency of 13.56 MHz and an oxygen flow rate of 200 ml minute^{-1} at a pressure of 1 mm Hg. The power input is kept at its lower value of 150 W; however, it can be increased continuously to 300 W to minimize the temperature elevation and distortion in the sample. A period of 10–15 min was found to be adequate for ashing. The ashed thin section was stuck onto a 1-cm carbon stub using normal araldite and coated with carbon in an evaporator with a layer of 20–30 nm thick to prevent charge buildup on the specimen and to hold the surface of the sample at a constant electro-potential. The Hitachi Instrument Co. model SEM S0520 was operated at an accelerating voltage of 15–25 kv. The ICN low-temperature asher model 302 supplied by the Tracerlab was used to remove the resin from thin section. Prospects of the technique are described by Jenkins (1980) and Price and Jenkins (1980).

In an earlier publication, Price and Jenkins (1980) emphasized the limitations on the use of LTA, showing crystals of gypsum cannot survive the process of LTA. Such damage to gypsum crystals has also been recorded by Frazer and Belcher (1973), thus suggesting the incapability of LTA technique to gypsids. In this context, limited investigations have been made to explore the details of 3D in thin sections because of either partial or complete loss of the section. More specifically these studies reported the loss of gypsum crystals through dehydration and hence show limited or no access to the third dimension.

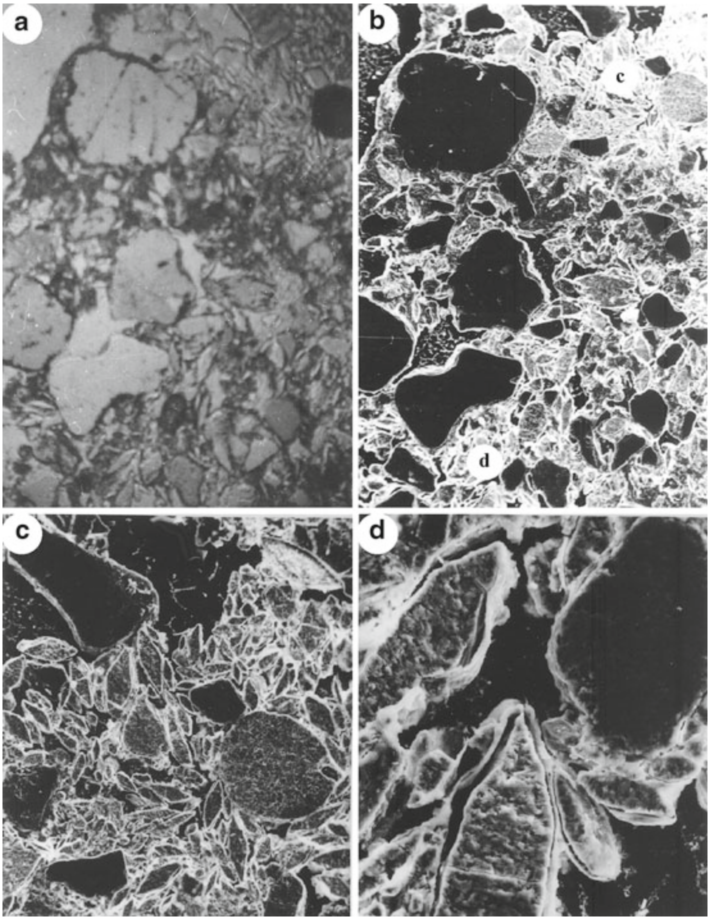


Fig. 1.6 Gypsic soil from Hofuf, Saudi Arabia in thin section showing lenticular gypsum crystals, (**a**) 2D feature under optical microscope (width 1.22 mm), (**b**) same feature as in (a) intact feature after removing resin through low temperature ashing-3D feature, (**c**) details of lenticular crystals revealing the survival after LTA process and showing third dimension (width 0.6 mm), (**d**) etching of lenticular gypsum crystal and coating features over gypsum crystals (width 0.17 mm)

For the last three decades, no further attempts have been made for such studies. In order to bridge the gap in such studies, an investigation was made on soil thin sections from Hofuf, Saudi Arabia (Fig. 1.6). The figure clearly revealed strong promise for 3D investigation in soil thin sections (Fig. 1.6a–d). The study provides evidences for great promise to study thin sections already studied by OM for their further 3D evaluation at the submicroscopic level. The objective of this investigation has been to reassess the technique for gypsids to elucidate if there is any possibility to open the closed chapter again and to study thin section at a submicroscopic level after the LTA process. Shahid (2009) has successfully studied calcids from Pakistan, where needle-shaped calcite (lublinite) has survived the LTA process.

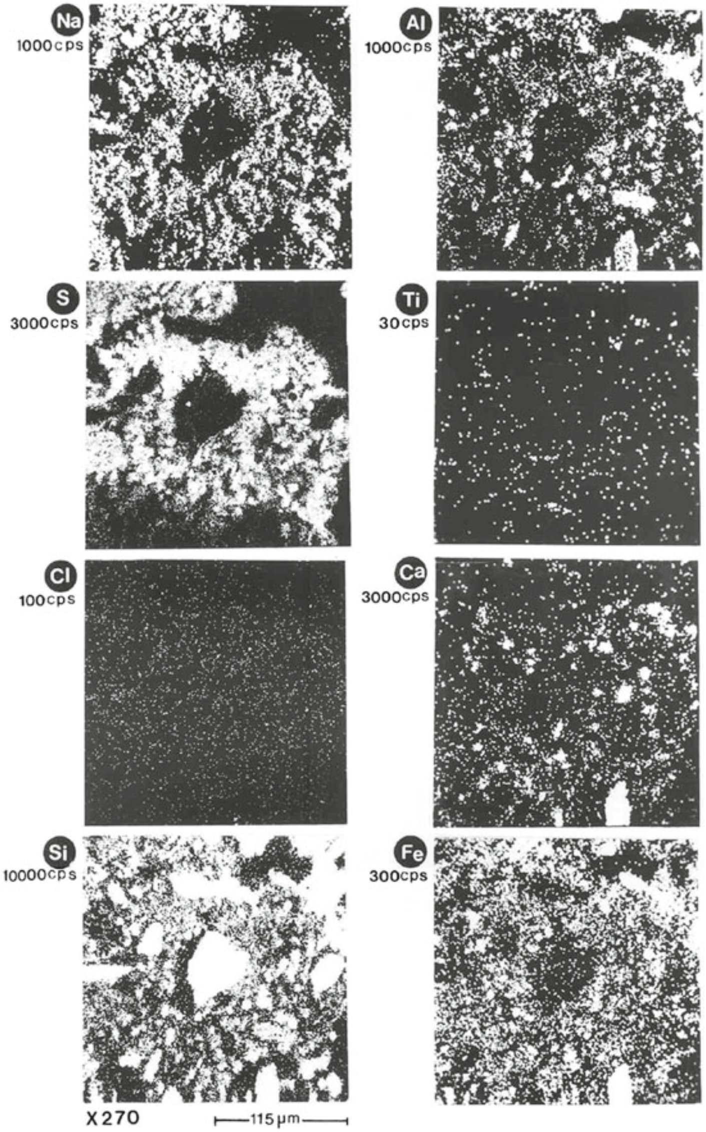


Fig. 1.7 Elemental mapping in a thenardite rich salt crust through Electron Probe Micro Analyses

1.4.5 Elemental Mapping in Saline Features: EPMA Observations

The feature (Fig. 1.4g) shows some anhedral crystals embedded in thenardan. These anhedral crystals were initially thought to be of some unknown salt minerals. The x-ray mapping (Fig. 1.7) shows the relative abundance of the Na, S, and Si, where

Na and S mainly exist together, which suggest the presence of thenardite. In the same sample, thenardite and mirabilite ($Na_2SO_4.10H_2O$) have been detected by other complementary techniques such as XRD. The anhedral crystals embedded in the thenardan only revealed presence of Si, which suggests the crystals to be of detrital quartz. It is assumed that these quartz grains are embedded in recrystallized thenardite from the evaporation of Na- and S-rich underground water. The thenardite matrix around the quartz also shows the presence of Si, Al, Ti, Ca, and Fe, suggesting the presence of quartz, feldspar, calcite, phyllosilicates, and small amounts rutile/brookite. The EPMA beam was also focused on the features where halite was expected, but this damaged the feature (destructive technique for halite analysis by EPMA) and the composition could not be revealed.

1.5 Conclusions and Recommendations

This chapter presents a comprehensive review of literature on soil salinity assessment technologies to aid measurements from regional, national, farm, to submicroscopic levels of investigation. The user can select the technique best suited to objective and availability of resources. When selecting the technology for a specific purpose, it is important to consider pros and cons of each technique. Integration of techniques can provide better salinity status and help future prediction to allow taking necessary action. RS imagery and GIS are great techniques for salinity mapping at small scales. In areas where saline-brackish water is used for irrigation purpose, farm-based salinity mapping and monitoring tools such as electromagnetic induction (EMI) equipment EM38 and salinity probes are recommended to understand day-to-day salinity status to manage soils for better agricultural production. For rapid salinity survey by EM38 and field scout, it is recommended to develop site-specific relations between EC measured by various techniques to obtain the standard salinity values of the ECe. Salinity modeling can provide important information; however, they require data which in many developing countries are not easy to produce. Elemental mapping through submicroscopic investigation can provide in situ salinity status and behavior in actual soil environment; however, such studies are mainly of academic interest and directly do not provide handy information for the farmers for salinity management. Innovative work on the study of thin section for 3D investigation by SEM provided opportunity for soil micromorphologists to study same features initially studied on the optical microscope for 2D information to be further studied by SEM for 3D information at submicroscopic level.

References

Abdelfattah MA, Shahid SA, Othman Y (2009) Soil salinity mapping model developed using RS and GIS – a case study from Abu Dhabi, United Arab Emirates. Eur J Sci Res 26(3):342–351

Abdelfattah MA, Shahid SA, Othman Y, Kumar A (2010) Soil salinity mapping through extensive soil survey and using geographical information System. Case study from Abu Dhabi. Paper presented at the international conference on management of soil and groundwater salinization in arid regions Sultan Qaboos University, Sultanate of Oman 11–14 Jan 2010

Abdelgawad G (2009) Soil salinity monitoring and assessment in irrigated Arab agriculture. In: Advances in the assessment and monitoring of salinization and status of biosaline agriculture. Reports of expert consultation held in Dubai, United Arab Emirates, 26–29 Nov 2007. World Soil Resources reports no 104. FAO, Rome, p 16

Acworth RI, Beasley R (1998) Investigation of EM31 anomalies at Yarramanbah/Pump Station Creek on the Liverpool Plains of New South Wales. WRL Research report no 195

Ahmad MD (1999) Estimating the interaction between soil moisture and groundwater using geo-information techniques. International Institute for Aerospace Survey and Earth Sciences, Enschede

Asif S, Ahmad MD (1999) Using state-of-the-art RS and GIS for monitoring waterlogging and salinity. Paper published by International Water Management Institute, Lahore, Pakistan, p 16

Baerends B, Raza ZI, Sadiq M, Chaudhry MA, Hendrickx JMH (1990) Soil salinity survey with an electromagnetic induction method. In: Proceedings of Indo-Pak workshop on soil salinity and water management, 10–14 Feb 1990, vol 1, Islamabad, Pakistan, pp 201–219

Barzanji AG, Stoops G (1974) Fabric and mineralogy of gypsum accumulation in some soils of Iraq. Proc 10th Int Congs Soil Sci Moscow 7:271–277

Bastiaanssen WGM, Allen RG, Droogers P, D'Usro G, Steduto P (2007) Twenty-five years modeling irrigated and drained soils: state of the art. Agric Water Manag 92(3):111–125

Batlle-Sales J (2009) Overview of salinity modeling approaches at different spatial-temporal. In: Advances in the assessment and monitoring of salinization and status of biosaline agriculture. Reports of expert consultation held in Dubai, United Arab Emirates, 26–29 Nov 2007. World Soil Resources reports no 104. FAO, Rome, p 27

Batlle-Sales J (2013) Soil salinity modeling, approaches and key issues. Chapter 2 In: Developments in soil salinity assessment and reclamation: Innovative thinking and use of marginal soil and water resources in irrigated agriculture (Shahid SA, Abdelfattah MA, Taha FK (ed.)), Springer, pp 45–59

Bennet BA (1998) Airborne remote sensing and field spectroscopy for soil salinity mapping at Pyramid Hill, Victoria. Unpublished Masters Thesis, School of Geology, UNSW, p 65

Bisdom EBA (1980) Submicroscopy of undisturbed soils and weathered rocks. 1st workshop of the international group on submicroscopy of undisturbed soil materials, Wageningen, The Netherlands

Braitsch O (1962) Entstehung und stoffbestand der salzlagerstatten. Min. und petr. In Einzeldarstellungen, 3. Springer, Berlin

Brena J, Sanvicente H, Pulido L (1995) Salinity assessment in Mexico. In: Vidal A, Sagardoy JA (eds) Water report no 4: use of remote sensing techniques in irrigation and drainage. FAO, Rome, pp 173–178

Buringh P (1979) Arid and semiarid soils. In: Introduction to the study of soils in tropical and subtropical regions. Center for Agriculture, Publishing and Documentation, Wageningen, pp 17–28

Cady JG (1965) Petrographic microscope technique. In: Black CA (ed) Methods of soil analysis. Part-I Am Soc Agro 9:604–631

Cameron DR, De Jong E, Read DWL, Oosterveld M (1981) Mapping salinity using resistivity and electromagnetic inductive techniques. Can J Soil Sci 61:67–78

Casas S (1995) Salinity assessment based on combined use of remote sensing and GIS. In Vidal A, Sagardoy JA (eds). Water Report No. 4: Use of remote sensing techniques in irrigation and drainage, pp 185–197. Rome, FAO

Chaturvedi L, Carver KR, Harlan JC, Hancock GD, Small FV, Dalstead KJ (1983) Multispectral remote sensing of saline seeps. IEEE Trans Geosci Remote Sens 21(3):239–250

Cheraghi SAM, Hashminejhad Y, Rahimian MH (2009) An overview of the salinity problem in Iran: assessment and monitoring technology. In: Advances in the assessment and monitoring of salinization and status of biosaline agriculture. Reports of expert consultation held in Dubai, United Arab Emirates, 26–29 Nov 2007. World Soil Resources reports no 104. FAO, Rome, p 21

Cheverry C, Fromaget M, Booquire G (1972) Quelques Aspects micromorphologiques de la pédogenese des sols de polders conquis sur le lac Tchad. Cdh O Tom Ser Pedol 10(4):373–388

Chinese Academy of Sciences (2001) Chinese soil taxonomy. Coordinated by Institute of Soil Science, Chinese Academy of Sciences, p 203
Cook PG, Walker GR (1992) Depth profiles of electrical conductivity from linear combinations of electromagnetic induction measurements. Soil Sci Soc Am J 56:1015–1022
Cook PG, Walker GR, Buselli G, Potts I, Dodds AR (1992) The application of electromagnetic techniques to groundwater recharges investigations. J Hydrol 130:201–229
Corwin DL, Rhoades JD (1982) An improved technique for determining soil electrical conductivity-depth relations from above ground electromagnetic measurements. Soil Sci Soc Am J 46:517–520
Corwin DL, Rhoades JD (1984) Measurement of inverted electrical conductivity profiles using electromagnetic induction. Soil Sci Soc Am J 48:288–291
Corwin DL, Rhoades JD, Simunek J (2007) Leaching requirement for soil salinity control. Steady-state versus transient models. Agric Water Manag 90(3):165–180
Crescimanno G, Marcum KB, Morga F, Reina C (2009) Assessing and monitoring the risk of salinization in a Sicilian vineyard using the Geonics 38. In: Advances in the assessment and monitoring of salinization and status of biosaline agriculture. Reports of expert consultation held in Dubai, United Arab Emirates, 26–29 Nov 2007. World Soil Resources reports no 104. FAO, Rome, p 10
Donar HE, Lynn WC (1971) Carbonates, halide, sulfate and sulfide minerals. In: Minerals in the soil environment. Soil Science Society of America, Madison, pp 75–98
Doolittle JA, Windhorm RD, Withers DL, McLeese RL (2009) High-intensity soil mapping with the aid of EMI in Northern Illinois. Soil Surv Horiz 2(50):68–74
Drees LR, Wilding LP (1982) Microradiography as a submicroscopic tool. Geoderma 30:65–76
Driessen PM (1970) Soil salinity and alkalinity in the great Konya Basin, Turkey. Center for Agricultural Publishing and Documentation, Wageningen
Driessen PM, Schoorl R (1973) Mineralogy and morphology of salt-efflorescences on saline soils in the great Konya Basin Turkey. J Soil Sci 24(4):436–442
Dutkiewics A, Lewis M (2008) Broadscale monitoring of salinity using satellite remote sensing: where to from here? 2nd International Salinity Forum, Adelaide, Australia, p 6
Dutt GR (1962) Prediction of the concentration of solutes in soil solutions for soil systems containing gypsum and exchangeable Ca and Mg. Soil Sci Soc Am Proc 26:341–343
Dutt GR, Tanji KK (1962) Predicting concentrations of solutes in effluents. J Geophy Res 67:3437–3439
Dutt GR, Terkeltoub RW, Rauschkolb RS (1972) Prediction of gypsum and leaching requirements for sodium-affected soils. Soil Sci 114:93–103
Dwivedi RS (1992) Monitoring and the study of the effect of image scale on delineation of salt-affected soils in the Indo-Gangetic plains. Int J Remote Sens 13:1527–1536
Dwivedi RS, Rao BRM (1992) The selection of the best possible Landsat TM band combination for delineating salt-affected soils. Int J Remote Sens 13(11):2051–2058
Dwivedi RS, Sreenivas KL (1998) Delineation of salt-affected soils and waterlogged areas in the Indo-Gangetic plains using IRS-1C LISS-III data. Int J Remote Sens 19:2739–2751
EAD (2009) Soil survey of Abu Dhabi Emirate, 5 vols. Environment Agency-Abu Dhabi, Abu Dhabi
EAD-ICBA (2012) Proposal for adding anhydrite soils to USDA soil taxonomy. Proposal to amend soil taxonomy. Jointly submitted by Environment Agency – Abu Dhabi and International Center for Baseline Agriculture. Proposal can be accessed at USDA website http://soils.usda.gov/technical/classification/taxonomy. Accessed 13 Mar 2012
El-Mubarak AA (2009) Assessment and management of salt-affected soils in Sudan. In: Advances in the assessment and monitoring of salinization and status of biosaline agriculture. Reports of expert consultation held in Dubai, United Arab Emirates, 26–29 Nov 2007. World Soil Resources reports no 104. FAO, Rome, pp 24–25
Eswaran H, Barzanji AF (1974) Evidence for the neoformation of attapulgite in some soils of Iraq. In: Proc 10th Int Congs Soil Sci Moscow 7:154–161
Eswaran H, Carrera M (1980) Mineralogical zonation in salt crusts. In: International symposium on salt-affected soils. Central Soil Salinity Research Institute, Kernal, pp 20–30

Eswaran H, Stoops G, Abatahi A (1980) SEM morphologies of halite (NaCl) in soils. J Microsc 120:343–352

Everitt JH, Escobar DE, Gerbermann AH, Alaniz MA (1988) Detecting saline soils with video imagery. Photogramm Eng Remote Sens 54(1):283–287

FAO (1997) Action in the near east region (http://www.fao.org) cf. Hussein 2001

FAO (2009) Advances in the assessment and monitoring of salinization and status of biosaline agriculture. Reports of expert consultation held in Dubai, United Arab Emirates, 26–29 Nov 2007. World Soil Resources reports no 104. FAO, Rome, p 72

FAO-UNESCO (1974) Soil map of the World. 1:5,000,000, UNESCO, Paris, France, Vols 1010

Farooq M, Nur Ud Din (1980) Application of multitemporal Landsat data in the identification of salinity in the Khairpur pilot project, Pakistan. In: Proceedings of the national seminar on application of remote sensing techniques in water resources development and management, Lahore, Pakistan, pp 74–81

Felmy AR (1990) GMIN: a computerized chemical equilibrium model using a constrained minimization of the Gibbs free energy. Pacific Northwest Lab Richland, Washington, DC

Fenton TE, Lauterbach MA (1999) Soil map unit composition and scales of mapping related to interpretations for precision soil and crop management in Iowa. In: Proc of the 4th international conference on site specific management. St Paul. 19–22 July 1998. ASA, Madison

Feofarova II (1940) Mineralogical determination of water soluble minerals in saline soils. Pochvovedeniye No 12

Feofarova II (1958) Sulfates in saline soils. Tr Pochv Inst Im VV Dokuheayeva, Volume 53

Fitzpatrick EA (ed) (1984) Micromorphology of soils. Chapman & Hall, London/New York, pp 1–433

Frazer FW, Belcher CB (1973) Quantitative determination of the mineral matter content of coal by a radio frequency oxidation technique. Fuel 52:41–46

Furby SL, Vallace JF, Caccetta PA, Wheaton GA (1995) Detecting and monitoring salt-affected land: a report from the LWRRDC project detecting and monitoring changes in land condition through time using remotely sensed data, Remote Sensing and Image Integration Group, CSIRO Division of Mathematics & Statistics, Western Australia

Garrels RM, Christ CL (1965) Solutions, minerals and equilibria. Harper and Row, New York

Gomaa MH (2009) Advances in the assessment and monitoring of soil salinization for managing salt-affected habitats in Egypt. In: Advances in the assessment and monitoring of salinization and status of biosaline agriculture. Reports of expert consultation held in Dubai, United Arab Emirates, 26–29 Nove 2007. World Soil Resources reports no 104. FAO, Rome, p 22

Goossens REA, El Badawi M, Ghabour TK, de Dapper M (1993) A simulation model to monitor the soil salinity in irrigated arable based upon remote sensing and GIS. EARSeL Adv Remote Sens 2(3):165–171

Greenhouse JP, Slaine DD (1983) The use of reconnaissance electromagnetic methods to map contaminant migration. Ground Water Monit Rev 3(2):47–59

Gumizzio J, Battle J, Casas J (1982) Mineralogical composition of salt efflorescences in a typic salorthid, Spain. Geoderma 28:39–51

Hanna FS, Stoops G (1976) Contribution to the micromorphology of saline soils of the North Nile delta in Egypt. Pedologie 26:55–73

Hardisk MA, Klemas V, Daiber FC (1983) Remote sensing salt marsh biomass and stress detection. Adv Space Res 2:219–229

Harrison Sir JB (1933) The katamorphism of igneous rocks under humid tropical conditions. Imp. Bureau Soil Science, Rothamstead Experimental Station, Harpenden

Hedley CB, Yule IJ, Eastwoof CR, Shephard TG, Arnold G (2004) Rapid identification of soil textural and management zones using electromagnetic induction sensing in soils. Aust J Soil Res 42:389–400

Hussein H (2001) Development of environmental GIS database and its application to desertification study in Middle East. A remote sensing and GIS application. PhD thesis Graduate School of Science and Technology, Chiba University Japan

Hussein H (2003) Remote sensing technology for salinity mapping. Presentation given at the training workshop on salinization of irrigated land and reclamation, held at ICBA Headquarter, Dubai, 5–9 Apr 2003

Hutson JL, Wagenet RJ (1990) LEACHM: Leaching estimation and chemistry model. ver 3. Dept Soil, Crop and Atmos. Sci Res Series No 92–3. Cornell University Ithaca NY, p 80.

Im-Erb R, Sukchan S (2009) Salt-affected soils in Thailand: assessment and monitoring of soil salinization. In: Advances in the assessment and monitoring of salinization and status of biosaline agriculture. Reports of expert consultation held in Dubai, United Arab Emirates, 26–29 Nov 2007. World Soil Resources reports no 104. FAO, Rome, pp 19–20

Im-Erb R, Yamclee P, Sukchan S (2005) Salt-affected soils in Thailand: assessment and monitoring on salinization. Land Development Department, Bangkok, Thailand

Irion G (1970) Mineralogisch-sedimntpetrographische und geochemische untersuchungen an Tuz Golu (salzsee), Turkei. Chem Erde 29:167–227

Isbell RF (1998) The Australian soil classification. CSIRO, Collingwood, p 143

Jaynes DB (1995) Electromagnetic induction as a mapping aid for precision farming. In: Clean water, clean environment, 21st century: team agriculture. Working to protect water resources. Kansas City, 5–8 Mar 1995, pp 153–156

Jenkins DA (1980) The transition from the optical microscopic to scanning electron microscopic studies on soils. In: Proceedings of first workshop of the international working group on submicroscopy of undisturbed soil materials, Wageningen, pp 237–248

Job JO, Loyer JY, Ailoul M (1987) Utilisation de la conductivite electromagnetique pour la mesure directe de la salinite des sols. Cah ORSTOM ser Pedol 23(2):123–131

Joshi MD, Sahai B (1993) Mapping of salt-affected land in Saurashtra coast using Landsat satellite data. Int J Remote Sens 14(10):1919–1929

Jury WA, Frenkel H, Stolzy LH (1978) Transient changes in the soil-water system from irrigation with saline water: I Theory. Soil Sci Soc Am Proc 42:579–585

Kachanoski RG, Gregorich EG, Van Wasenbeeck IJ (1988) Estimating spatial variations of soil water content using non contacting electromagnetic inductive methods. Can J Soil Sci 68: 715–722

Kalkhan MA, Stohlgren TJ, Chong GW, Lisa D, Reich RM (2000) A predictive spatial model of plant diversity: integration of remotely sensed data, GIS, and spatial statistics report of The World Bank, Washington, DC

Khan NM, Sato YS (2001) Monitoring hydro-salinity status and its impact in irrigated semi-arid areas using IRS-1B LISS-II data. Asian J Geoinf 1(3):63–73

King JA, Dampney PM, Lark RM, Wheeler HS, Bradley RI, Mayr TR (2005) Mapping potential crop management zones within fields: use of yield map series and patterns of soil physical properties identified by electromagnetic induction sensing. Precis Agric 6:167–181

KISR (1999a) Soil survey for the state of Kuwait, vol II, Reconnaissance survey. AACM International, Adelaide

KISR (1999b) Soil survey for the state of Kuwait, vol IV, Semi-detailed survey. AACM International, Adelaide

Kovda VA (1946) Origin of saline soils and their regime. Academy of Sciences of the USSR. Dokuchaev Soil Sci Inst LI Prasolov (ed) Translated from Russian by Israel Program for Scientific Trans, vol 1, Jerusalem, p 509

Kovda VA, Szabolcs I (1979) Modeling of soil salinization and alkalinization. Agrokemia es Talajtan (Suppl)

Kubiena WL (1931) Micropedological studies (Mikropedologische studien) Atch. Pflanzenbau 5(4):613–648

Kubiena WL (1938) Micropedology. Collegiate Press, Ames, pp 50–53

Maher MAA (1990) The use of remote sensing techniques in combination with a geographic information system for soil studies with emphasis on quantification of salinity and alkalinity in the northern part of the Nile delta. MSc thesis, ITC Enschede, Netherlands

Makin IW (1986) Applications of remotely sensed, multi-spectral data in monitoring saline soils. Technical note no. 19. IPRI, Amritsar

Madrigal LP, Meraz JG (2009) Using satellite imagery and electromagnetic induction to assess soil salinity, drainage problems and crop yield in Rio Fuerte Irrigation District. In: Advances in the assessment and monitoring of salinization and status of biosaline agriculture. Reports of expert consultation held in Dubai, United Arab Emirates, 26–29 Nov 2007. World Soil Resources reports no. 104. FAO, Rome, p 14

Massoud FI (1981) Salt-affected soils at a global scale and concepts of control. FAO Land and Water Development Division, Technical Paper, Rome, p 21

McNeill JD (1980) Electromagnetic terrain conductivity measurements at low induction numbers. Geonics Limited Technical Notes TN-6, Geonics Ltd., Mississauga

Menenti M, Lorkeers A, Vissers M (1986) An application of thematic mapper data in Tunisia. ITC J 1:35–42

Metternicht GB, Zink JA (1996) Spatial discrimination of salt and sodium affected soil surfaces. Int J Remote Sens 18:2571–2586

Morales JA, Batlle-Sales J (2009) Use of an aboveground electromagnetic induction meter for assessing salinity changes in natural landscapes and agricultural fields. In: Advances in the assessment and monitoring of salinization and status of biosaline agriculture. Reports of expert consultation held in Dubai, United Arab Emirates, 26–29 Nov 2007. World Soil Resources reports no. 104. FAO, Rome, p 11

Morgan AJ (1985) X-ray microanalysis in electron microscopy for biologists, Microscopy handbook-05. Royal Microscopical Society, Oxford, pp 1–79

Mougenot B, Pouget M, Epema GF (1993) Remote sensing of salt affected soils. Remote Sens Rev 7:241–259

Mulders MA, Epema GF (1986) The thematic mapper: a new tool for soil mapping in arid areas. ITC J 1:24–29

Muller G, Irion G (1969) Salt-biscuits. A special growth structure of NaCl in salt sediments of the Tuz Golu (salt trace), Turkey. J Sed Pet 39(3):1604–1607

Norman CP, Lyle CW, Heuperman AF, Poulton D (1989) Pyramid hill irrigation area – soil salinity survey, May–June 1988, Research Report Series no 80. Victoria Department of Agriculture and Rural Affairs, Australia

Norman C, Heath J, Turnour R, MacDonald P (1995a) On-farm salinity monitoring and investigations. Institute of Sustainable Irrigated Agriculture (ISIA), Tatura, Report 1993–1995, p 164

Norman C, Challis P, Oliver H, Robinson J, Gillespie K, Rankin C, Tonkins S, Heath J (1995b) Whole farm soil salinity surveys in the Kerang region. Institute of Sustainable Irrigated Agriculture (ISIA), Tatura, Report 1993–1995, p 162

Northcote KH, Skene JKM (1972) Australian soils with saline and sodic properties, CSIRO Australia, Soil publication no.27. CSIRO, Melbourne

Oster JD, Rhoades JD (1975) Calculated drainage water compositions and salt burdens resulting from irrigation with river waters in the Western United States. J Environ Qual 4:73–79

Oster JD, Rhoades JD (1990) Steady state root zone salt balance. In: Tanji KK (ed) Agricultural salinity assessment and management manual. ASCE, New York, pp 469–481

Pazira E (1999) Land reclamation research on soil physico-chemical improvement by salt-leaching in southwest part of Iran. IERI, Karaj

Pessarakli M, Szabolcs I (2011) Soil salinity and sodicity as particular plant/crop stress factors. In: Pessarakli M (ed) Handbook of plant and crop stress, 3rd edn. CRC Press, Boca Raton, pp 3–21

Price F, Jenkins DA (1980) Removal of resin from standard soil thin sections by low temperature ashing as a means of following transmitted optical by scanning electron microscopy. Clay Miner 15:309–315

Ragab R (2001) A holistic genetic integrated approach for irrigation, crop and field management: the SALTMED model. Paper presented at the international workshop on sustained management of irrigated land for salinity and toxic element control, Riverside, CA, USA, 25–27 June 2001

Ranatunga K, Nation ER, Barratt DG (2008) Review of soil water models and their applications in Australia. Environ Model Softw 23(9):1182–1206

Rao BR, Dwivedi RS, Venkataratnam LM, Thammappa SS, Bhargawa GP, Singh AN (1991) Mapping the magnitude of sodicity in part of the Indo-Gangetic plains of Uttar Pradesh, Northern India using Landsat-TM data. Int J Remote Sens 12(3):419–425

Rhoades JD (1972) Quality of water for irrigation. Soil Sci 113:277–284

Rhoades JD (1977) Potential for using saline agricultural drainage water for irrigation. In: Proceedings on water management for irrigation and drainage. ASCE, Reno, NV, July 1977, 177:85–116

Rhoades JD (1984) Principles and methods of monitoring soil salinity. In: Soil salinity and irrigation processes and management. Springer, Berlin 5:130–142

Rhoades JD (1987) Use of salinity water for irrigation. Water Qual Bull 12:14–20

Rhoades JD (1988) The problem of salt in agriculture. In: Yearbook of science and the future. Encyclopedia Britannica, Chicago, pp 118–135

Rhoades JD (1992) Instrumental field methods of salinity appraisal. In: Topp GC, Reynolds WD, Green RE (eds) Advances in measurements of soil physical properties: bringing theory into practice, SSSA Special Publication 30. ASA/CSSA/SSSA, Masison, pp 221–248

Rhoades JD (1995) Field investigations and methods of measurements, monitoring and mapping of salinity in salt-affected soils. Paper presented at regional workshop on management of salt-affected soils in the Arab Gulf States, 29 Oct – 2 Nov, Abu Dhabi

Rhoades JD, Corwin DL (1981) Determining soil electrical conductivity-depth relations using an inductive electromagnetic soil conductivity meter. Soil Sci Soc Am J 45:255–260

Rhoades JD, Merrill SD (1976) assessing the suitability of water for irrigation: throretical and empirical approaches. In Prognosis of Salinity and Alkalinity. Soils Bull 31, FAO Rome, pp 69–109

Rhoades JD, Suarez DL (1977) Reducing water availability degradation through minimized leaching management. Agric Water Manag 1:127–142

Rhoades JD, Raats PA, Prather RJ (1976) Effects of liquid-phase electrical conductivity, water content, and surface conductivity on bulk soil electrical conductivity. Soil Sci Soc Am J 40:651–655

Rhoades JD, Manteghi NA, Shouse PJ, Alves WJ (1989a) Soil electrical conductivity and soil salinity: new formulations and calibrations. Soil Sci Soc Am J 53:433–439

Rhoades JD, Lesch SM, Shouse PJ, Alves WJ (1989b) New calibrations for determining soil electrical conductivity-depth relations from electromagnetic measurements. Soil Sci Soc Am J 53:74–79

Richards LA (ed) (1954) Diagnosis and improvement of saline and alkali soils, USDA handbook no 60. US Department of Agriculture, Washington, DC, pp 79–81

Robbins CW, Jurinak JJ, Wagenet RJ (1980) Calculating cation exchange in a salt transport model. Soil Sci Soc Am J 44:1195–1200

Slavich PG (1990) Determining ECa-depth profiles from electromagnetic induction measurements. Aust J Soil Res 28:443–452

Shahid SA (1988) Studies on the micromorphology of salt-affected soils in Pakistan. PhD dissertation, School of Agricultural and Forest Sciences, University College of North Wales, Bangor, (Two volumes, p 595)

Shahid SA (1992) Use of submicroscopic technique (SEM/EDXRA) for in situ micro-morphological and microchemical analysis of salt-efflorescence from a typic salorthid in Pakistan. Pak J Agric 1(2):82–87

Shahid SA (2009) Transition from 2D to 3D in-situ soil information. Eur J Sci Res 27(3):349–357

Shahid SA, Abdelfattah MA (2009) Gypsum polymorphism in the desert environment of Abu Dhabi Emirate. Eur J Sci Res 29(2):237–248

Shahid SA, Jenkins DA (1994) Mineralogy and micromorphology of salt crusts from the Punjab, Pakistan. Dev Soil Sci, Elsevier, Amsterdam, 22:799–810

Shahid SA, Mufti KA (1994) A modern submicroscopic method for in-situ micromorphological and microchemical analysis of soil components. I. Salt crust. Mod Agric 5(4,5):32–39

Shahid SA, Rahman K (2011) Soil salinity development, classification, assessment and management in irrigated agriculture. In: Pessarakli M (ed) Handbook of plant and crop stress, 3rd edn. CRC Press, Boca Raton, pp 23–39

Shahid SA, Qureshi RH, Jenkins DA (1990) Salt-minerals in the saline-sodic soils of Pakistan. In: Proceedings of Indo-Pak workshop on soil salinity and water management, 10–14 Feb 1990, Islamabad 1:175–191

Shahid SA, Jenkins DA, Hussain T (1992) Halite morphologies and genesis in the soil environment of Pakistan. In: Proc of international symposium on strategies for utilizing salt-affected lands, 17–25 Feb 1992, Bangkok, pp 59–73

Shahid SA, Abo-Rezq H, Omar SAS (2002) Mapping soil salinity through a reconnaissance soil survey of Kuwait and geographic information system. Annual research report, Kuwait Institute for Scientific Research, Kuwait, KSR 6682:56–59

Shahid SA, Abdelfattah MA, Arshad KR, Al Muhairbi MA, Othman YRA, Al Haji A, Al Mansouri MA, Ahmed S, Siddiqui A, Azimullah KM, Sekaly AL, Al Qubaisi BS (2004) Soil survey for the coastline of Abu Dhabi Emirate. Volume I: Reconnaissance Survey, p 163. Environmental Research and Wildlife Development Agency Abu Dhabi, United Arab Emirates

Shahid SA, Abdelfattah MA, Wilson MA (2007) A unique anhydrite soil in the coastal sabkha of Abu Dhabi Emirate. Soil Surv Horiz 48(1):75–79

Shahid SA, Dakheel AJ, Mufti KA, Shabbir G (2008) Automated in-situ salinity logging in irrigated agriculture. Eur J Sci Res 26(2):288–297

Shahid SA, Abdefattah MA, Omar SAS, Harahsheh H, Othman Y, Mahmoudi H (2010) Mapping and monitoring of soil salinization-remote sensing, GIS, modeling, electromagnetic induction and conventional methods – case studies. In: Ahmad M, Al-Rawahy SA (eds) Proceedings of the international conference on soils and groundwater salinization in arid countries. Sultan Qaboos University, Oman 1:59–97

Sharma RC, Bhargawa GP (1988) Landsat imagery for mapping saline soils and wetlands in northwest India. Int J Remote Sens 9:69–84

Simunek J, Suarez DL (1997a) Sodic soil reclamation using multicomponent transport modeling. J Irrig Drain Eng 123:367–376

Simunek J, Suarez DL (1997b) The UNSCHEM code for simulating the one-dimensional variably saturated water flow, heat transport, carbon dioxide production and transport, and multicomponent solute transport with major ion equilibrium and kinetic chemistry. In: Simunek J, Suarez DL, Sejna M (eds) 1996. The UNSATCHEM software package, ver. 2.0 Res Report No. 141. US Salinity Laboratory, USDA-ARS, Riverside

Singh AN, Dwivedi RS (1989) Delineation of salt-affected soils through digital analysis of Landsat MSS data. Int J Remote Sens 10:83–92

Singh G, Mandal AK (2009) Advances in assessment of salt-affected soils for mapping, monitoring and management strategies in India. In: Advances in the assessment and monitoring of salinization and status of biosaline agriculture. Reports of expert consultation held in Dubai, United Arab Emirates, 26–29 Nov 2007. World Soil Resources reports no 104. FAO, Rome, pp 17–18

Soil Survey Division Staff (1993) Soil survey Manual. USDA Handbook no 18. United States Department of Agriculture, U.S. Government Printing Office, Washington, DC 20402, pp 437

Soil Survey Staff (2010) Aridisols. In: Keys to soil taxonomy, 11th edn. USDA-NRCS, Washington, DC, pp 97–122

Spies B, Woodgate P (2004) Technical report: salinity mapping methods in the Australian context, prepared for the Programs Committee of the Natural Resources Management, Ministerial Council through Land and Water Australia and the National Dryland Salinity Program

Srivastava AD, Tripathi NK, Gokhale KV (1997) Mapping groundwater salinity using IRS-1B LISS II data and GIS techniques. Int J Remote Sens 18:2853–2862

Stewart FH (1963) Marine evaporites. Chapter Y in data of Geochemistry, 6th edn. US Geological Survey. Professional papers, 440-y, pp 1–52

Stoops G, Eswaran H, Abtahi A (1978) Scanning electron microscopy of authigenic minerals in soil. In: Proceedings of the 5th international working meeting on soil micromorphology, Gernanda, Espana, pp 1093–1113

Suarez DL (1977) Ion activity products of calcium carbonate in water below the root zone. Soil Sci Soc Am J 41:310–315

Suarez DL, Dudley LM (1998) Hydrochemical considerations in modeling water quality within the vadose zone. In: Dudley LM, Guitjens CG (eds) Agroecosystems and the environment: Sources, control, remediation of potentially toxic, trace elements oxyanions. Pacific Division AAAS, San Francisco, pp 113–136

Suarez DL, Simunek J (1997) UNSATCHEM: unsaturated water and solute transport model with equilibrium and kinetic chemistry. Soil Sci Soc Am J 61:1633–1646

Suarez DL, Vaughan P (2002) FAO-salinity laboratory SWS model. FAO, Rome

Sukchani S, Yamamoto Y (2005) Classification of salt-affected areas using remote sensing. Paper published by Soil Survey and Classification Division, Department of Land Development (LDD) Ministry of Agriculture and Cooperative, Phaholyothin Road, Chatichak, Bangkok 10900 Thailand and Japan International Research Center for Agricultural Sciences (JIRCAS), Ohwashi 1–1, Tsukuba, Ibaraki 305–8686, Japan, p 7

Szabolcs I (1989) Salt-affected soils. CRC Press, Boca Raton, p 274

Tedrow JCF (1966) Polar desert soils. Soil Sci Soc Am Proc 30:381–387

Thomas RS (1974) Use of chemically reactive gaseous plasmas in preparation of specimens for microscopy. In Techniques and application of plasma chemistry (Hallahan JR, Bell AT (eds)), Wiley-Interscience, pp. 255–387

US Salinity Lab Staff (1954) Diagnosis and improvement of saline and alkali soils, USDA handbook no 60. US Dept of Agriculture, Washington, DC, pp 79–81

Vaughan P, Lesch SM, Crown DL, Cone DG (1995) Water content effect on soil salinity prediction. A geostatistical study using cokriging. Soil Sci Soc Am J 59:1146–1156

Vergouwen L (1980) Scanning electron microscopy applied on saline soils from the Konya basin in Turkey and from Kenya. In: Bisdom EBA (ed) Submicroscopy of soil and weathered rocks, pp 237–248

Verma KS, Saxena RK, Barthwal AK, Deshmukh SN (1994) Remote-sensing technique for mapping salt affected soils. Int J Remote Sens 15(9):901–1914

Vincent B, Vidal A, Tabbet D, Baqri A, Kapur M (1996) Use of satellite remote sensing for the assessment of waterlogging or salinity as an indication of the performance of drained systems. In: Vincent B (ed) Evaluation of performance of subsurface drainage systems: 16th congress on irrigation and drainage, Cairo. ICID, New Delhi, pp 203–216

WAPDA (1984) Applicability of Landsat imagery for monitoring soil salinity trends. Publ 529. Directorate of Reclamation and Investigation Organization, Lahore

Williams BG, Baker GC (1982) An electromagnetic induction technique for reconnaissance survey of salinity hazards. Aust J Soil Res 20:107–118

Williams BG, Hoey D (1987) The use of electromagnetic induction to detect the spatial variability of the salt and clay contents of soils. Aust J Soil Res 25:21–27

Yang J (2009) Recent evolution of soil salinization and its driving processes in China. In: Advances in the assessment and monitoring of salinization and status of biosaline agriculture. Reports of expert consultation held in Dubai, United Arab Emirates, 26–29 Nov 2007. World Soil Resources reports no 104. FAO, Rome, p 23

Zevenbergen AW (1990) Integrating remote sensing and conventional information. Land Water Int 56:7–9

Zuluaga JM (1990) Remote sensing applications in irrigation management in Mendoza, Argentina. In: Menenti M (ed) Remote sensing in evaluation and management of irrigation. Instituto Nacional de Ciencia y Tecnic, Mendoza, pp 37–58

Chapter 2
Soil Salinity Modeling, Approaches, and Key Issues

Jorge Batlle-Sales

Abstract Salinization is a progressive soil and water degradation process. Soil salinity can be natural or induced by human affecting aquifers and the most productive irrigated agroecosystems in arid and semiarid regions, representing an increasing environmental concern. Root zone soil salinity can be managed using advanced tools and adjusting irrigation application and using the concept of leaching requirement. Modeling the reactive transport in soil uses simplified representations of the reality, but can reveal complex interrelations of properties of the system under study, and is best suited for drawing scenarios for investigating "what-if…" questions. Each modeling effort tries to give answer to a particular question; hence, the input information required for running the models ranges in complexity as does the data acquisition efforts. The scale of application, geometry of the system, and biological, chemical, and physical processes represented, as well as the capability of representing an evolving system, are main differences among models. Some aspects important under normal agricultural practices are not well reproduced by some codes nowadays. Management practices, geometry of irrigation and evaporation, sinks of solutes (plant uptake), and interaction of fertilizers with soil components are incorporated in an uneven way in the available codes and should be further developed. Currently models become more and more mechanistic and require very intensive research efforts. There are uncertainties associated to the values of the input parameters, to the computation procedure, or to the inaccurate description of the system. The parameter estimation, analysis of sensitivity, and validation procedures are refinements applicable to most models. This chapter presents an overview of different modeling approaches, discusses the limits of application of models, and develops a study case.

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2.1 Introduction

Soil salinity is high concentration of ions in the soil solution, more specifically in soil saturation extract. This condition is very restrictive for plant's growth due to high osmotic potential of the solution that restricts the plant water uptake and induces specific ion effects causing nutritional imbalances. Soil salinity affects crop productivity and feasibility, especially in arid and semiarid zones, where mostly irrigated agriculture is practiced. The chemical equilibrium established between the exchange complex of clays, organic soil components, and soil solution can cause dispersion of fine-sized clays that ultimately degrade soil structure.

In areas where potential evapotranspiration (PET) exceeds water application plus rainfall, the soil solution can be concentrated until that solids can precipitate from liquid phase, forming solid salt accumulations at the soil surface or inside the soil. Also in areas where water table is high and soils are fine textured, the soil water reaches surface through capillary ascent capability and precipitates at surface through evaporation.

Salinity is a transient condition in most salt-affected soils. A concentration of the soil solution follows to the water uptake from the soil by the plant roots, as well as to water loss by evaporation at soil surface. Subsequent irrigation or rainfall can dilute the soil solution, or the solutes can be removed from the system by leaching of the soil to drains or by deep drainage. In a scenario of water scarcity, an irrigated agriculture should minimize the volume of water required for optimum yield and ensure the leaching of salts from the root zone.

Leaching requirement is the extra water applied (above the plant water requirements – PET) to an irrigated field (under risk of salinization), to keep dissolved the solutes that concentrate during the root uptake and allow their drainage from the root zone (U.S. Salinity Laboratory Staff 1954; Rhoades 1974).

The electrical conductivity (EC) of the irrigation water and the EC of the resultant drainage water (specific crop-threshold EC) determines the leaching requirements for the irrigated soil (Rhoades et al. 1992). It is essential to know the threshold EC value of the crop under cultivation to assure the saline water available for irrigation can be used successfully. Highly saline irrigation waters are unfeasible for economical crop production under any leaching fraction (salt-sensitive crops). The use of very solute-concentrated waters for irrigation can induce groundwater degradation by high salt loadings of drainage water.

Inadequate irrigation practices can lead to soil and aquifers salinization (Milnes and Renard 2004; Misra and Mishra 2007; Petheram et al. 2008; Fakir et al. 2001) and impact the hydrological resources of a region. The human-induced secondary soil salinization is a progressive soil and water degradation process, affecting the most productive irrigated agroecosystems in the arid and semiarid regions, representing an increasing environmental concern. A dramatic example is soil salinization in the Aral Sea area (Kitamura et al. 2006); also many salinized areas in the world exist at any latitude, requiring high economical cost for their reclamation (Janmaat 2004). An environmentally sound and economically feasible land management should take advantage from the most advanced tools for adjusting irrigation application (de Clercq et al. 2009; Jorenush and Sepaskhah 2003; Metternicht and Zinck 2003; Wang et al. 2007) to tackle soil salinity in irrigated agricultural fields taking into account the leaching requirements.

2.2 Modeling Water Flow and Reactive Transport

There exist many models addressing soil-water-plant-atmosphere-aquifers system, as a whole or as subsystems, taking into account several biological, physical, and chemical processes. All models are simplifications of the reality, but considering several coupled processes together, they can derive in models of great complexity. In most soil-centered models, the atmospheric processes, the plant growth, and the aquifers loading, rather than modeled, are considered as input variables that should be given for the model run. Modeling the reactive transport in soil can reveal complex interrelations of properties of the system under study. This can also serve as a tool to answer questions of the type “what-if…” in particular scenarios. Each modeling effort tries to give answer to relevant questions, and the type, amount, and precision of data required for running the models ranges in complexity.

The first task for a soil transport model is to solve the water flow. A recent review of water transport models by Ranatunga et al. (2008) reports the application that can be used for each model and highlights that the elaboration of models of increasing complexity and wide-range application is often hampered by a lack of the required input data.

In the simplest soil water transport models, the soil water content is computed considering the soil as tipping bucket of a certain capacity. The bucket loses water due to the plant water uptake, and the irrigation and rainfall fill in the bucket. The size of the bucket determines the reserve of water during the periods of no infiltration. If the capacity of the bucket is surpassed by the water inflow, drainage occurs. Those models can be monolayer or multilayer (cascade) and cannot simulate water capillary raise. More complex models incorporate a continuous soil profile where water flows (in any direction) are based on the Richards equation (Richards 1931) for computing the movement of water and solute through porous media.

Some of those models approach the system considering it under steady-state conditions, what is an oversimplification of the real conditions, allowing easy calculations with limited input data, although they are of limited value for a satisfactory irrigation design. An example of this is the WATSUIT model (Rhoades and Merrill 1976) that considers the composition of the irrigation water and includes the processes of salt precipitation and the dissolution of calcite and gypsum present in soil. Other models approach the system considering transient conditions and much more adjusted to the reality but also need more intensive data acquisition efforts. The capability of steady-state models versus transient models is compared by Corwin et al. (2007) for optimizing the calculus of the leaching fraction under risk of salinization. Another review of the relative merits of the transient versus steady-state models is given by Letey and Feng (2007) with respect to the evaluation of the irrigation management using saline waters. Bastiaanssen et al. (2007) make a literature review of the models suitable to describe irrigation and drainage processes for the unsaturated zone.

Some soil models can simulate very complex processes as reactive transport of water, solutes, and heat in the vadose zone in interaction with vegetation development. Those models employ the Richards equation including root water extraction to simulate soil moisture movement in variably saturated soils, considering the processes of convection, dispersion, adsorption, and decomposition. The existing models differ in their capability of the hydrological part, for simulating bypass flow, hysteresis, dual porosity, dual density, variable conditions of the upper and lower limit of the soil, pedotransfer functions for estimating the unsaturated hydraulic conductivity at any soil moisture content, resolution of texture discontinuities, and changes in permeability due to clays dispersion, among others.

Only a reduced number of complex models can solve the reactive transport of solutes, including the cation exchange of the soil solution with the solid phase of the soil, the precipitation or dissolution of numerous mineral phases, the simulation of nonequilibrium conditions, or the kinetic aspect of some reactions, that take place during the reactive transport. The capability to simulate the transport of CO_2 affects the carbonate chemistry in a decisive way, and only a few models are capable of simulating this chemical aspect.

In most salt-affected soils, the concentration of ions is so high that the equilibrium constants for the possible reactions, applicable to the dilute systems, are no longer valid. This is a very serious constraint of models that try to make chemical predictions for the equilibria that are established in media of high ionic strength. The most advanced models (Simunek and Suarez 1993, 1997; Simunek et al. 1996) used Pitzer approach (Pitzer 1973) for calculating ion activity that could be used to reliably model the solubilities of solutes present in complex, highly concentrated, natural brines and to model the diagenetic precipitation sequences resulting from evaporation of diverse types of natural waters. Very recently, the Brönsted-Guggenheim-Scatchard Specific Ion Interaction Theory (SIT) approach (Sipos 2008) has been introduced in the PHREEQC (Parkhurst and Appelo 1999), which is one of the more robust geochemical models. This is one of the few models that can deal with reducing conditions that appear in soils under stagnant-anoxic circumstances.

The transport processes, which are predominantly vertical, can be considered one-dimensional, that is, the simplest case of water and solute movement, as in furrow or flood irrigation. In cases of drip irrigation, 2D or 3D models are needed to take into account the lateral movements as well as the vertical fluxes. This increases the complexity for obtaining the input information for the model.

In the domain of hydrogeology exist many computer programs that can be used for simulating groundwater flow, solute transport, and multicomponent geochemical reactions, but most of the existing models consider only saturated water flow,

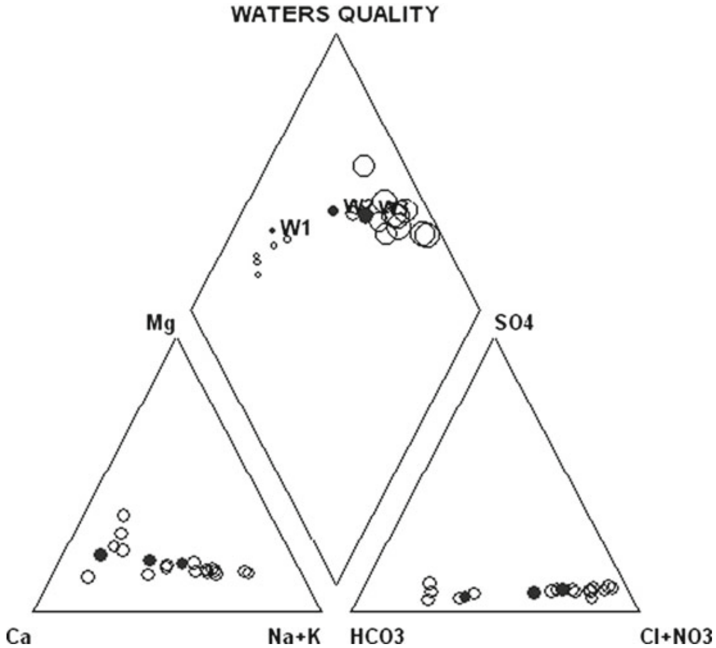

Fig. 2.1 Piper diagram of the quality of water wells

whereas soil salinity models are focused in modeling an unsaturated depth with time-changing boundary conditions. In this sense a coupling of a model for the vadose zone and a model for the aquifers is necessary because the downward output of water and solutes from the vadose zone is the input for the hydrogeological model.

2.3 Case Study: Optimization of Irrigation with Low-Quality Water

An agricultural area of the Western Mediterranean region (Castellon Province, Spain) was selected for studying the long-term effect of irrigation with low-quality waters on the soils and on the underlying aquifers of the area. Two different detritic aquifers exist, one free aquifer and the other a confined aquifer; both are affected by marine intrusion due to the disruption of the fringe freshwater/seawater by over pumping the wells used for irrigation. The occurrence of marine intrusion in the aquifers of the study area (Torreblanca) has been studied by Gimenez (Gimenez et al. 1996).

The chemical composition of the waters is presented in Fig. 2.1, as a Piper plot, each point in the rhomboidal area with radius proportional to the water electrical conductivity. The shape of the distribution of points close to aligned suggests a process of mixing of freshwater and seawater, modified by processes of cation exchange and sulfates reduction (Batlle-Sales et al. 2002).

The scarcity of volumes of low-conductivity water and the use of solute-concentrated water for irrigation increase the risk of soil salinization processes as well as promote a higher solute loading of the aquifers that receive the deep drainage of agricultural parcels.

Although the tendency in the agricultural area is changing to drip irrigation for saving water and allowing fertigation, there still exist many fields irrigated by furrow, with periodical availability of water (not on demand). One of such plots was selected for modeling purposes, using two different one-dimensional models, LEACHC (Hutson and Wagenet 1992) and UNSATCHEM (Simunek and Suarez 1997). The objective is to optimize the irrigation rotation to avoid the exposure of the crop both to hydric and to osmotic stress.

2.3.1 Description of the Experiment

A soil under cultivation of Citrus sinensis, classified as a Typic Calcixerept in the soil taxonomy (Soil Survey Staff 1999), was selected to perform the study. Its effective depth is 100 cm, with free depth drainage. Four distinct horizons were recognized in the profile and were sampled for subsequent analysis of physical, chemical, and mineralogical properties.

The texture of the first horizon is loamy, and the other horizons have clay-loamy texture. The upper two horizons have around 20% of their mass in coarse fraction (>2 mm). The calcium carbonate equivalent content (w/w) ranges from 10% in the upper horizon to 29% at the bottom horizon, part of this is in the form of calcium carbonate nodules. The pH of the extract of the saturated paste ranges from 8.21 to 8.45 (moderately alkaline) and the ECe < 1 dS m^{-1} in all horizons.

Soil mineralogy is dominated by calcite ($CaCO_3$) and clay minerals kaolinite and weathered illite with minor proportion of montmorillonite, and gypsum ($CaSO_2.2H_2O$) was undetectable. Cation-exchange capacity (CEC) ranges from 209 to 235 mmol(+) kg^{-1} and the exchangeable sodium percentage (ESP) less than 1. This suggests the soil to be moderately alkaline, nonsaline, and non-sodic (US Salinity Lab Staff 1954).

A computerized station capable of measuring solar radiation, temperature, humidity, wind direction and velocity, as well as precipitation measured the meteorological data during the course of the experiment, with records at every 5-min interval. Evapotranspiration was computed using Penman-Monteith method.

Several devices were installed in the profile: a groundwater-level observation well, a fiberglass guide for measuring soil volumetric moisture (theta) with a time-domain reflectometry (TDR) meter at any depth, several sensors of matric potential, and captors for measuring soil solution and soil atmosphere, located at different depths.

The placement of all these devices allowed obtaining real-time data from soil, at fixed dates, the same dates that were requested to the models giving predictions for soil conditions, allowing comparison of observed data versus properties predicted, for purposes of calibration and validation of the models. Such measurements were performed six times during the 376 days duration of the experiment. During this period the soil was irrigated with water of EC = 2.09 dS m^{-1} and composition indicated as "W2" (Table 2.1). PHREEQC (Parkhurst and Appelo 1999) was used for computing the saturation indices of the water for calcite and gypsum, revealing that water "W2" at 25°C and atmospheric P_{CO_2} is in equilibrium with calcite and undersaturated to gypsum.

The models UNSATCHEM and LEACHC were calibrated with the soil information measured initially; the soil hydraulic properties were estimated using the pedotransfer functions included in both models that use different equations for calculus. Gapon coefficients for cation exchange were provided from experimental measurement.

2.4 Results and Discussion

Figure 2.2 presents, with bars, the water balance for the soil during the experimental period. The upper part presents details of water inputs (rainfall + irrigation), whereas the bottom part details the outputs (evaporation, crop transpiration, drainage, and runoff), computed on a daily basis, but for clarity they are expressed on a weekly basis. Lines represent the soil matric potential at each of four depths, grouped weekly.

Neither measurements nor predictions were advised from development of osmotic stress at any time for the crop, under the conditions of irrigation, but an unwanted high hydric potential was measured and predicted by the two simulation models at the middle of the experiment (the driest and hotter part of the year in the area). This was a clear evidence that the irrigation scheme was incorrect and should be corrected.

The validation of the goodness of fit of the predictions made by the models was evaluated using a set of statistical indices (Hagi-Bishow and Bonnell 2000) that give different information about the performance of the models. The index RMSE (root-mean-square error) highlights how the simulations over the measures are overestimated or underestimated. The CD (coefficient of determination) statistic shows the relationship between the dispersion of the values of the simulation from the mean of the observations. The EF (efficiency of the model) index compares the simulated values with the average of the measured values so that a negative value of EF indicates that the average of the measures provides a better estimate than the simulations. Finally, the CRM (coefficient of residual mass) index is an indicator of the tendency of the model to overestimate or underestimate the measurements. The CRM positive values indicate an underestimation by the model, while positive

Table 2.1 Chemical composition of waters used for irrigation

Reference water	pH	EC (dS m^{-1} 25°C)	Ca^{2+} (mmolc L^{-1})	Mg^{2+} (mmolc L^{-1})	Na^{+} (mmolc L^{-1})	K^{+} (mmolc L^{-1})	Alkalinity (mmolc L^{-1})	Cl^{-} (mmolc L$^{-1)}$	SO_4^{2-} - (mmolc L^{-1})	SI calcite	SI gypsum
W2	7.00	2.09	7.49	3.40	8.13	0.09	4.50	12.91	1.70	–0.04	−1.58
W3	6.98	3.15	14.44	3.74	11.13	0.06	3.90	23.94	1.53	0.10	−1.17

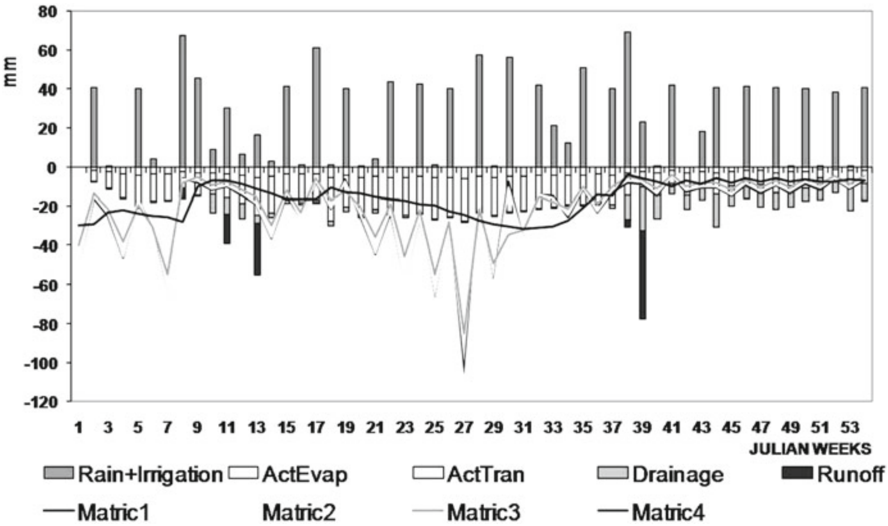

Fig. 2.2 Soil water balance after simulation

values indicate a tendency to overestimate the measurements. A perfect fit between observations and simulations gives the following values: RMSE = 0.0, CRM = 0.0, CD = 1.0, and EF = 1.0.

$$\text{RMSE} = \left[\frac{\sum_{i=n}^{n} \left(P_i - O_i\right)^2}{n} \right]^{0.5} * \frac{100}{\bar{\text{O}}} \tag{2.1}$$

$$\text{CD} = \frac{\sum_{i=1}^{n} \left(O_i - \bar{O}\right)^2}{\sum_{i=1}^{n} \left(P_i - \bar{O}\right)^2} \tag{2.2}$$

$$\text{EF} = 1 - \frac{\sum_{i=1}^{n} \left(P_i - O_i\right)^2}{\sum_{i=1}^{n} \left(O_i - \bar{O}\right)^2} \tag{2.3}$$

$$\text{RMSE} = \left[\frac{\sum_{i=n}^{n} (P_i - O_i)^2}{n} \right]^{0.5} * \frac{100}{\bar{\text{O}}} \tag{2.4}$$

Table 2.2 Statistical indices for theta

Index	RMSE %	CD	EF	CRM
Optimal value	0	1	1	0
Statistical indices UNSATCHEM (theta)				
0–20 cm	7.42	0.67	0.80	−0.05
20–40 cm	8.62	0.51	0.79	0.02
40–60 cm	3.63	0.88	0.97	0.02
60–80 cm	5.31	0.94	0.92	−0.03
Average	6.15	0.63	0.87	0.00
Statistical indices LEACHC (theta)				
0–20 cm	15.61	0.99	0.13	0.02
20–40 cm	7.15	1.51	0.86	0.04
40–60 cm	11.46	3.06	0.67	−0.02
60–80 cm	5.21	1.39	0.92	−0.04
Average	10.64	1.62	0.60	0.01

Table 2.3 Statistical indices for chloride

Index	RMSE %	CD	EF	CRM
Optimal value	0	1	1	0
Statistical indices UNSATCHEM (Cl^-)				
0–20 cm	17.63	0.74	0.77	0.07
20–40 cm	12.13	0.89	0.93	−0.01
40–60 cm	21.98	0.65	0.44	0.17
60–80 cm	23.33	0.33	0.32	0.03
Average	16.52	0.83	0.81	0.06
Statistical indices LEACHC (Cl^-)				
0–20 cm	45.13	1.00	−0.52	−0.12
20–40 cm	79.81	0.49	−1.91	−0.39
40–60 cm	28.32	1.48	0.08	0.07
60–80 cm	11.85	0.89	0.82	−0.02
Average	53.12	0.57	−1.10	0.12

where O_i are observed values, P_i are predicted values, $\bar{O}$ is the mean of observed values, and n is number of observations.

The Table 2.2 presents the indices elaborated for the comparison between the values of soil volumetric water content, measured in the field, and the values predicted by the models UNSATCHEM and LEACHC, at different soil depths. This gives information about how well the water flow in the soil is modelized. The values suggest a better performance of the UNSATCHEM model for the case under study.

Chloride ion experiment-anion exclusion in soils is very soluble and can serve as autotracer of the efficiency of the modelization of the chemical part (reactive transport). The comparison of observed and predicted values for the chloride ion can be found in the Table 2.3. The chloride indices reveal again a superior performance of the

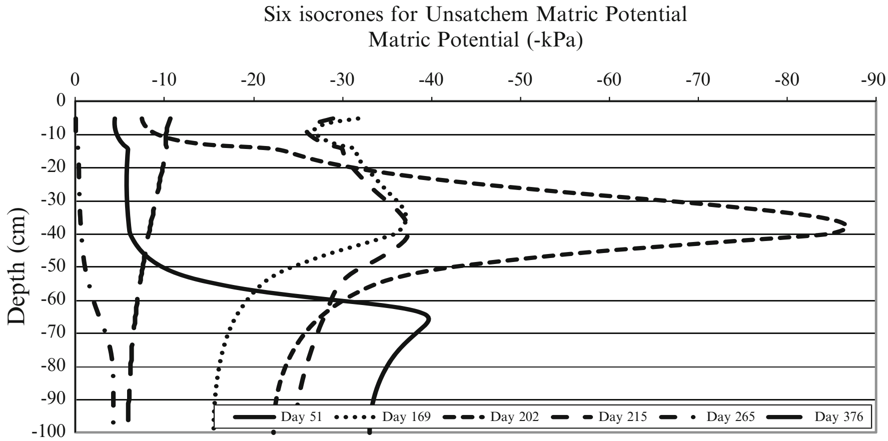

Fig. 2.3 Isochrones for UNSATCHEM. Matric potential

UNSATCHEM model over the LEACHC model in part because the errors of the hydraulical part (solute flow) are added to the errors in the chemical part, for the whole modeled reactive transport process.

On the basis of the information of the soil water balance (Fig. 2.2), the irrigation was adjusted (increased in the critical period) to reduce the water matric potential. Once adjusted, the same irrigation doses were considered for a simulation of the risk of soil salinization using the water quality labeled "W3" in Table 2.1, of EC = 3.15 dS m^{-1}. This water at 25°C and atmospheric P_{CO_2} is slightly oversaturated with calcite and undersaturated to gypsum.

Both models UNSATCHEM and LEACHC were reset with the same initial soil conditions, climatic data, as well as schedule and irrigation doses (adjusted), but using water of quality "W3." Predictions for the matric potential are shown in Figs. 2.3 and 2.4, and predictions for electrical conductivity are shown in Figs. 2.5 and 2.6. Both models give similar results for the values of matric potential at different dates, but differ a few in the predictions for electrical conductivity: UNSATCHEM gives a maximum of close to EC = 2 dS m^{-1}, whereas the predictions for the LEACHC are higher, with a maximum of EC = 3 dS m^{-1} and higher EC in the middle of the soil depth at any time.

Due to the high calcite content of the soil and the composition of the irrigation water, oversaturated to calcite, the soil Na exchangeable remains low, the soil solution sodium adsorption ratio – SAR < 6; hence, no risk of clays dispersion is anticipated. The conditions of water matric potential, electrical conductivity, and SAR predicted by the two models do not affect the normal growth of the citrus, even with water labeled as "B." Whatsoever the use of water "B" instead of water "A" will increase the salt loading of the underlying aquifers, with respect to the loadings produced by using water "A."

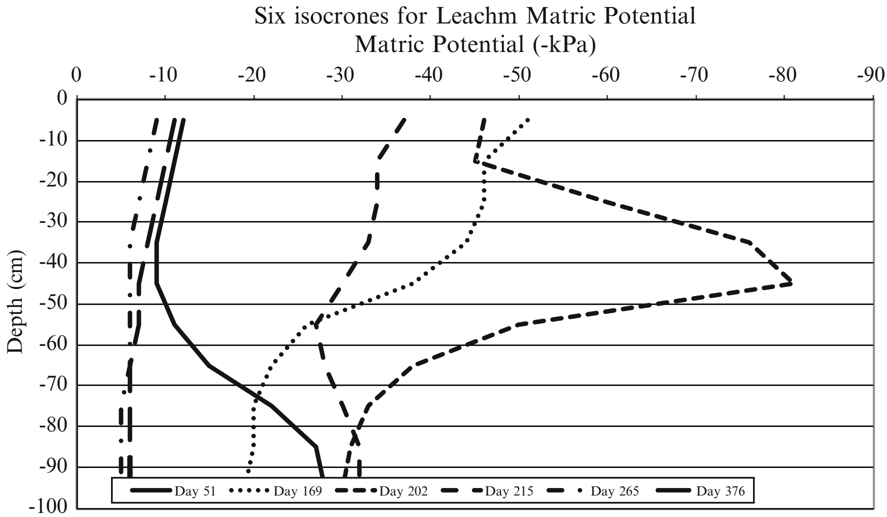

Fig. 2.4 Isochrones for LEACHC. Matric potential

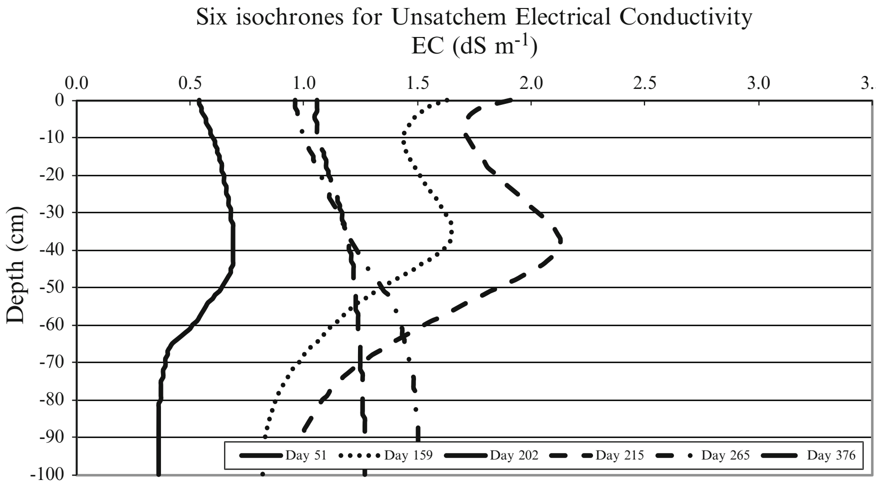

Fig. 2.5 Isochrones for UNSATCHEM. Electrical conductivity

2.5 Conclusions and Recommendations

The versions of both models LEACHC and UNSATCHEM used in this work are unidimensional; hence, heterogeneous fields can affect the results and validation of the models. Bypass flow cannot be represented by the codes used, so even small cracks can lead to divergence in the salts distribution in the upper part of the soil.

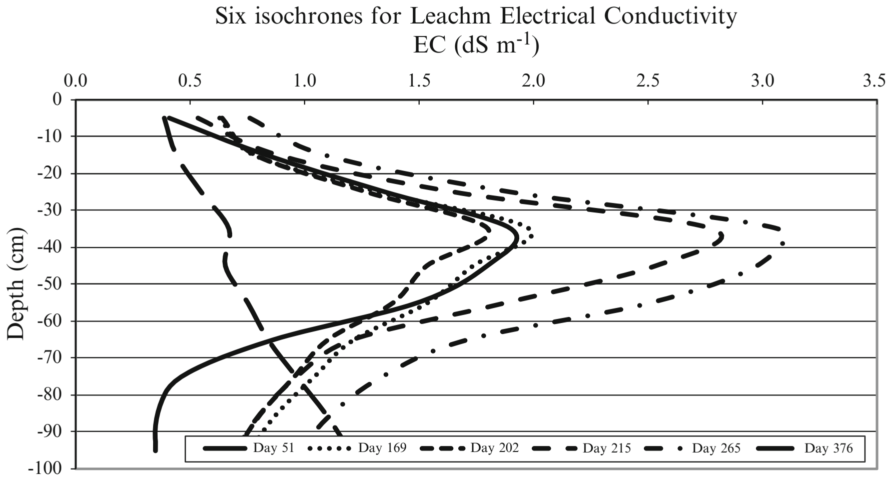

Fig. 2.6 Isochrones for LEACHC. Electrical conductivity

Most models do not consider the case of soils with high portion of soil particles in the coarse fraction (>2 mm), affecting soil hydraulic conductivity computed only on the basis of the textural class. Plant uptake of fertilizers and solutes is not simulated by any of the two models used. Small differences in outputs from both models can be attributed to their different codes, pedotransfer functions used, and capability of dealing with high ionic strength of solutions, although tendencies for both models were congruent with observed data. Results can be used for recommendations about irrigation strategies and management practices, as well as for estimating salt loading of underlying aquifers due to percolation of drainage waters, giving an input for hydrogeological modeling. Models can be used for simulating hypothetical future conditions derived from use of several water types within the composition existing in the area.

References

Bastiaanssen WGM, Allen RG, Droogers P, D'Urso G, Steduto P (2007) Twenty-five years modeling irrigated and drained soils: state of the art. Agric Water Manag 92(3):111–125

Batlle-Sales J, Hurtado A, Batlle-Montero E (2002) Effect of wetland transformation on groundwater quality and soil salinization in neighbouring agricultural areas. In: Proceedings of the 17th World Congress of Soil Science, Bangkok, Thailand

Corwin DL, Rhoades JD, Šimùnek J (2007) Leaching requirement for soil salinity control: steady-state versus transient models. Agric Water Manag 90(3):165–180

de Clercq WP, Van Meirvenne M, Fey MV (2009) Prediction of the soil-depth salinity-trend in a vineyard after sustained irrigation with saline water. Agric Water Manage 96(3):395–404

Fakir Y, Zerouali A, Aboufirassi M, Bouabdelli M (2001) Exploitation et salinité des aquifères de la Chaouia côtière, littoral atlantique, MarocPotential exploitation and salinity of aquifers, Chaouia coast, Atlantic shoreline, Morocco. J African Earth Sci 32(4):791–801

Gimenez E, Morell I, Fidelibus MD (1996) Importancia de los procesos de intercambio iónico en la caracterización de la intrusión marina en el acuífero de Oropesa (Castellón-España). Correlación Geológica 11:183–192
Hagi-Bishow M, Bonnell RB (2000) Assessment of LEACHM-C Model for semi-arid saline irrigation. ICID J 49(1):29–42
Hutson JL, Wagenet RJ (1992) LEACHM: leaching estimation and chemistry model: a process based model of water and solute movement transformations, plant uptake and chemical reactions in the unsaturated zone. Continuum vol 2, Water Resources Institute, Cornell University, Ithaca, Version 3
Janmaat J (2004) Calculating the cost of irrigation induced soil salinization in the tungabhadra project. Agric Econ 31(1):81–96
Jorenush MH, Sepaskhah AR (2003) Modelling capillary rise and soil salinity for shallow saline water table under irrigated and non-irrigated conditions. Agric Water Manage 61(2):125–141
Kitamura Y, Yano T, Honna T, Yamamoto S, Inosako K (2006) Causes of farmland salinization and remedial measures in the Aral Sea basin-Research on water management to prevent secondary salinization in rice-based cropping system in arid land. Agric Water Manage 85(1–2):1–14
Letey J, Feng GL (2007) Dynamic versus steady-state approaches to evaluate irrigation management of saline waters. Agric Water Manage 91(1–3):1–10
Metternicht GI, Zinck JA (2003) Remote sensing of soil salinity: potentials and constraints. Remote Sens Environ 85(1):1–20
Milnes E, Renard P (2004) The problem of salt recycling and seawater intrusion in coastal irrigated plains: an example from the Kiti aquifer (Southern Cyprus). J Hydrol 288(3–4):327–343
Misra AK, Mishra A (2007) Study of quaternary aquifers in Ganga Plain, India: focus on groundwater salinity, fluoride and fluorosis. J Hazard Mater 144(1–2):438–448
Parkhurst DL, Appelo CAJ (1999) User’s guide to PHREEQC (Version2) – a computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations. U.S. Geological Survey Water-Resources Investigations Report 99-4259, p 310
Petheram C, Bristow KL, Nelson PN (2008) Understanding and managing groundwater and salinity in a tropical conjunctive water use irrigation district. Agric Water Manage 95(10):1167–1179
Pitzer KS (1973) Thermodynamics of Electrolytes. I. Theroetical Basis and General Equations. J Phys Chem 77:268–277
Ranatunga K, Nation ER, Barratt DG (2008) Review of soil water models and their applications in Australia. Environ Model Softw 23(9):1182–1206
Rhoades JD (1974) Drainage for salinity control. In: van Schilfgaarde J (ed) Drainage for agriculture, Agronomy monograph no. 17. SSSA, Madison, pp 433–461
Rhoades JD, Merrill SD (1976) Assessing the suitability of water for irrigation: theoretical and empirical approaches. In: Prognosis of salinity and alkalinity. Soils Bull 31. FAO, Rome, pp 69–109
Rhoades JD, Kandiah A, Mashali AM (1992) The use of saline waters for crop production, FAO Irrigation and Drainage paper 48. FAO, Rome, p 133
Richards LA (1931) Capillary conductivity of liquid through porous media. Physics 1:318–333
Simunek J, Suarez DL (1993) UNSATCHEM-2D code for simulating two-dimensional variably saturated water flow, heat transport, carbon dioxide production and transport, and multicomponent solute transport with major ion equilibrium and kinetic chemistry, Version 1.1. Research report no. 128, USDA-ARS U.S. Salinity Laboratory, Riverside
Simunek J, Suarez DL (1997) UNSATCHEM: unsaturated water and solute transport model with equilibrium and kinetic chemistry. Soil Sci Soc Am J 61:1633–1646
Simunek J, Suarez DL, Sejna M (1996) The UNSATCHEM software package for simulating one-dimensional variably saturated water flow, heat transport, carbon dioxide production and transport, and solute transport with major ion equilibrium and kinetic chemistry, version 2. Research report no. 141. USDA-ARS. US Salinity Laboratory, Riverside, p 186

Sipos P (2008) Application of the Specific Ion Interaction Theory (SIT) for the ionic products of aqueous electrolyte solutions of very high concentrations. J Mol Liq 143(1):13–16
Soil Survey Staff (1999) Soil taxonomy, a basic system of soil classification for making and interpreting soil surveys, 2nd edn. United States Department of Agriculture Handbook Natural Resources Conservation Service Number 436, Washington, DC
US Salinity Laboratory Staff (1954) Diagnosis and improvement of saline and alkali soils, US Department of Agriculture, handbook 60. US Government Printing Office, Washington, DC, p 160
Wang H, Hsieh YP, Harwell MA, Huang W (2007) Modelling soil salinity distribution along topographic gradients in tidal salt marshes in Atlantic and Gulf coastal regions. Ecol Model 201(3–4):429–439

Chapter 3
Quantification of the Salt Content of Soils Under Different Climatic Conditions on a National Scale in South Africa

J.P. Nell

Abstract The effect of rainfall, evaporation, and aridity on salt accumulation in the soil, on a national scale, is not straightforward, and other factors such as geology, position in the landscape, and previous climatic conditions should be considered. Good decisions for the management of salt-affected soils on a national scale require good information, derived from raw data. Such data must be generated with specific goals in mind, and it must be stored properly in a format that is easy to access and process. Like any basic resource, the data environment must be managed meticulously. In this study although data verification was previously done on most samples, much effort was devoted to data cleaning. Of the more than 40,000 original data points, only 22,404 data points were used due to the stringent cleaning protocol. A forward selection stepwise regression was used to simplify the various models. In a stepwise regression, variables are added or removed from a regression model one at a time, with the goal of obtaining a model that contains only significant predictors, but does not exclude any useful variables. The accuracy with which EC, ESP, and pH_{water} were predicted with stepwise multiple linear regression relationships on a national scale is surprising, considering that the various models included all "outlier" values. The R^2 statistic indicated that the models as fitted explained the variability in EC and ESP much better for the low rainfall class (<550mm annual rainfall), than for the high rainfall class (>550mm annual rainfall). For EC, <550mm annual rainfall class in the model explains 58% of the variability and for >550mm annual rainfall class 39% of the variability. Values for ESP are 85% for <550mm annual rainfall class and 52% for >550mm annual rainfall class.

Keywords Climatic conditions • ESP • Model • pH • Salt-affected soils • South Africa

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3.1 Introduction

Formerly it was considered that salt-affected soils were always related to arid conditions (Balba 1995; Birkeland 1984; Gerrard 1992). According to Szabolcs (1989), however, bearing in mind the diversity of the different types of salt-affected soils, it becomes obvious that they not only occur in desert and semidesert areas but may develop in practically all the climatic zones of the world and at all latitudes. It is, however, true that primary salt-affected soils are more extensive in arid than in non-arid areas and that South Africa is no exception to the rule. Salt-affected soils generally occur in regions that receive salts from other areas, with water the primary carrier.

Through the whole debate about global warming and the greenhouse gas effect (GHGE) is an underlying notion that the world's climate should stay exactly as it is. The geological and soil records tell us that this is a vain and naïve hope. Instead, it tells us that dramatic change is inevitable. The opening of the Drake Passage and the resulting circumpolar circulation resulted in expansion of the Antarctic ice sheet and cooling of the Southern Ocean (McCarthy and Rubidge 2005). The separation of South America from Antarctica is widely believed to have influenced Cenozoic cooling because these events enable the development of the Antarctic Circumpolar Current (Scher and Martin 2006). In the atmosphere, a strong, semipermanent high-pressure system was established over the South Atlantic Ocean, producing offshore drift of water off the west coast of southern Africa. This gave rise to the Benguela upwelling system. Cooling of the ocean water along the west coast radically changed the climate of southern Africa. Whereas previously, moist air was supplied to the subcontinent from both the Indian and Atlantic Oceans, producing relatively moist conditions on both sides of the continent, the upwelling of cold water on the west coast cut off the moisture supply from the Atlantic. The west coast became very arid, the Namib Desert formed, and the rainfall gradient from the east to the west coast was established. Lower winter rainfall conditions in the western part of South Africa are of fairly recent origin (Bühmann et al. 2004). These changes are partially preserved in deep weathering profiles, often capped by paleo-features that are out of phase with present day conditions, such as silcretes or ferricretes (Ellis 1973; Summerfield 1983; Ellis and Lambrechts 1994; Francis 2008). Bühmann et al. (2004) also indicate that kaolinite (1:1 type) in Cape Granite was the dominant phyllosilicate (layer silicate) alteration product, even in areas receiving as little as 122mm annual precipitation at present. The kaolinite in these arid areas may well reflect much wetter possibly Cretaceous, paleoclimatic conditions as kaolinite formation from granite starts only at an annual precipitation >400mm.

South Africa receives only half the world's average rainfall. About 65% of the country receives less than 500mm of rainfall annually, which is regarded as the minimum for dryland farming. A high rate of evaporation results in only 8% of the country's total rainfall being carried off to the sea by rivers, while the world mean is 31% (Van Zyl 2003). Over the interior there is a distinct east-west trend in rainfall. Northeasterly airstreams affecting the eastern Highveld bring annual rainfall totalling around 800mm, concentrated in the summer months. Rainfall totals decrease to below 125mm in the arid west, bringing desert conditions to the Kalahari and southern Namibia (Vogel 2000). Mountains impact especially on two climate regions of South Africa. The Cape Mountains deprive the Karoo of rain, by restricting rain to the ocean side of the mountains. The Drakensberg region benefits from rain on the ocean side of the Drakensberg mountains (Van Zyl 2003).

Walling (1996) notes the extremely high interannual variability of precipitation over southern Africa compared to that of the rest of the world. Only Australia shows similar variability. The coefficient of variability of mean annual runoff is just below 0.8, compared to 0.7 for Australia and between 0.25 and 0.40 for the rest of the world. Mean annual evaporation in South Africa exceeds rainfall at all but the highest altitudes of the most southwesterly and northeasterly regions.

Mean annual potential evaporation is around 1,400mm in the Drakensberg and 1,600–1,800mm along the eastern and southern coastal areas, with a general southeast–northwest increasing trend cumulating in highs exceeding 3,000mm per annum in the northwest (Schulze 1997).

The aridity index based on the ratio between annual precipitation to potential evaporation indicates that 0.8% of South Africa is hyperarid, 36.9% arid, 44.3% semiarid, 8.5% dry subhumid, and only 9.4% humid (ARC-ISCW 2004).

3.2 Methodology

Elementary statistical techniques such as median, lower quartile, upper quartile, and average were used to identify relationships between the climatic classes (Statgraphics 2005). The emphasis was, however, on the median, although mathematically it is more complex to use than the average value. The main advantage is that the median is not disturbed by the size of extreme values (outliers) or significant skewness. In this study, the term “outlier” is not being used in its statistical meaning, i.e., being “any observation that appears surprising or discrepant to the investigator” or “any observation that is not a realization from the target distribution” (Beckman and Cook 1983). It is used here as meaning an observation that deviates markedly, for obvious and/or explicable reasons, from the other members of the population and as such is representative of typical variability in a natural situation.

Although data verification was previously done on most samples, much effort was devoted to data cleaning. Of the more than 40,000 original data points, only 22,404 data points were used due to the stringent cleaning protocol. Good decisions for the management of salt-affected soils on a national scale require good information, derived from raw data. Such data must be generated with specific goals in mind, and it must be stored properly in a format that is easy to access and process. Like any basic resource, the data environment must be managed meticulously.

A forward selection stepwise regression was used to simplify the various models. In a stepwise regression, variables are added or removed from a regression model one at a time, with the goal of obtaining a model that contains only significant predictors, but does not exclude any useful variables.

Coordinates of the soil profiles were imported into ArcView 9.2 to map the positions of the profiles on a national scale. As most of the points were captured by reading off the positions of the profiles from old 1:50,000 topo cadastral map sheets published in Cape datum, and before using GPS and being aware of setting datum, the assumption was made that all points were in Cape datum and defined as such in ArcView. The newly created point file was transformed to the WGS84 datum to be overlaid with other data.

For the majority of the samples in the database, analyzed between 1970 and 1980, the cation-exchange capacity (CEC), sodium, calcium, and magnesium contents were determined by LiCl extraction. The LiCl solution served as extractant for exchangeable plus soluble cations and at the same time saturated the soil's exchange complex with Li. After removal of non-adsorbed Li with ethyl alcohol, the adsorbed Li was displaced from the Li-saturated soil with $Ca(NO_3)_2$ and then taken as an index of the CEC. Soluble cations were determined separately in soils containing significant quantities of soluble salts (electrical resistance <460 Ω). These were subtracted from the LiCl-extractable cations to obtain the exchangeable cations. The LiCl-extracting solution (0.5 mol L^{-1} LiCl, buffered at pH 8) was used instead of the 0.25 mol L^{-1} $BaCl_2$ as recommended by Peech (1965). In soils containing lime or gypsum or those with a very high salt content, not all the water soluble salts were dissolved in the saturation extract (Land Type Survey Staff 1987). In these cases, the sum of exchangeable cations is higher than the CEC. Less than 12% of samples used in this study were analyzed by extraction with LiCl. These samples were also predominantly from the higher rainfall areas in South Africa and therefore largely nonsaline and non-sodic. Any discrepancies in the results between the two methods are therefore expected to be negligible for the purpose of quantification of salinity and sodicity. Results obtained from the LiCl and NH_4OAc analyses were therefore pooled in this study.

Soil samples in the database from 1980 onward were predominantly analyzed for CEC and cations using NH_4OAc (1 mol dm^{-3}, pH7) as extractant. According to Land Type Survey Staff (1987), the correlation between CEC as determined by LiCl and NH_4OAc extractants was good (R^2 of 0.95), with NH_4OAc giving values on average 14% higher than LiCl. The individual cations extracted with these two solutions were in good agreement, with the exception of K. This implies very little difference between the sums of cations determined using the LiCl- and NH_4OAc-extracting methods. This is somewhat contradictory to the remark made by the Non-Affiliated Soil Analysis Work Committee (1990) that "the NH_4OAc method does not give accurate results with respect to the exchangeable plus water soluble cation status." Saturation extractable cations were determined by filtration under suction of the water-saturated soil paste. For the majority of the samples in the database that were analyzed since 1980, the electrical resistance <460 Ω rule was not applied. Water-saturation-extractable cations (and electrical conductivity) were therefore determined on the majority of samples, including saline and nonsaline soils. Soil pH was determined using a 1:2.5 soil-to-water suspension.

Data from the Agricultural Research Council (ARC) Institute for Soil, Climate, and Water and the South African Weather Service (SAWS) weather stations with a recording period of 10 years or more were used to determine the median annual rainfall for South Africa. Initially a trend surface was developed using monthly data. Subsequent regression analyses were used to relate the difference between station rainfall values and trend surface values for specific months to topographic indices such as rain shadow and aspect. These relationships and the trend surface were used to model the rainfall surface (1 × 1 km cells) from spatial topographic indices in ArcView (ARC-ISCW 2004). It was decided to use the median annual rainfall and not the mean annual rainfall because negative departures of annual rainfall (i.e., low rainfall years) are more numerous than positive ones (i.e., higher than average years) and annual rainfall values are therefore not normally distributed (i.e., they are positively skew). In South Africa mean annual rainfall is frequently inflated by a few very high annual totals from very wet years, especially in areas of low rainfall (Schulze 1997). The natural availability of water across the country is highly uneven due to the poor spatial distribution of rainfall.

Because of a rather limited number of weather stations recording A-pan evaporation (Schulze 1997), the development of a detailed national coverage also had to take a modeling route. Data were used from weather stations with records of 5 years or more with respect to A-pan evaporation, rainfall, and temperature. Monthly values for rainfall, maximum temperature, and the difference between maximum and minimum temperature were used in regression equations with the available A-pan evaporation values. The maximum and minimum temperature surfaces as well as the rainfall surfaces were used in ArcView to develop evaporation surface by means of the regression equations (ARC-ISCW 2004).

Aridity indices provide a simple way to express the ratio of precipitation to evaporation. The aridity index used is based on the ratio of annual precipitation to potential evapotranspiration (P/PET) and largely follows the classification used in a 1984 UNESCO study to produce the global humidity index map (UNEP 2009). The aridity indices data are produced by overlaying rainfall grids with PET grids released by the Department of Agricultural Engineering, University of KwaZulu-Natal (Schulze 1997). Aridity was subsequently classified into four aridity classes and one humid class.

3.3 Results and Discussion

The large differences in the median and average values for salinity as indicated by EC and sodicity as indicated by the exchangeable sodium percentage (ESP) are a clear indication of the variability and skewness of the data on a national scale. The small differences between the average and median pH_{water} values are indicative of a normal distribution pattern and a parameter that is buffered against large fluctuations. Outliers with values several hundred percent higher than the lowest value were not unusual. As was previously stated, the term “outlier” is not being used in its

Table 3.1 Soil electrical conductivity (dS m^{-1}) statistics for the different rainfall classes

Annual rainfall (mm)	Median	Lower quartile	Upper quartile	Average	Standard deviation	Sample size
<100	1.58	0.59	4.92	6.06	10.53	232
101–200	0.49	0.27	2.75	5.30	15.32	934
201–400	0.49	0.28	1.57	2.62	7.45	2,685
401–600	0.39	0.22	0.90	1.04	3.15	4,652
601–800	0.27	0.15	0.49	0.60	1.42	5,586
801–1,000	0.20	0.11	0.32	0.36	0.97	4,509
>1,000	0.16	0.90	0.24	0.22	0.30	1,484

Table 3.2 Soil electrical conductivity (dS m^{-1}) statistics for the different evaporation classes

Annual evaporation (mm)	Median	Lower quartile	Upper quartile	Average	Standard deviation	Sample size
<1,400	0.18	0.11	0.28	0.28	0.76	1,980
1,401–1,600	0.21	0.12	0.36	0.46	1.22	4,062
1,601–1,800	0.30	0.17	0.59	0.88	3.11	5,197
1,801–2,000	0.29	0.15	0.64	0.96	4.01	2,959
2,001–2,200	0.45	0.25	1.03	1.33	3.75	2,261
2,201–2,400	0.45	0.23	1.25	2.31	6.76	2,239
>2,401	0.41	0.25	1.44	3.99	12.95	1,384

statistical meaning, i.e., being "any observation that appears surprising or discrepant to the investigator" but rather "any observation that is not a realization from the target distribution."

There is a clear decrease in EC as indicated by the average value from the lowest annual rainfall class to the highest annual rainfall class (Table 3.1). This is an indication of the importance of rainfall on the leaching or accumulation of salts in an environment. When considering the median values, the tendency is not so clear because the median values for 101–200mm class and 201–400mm class are both 0.49 dS m^{-1}.

When using 4 dS m^{-1} as a threshold value to separate saline from nonsaline soils, <100mm and 101–200mm rainfall classes tended to be saline if average values were used as indicator of salinity. None of the classes were saline when using the median value (Table 3.1).

There are no statistically significant differences at the 95% confidence level between <100mm and 101–200mm annual rainfall classes. The same applies for the three rainfall classes between 601 and >1,000mm.

There is an increase in EC as indicated by the average value from the lowest annual evaporation class to the highest annual evaporation class (Table 3.2). When considering the median values, the tendency is not so clear because the median values for 1,601–1,800mm class and 1,801–2,000mm class are 0.29 and 0.30 dS m^{-1},

Table 3.3 Soil electrical conductivity (dS m^{-1}) statistics for the different aridity classes

Aridity zones	P/PET	Median	Lower quartile	Upper quartile	Average	Standard deviation	Sample size
Hyperarid	<0.05	0.59	0.27	3.57	5.55	15.07	677
Arid	0.05–0.20	0.49	0.26	1.32	2.65	8.05	3,819
Semiarid	0.20–0.50	0.32	0.17	0.60	0.79	2.40	9,901
Dry subhumid	0.50–0.65	0.21	0.12	0.36	0.41	0.99	3,360
Humid	>0.65	0.16	0.09	0.26	0.23	0.63	2,325

Table 3.4 Exchangeable sodium percentage (*ESP*) statistics for the different rainfall classes

Annual rainfall (mm)	Median	Lower quartile	Upper quartile	Average	Standard deviation	Sample size
<100	14.5	5.8	37.9	34.2	61.5	232
101–200	5.9	2.5	15.5	19.1	55.9	952
201–400	3.7	1.6	10.3	12.7	31.5	2,730
401–600	2.3	1.1	5.9	5.9	27.7	4,913
601–800	1.7	0.7	3.9	4.0	7.5	5,957
801–1,000	1.5	0.8	2.7	2.9	8.0	4,720
>1,000	1.5	0.8	2.6	3.0	29.9	1,498

respectively, and for 2,001–2,200mm and 2,201–2,400mm classes, the median value is 0.45 dS m^{-1} for both classes. This is an indication that annual evaporation alone is not a good indicator of salt accumulation or it is a consequence of a rather limited number of weather stations recording A-pan evaporation.

There are no statistically significant differences at the 95% confidence level between <1,400mm and 1,401–1,600mm annual evaporation classes. The same applies for the annual evaporation classes between 1,601–1,800mm and 1,801–2,000mm, as well as 1,801–2,000mm and 2,001 and 2,200mm classes for EC.

There is a drastic decrease in average EC from the hyperarid to the humid aridity zones and to a lesser degree if the median values are considered (Table 3.3). This is a clear indication of the low leaching of salt in the hyperarid areas that results in salt accumulation, compared to the high leaching of salts in the humid areas.

When using 4 dS m^{-1} threshold value to separate saline from nonsaline soils, only the hyperarid zone is saline, if the average values are used as an indicator and none if the median values are used (Table 3.3). There are no statistically significant differences at the 95% confidence level between the dry subhumid and humid aridity zones.

There is a decrease in ESP as indicated by the average and median values from the lowest annual rainfall class of <100mm to 801–1,000mm annual rainfall class (Table 3.4). The maximum potential amount of Na leaching occurs between 801 and 1,000mm annual rainfall classes, with no further decrease in ESP when the annual rainfall is higher than 1,000mm. It can probably also be the result of low cation-exchange capacities that are associated with kaolinitic soils in high rainfall areas.

Table 3.5 Exchangeable sodium percentage (*ESP*) statistics for the different evaporation classes

Annual evaporation (mm)	Median	Lower quartile	Upper quartile	Average	Standard deviation	Sample size
<1,400	1.7	0.9	3.3	3.7	25.6	2,099
1,401–1,600	1.6	0.9	3.3	3.5	8.6	4,363
1,601–1,800	2.1	1.0	4.9	5.5	25.6	5,334
1,801–2,000	1.9	0.7	4.8	5.7	19.3	3.044
2,001–2,200	2.1	1.0	5.6	6.8	19.9	2,414
2,201–2,400	2.5	1.1	7.1	9.3	21.3	2,355
>2,401	3.6	1.6	10.6	17.3	55.2	1,392

Table 3.6 Exchangeable sodium percentage (*ESP*) statistics for the different aridity classes

Aridity zones	P/PET	Median	Lower quartile	Upper quartile	Average	Standard deviation	Sample size
Hyperarid	<0.05	8.0	3.2	22.6	27.6	72.5	677
Arid	0.05–0.20	3.2	1.4	10.0	11.3	28.8	3,935
Semiarid	0.20–0.50	2.0	0.9	4.6	4.9	19.5	10,397
Dry subhumid	0.50–0.65	1.6	0.8	2.9	3.2	6.1	3,586
Humid	>0.65	1.4	0.8	2.6	2.9	23.7	2,407

When an ESP value of 15 is used to separate sodic from non-sodic soils based on the average values, <100mm and 101–200mm annual rainfall classes can be considered as sodic. If a value of six is used to separate sodic from non-sodic, based on the average ESP values, the annual rainfall class of 201–400mm is also sodic. Only the annual rainfall class of <100mm is sodic when using the median ESP of six to separate sodic from non-sodic soils (Table 3.4). There are no statistically significant differences at the 95% confidence level among the three annual rainfall classes between <100 and 601mm for ESP.

There is no clear indication of an increase in ESP as indicated by the average or median values from the lowest annual evaporation class to the highest annual evaporation class (Table 3.5). There is, however, an observable increase in the average value from 1,401 to 1,600mm annual evaporation class to >2,401mm class and from 1,801 to 2,000mm to >2,401mm class as indicated by the median value.

When an ESP value of 15 is used to separate sodic from non-sodic soils based on the median values, the annual evaporation class of >2,400mm can be considered as sodic. When using an ESP value of six to separate sodic from non-sodic based on the median values, the annual evaporation classes of 2,001–2,200mm and 2,201–2,400mm are also sodic (Table 3.5). There are no clear statistically significant differences at the 95% confidence level for the four evaporation classes between <1,400 and 2,000mm for ESP.

There is a drastic decrease in ESP values from the hyperarid to the humid aridity zones as indicated by the average value and to a lesser degree if the median values are considered (Table 3.6).

Table 3.7 pH_{water} statistics for different rainfall classes

Annual rainfall (mm)	Median	Lower quartile	Upper quartile	Average	Standard deviation	Sample size
<100	8.5	8.1	9.0	8.4	1.1	232
101–200	8.2	7.6	8.7	8.1	0.9	962
201–400	8.0	7.1	8.5	7.8	1.0	2,713
401–600	7.0	6.3	7.6	7.1	1.1	4,891
601–800	6.2	5.6	6.9	6.3	1.0	6,273
801–1,000	5.8	5.2	6.3	5.9	0.9	4,745
>1,000	5.5	5.2	5.9	5.6	0.7	1,524

Table 3.8 pH_{water} statistics for different evaporation classes

Annual evaporation (mm)	Median	Lower quartile	Upper quartile	Average	Standard deviation	Sample size
<1,400	5.7	5.2	6.2	5.8	0.8	2,157
1,401–1,600	5.9	5.3	6.5	6.0	0.9	4,423
1,601–1,800	6.4	5.8	7.5	6.5	1.1	5,355
1,801–2,000	6.5	5.5	7.3	6.6	1.2	3,163
2,001–2,200	6.9	6.2	7.9	7.0	1.2	2,521
2,201–2,400	7.7	6.7	8.4	7.5	1.1	2,327
>2,401	8.2	7.6	8.7	8.0	0.9	1,394

When an ESP value of 15 is used to separate sodic from non-sodic soils based on the average values, the hyperarid zone can be considered sodic. If a value of six is used to separate sodic from non-sodic based on the average ESP values, the arid zone is also sodic, and if the median value is used, the hyper zone is also sodic (Table 3.6). There are no statistically significant differences at the 95% confidence level between the dry subhumid and humid aridity zones for ESP.

There is a clear decrease in pH_{water} as indicated by the average and median values from the lowest annual rainfall class of <100mm to the highest rainfall class of >1,000mm (Table 3.7). There are statistically significant differences at the 95% confidence level between all the rainfall classes for pH_{water}. There is an increase in pH_{water} as indicated by the average and median values from the lowest annual evaporation class to the highest annual evaporation class (Table 3.8). There are clear statistically significant differences at the 95% confidence level between the evaporation classes. There is an obvious decrease in pH_{water} as indicated by the average and median values from the hyperarid to the humid zone (Table 3.9).

Since the *p*-value is less than 0.05, there is a statistically significant relationship between the variables for the different rainfall classes at the 95% confidence level for EC. The R^2 statistic indicates that the model explains 58.28% of the variability in EC for <550mm rainfall class, only 38.66% for the >550mm rainfall class, and 54.93% if no distinction is made between rainfall classes. The highest *p*-values for the independent variables are annual rainfall, and pH_{water} for <550mm rainfall class

Table 3.9 pH_{water} statistics for different aridity classes

Aridity zones	P/PET	Median	Lower quartile	Upper quartile	Average	Standard deviation	Sample size
Hyperarid	<0.05	8.4	7.9	8.8	8.3	0.8	677
Arid	0.05–0.20	7.9	7.0	8.5	7.7	1.1	3,897
Semiarid	0.20–0.50	6.5	5.8	7.4	6.6	1.0	10,751
Dry subhumid	0.50–0.65	5.8	5.3	6.4	6.0	0.9	3,537
Humid	>0.65	5.5	5.2	6.0	5.6	0.7	2,478

Table 3.10 Multiple linear regression relationships to predict EC (mS m^{-1}) for different rainfall classes

Equation of the fitted model	R^2	Rainfall class	Sample size
$EC = 357.7 - 0.147 \times rain - 48.04 \times pH_{water} + 6.203 \times Ca + 139.7 \times Na + 9.299 \times aridity$	54.93%	All	19,016
$EC = 582.0 - 0.5615 \times rain - 57.68 * pH_{water} + 9.29 * Ca + 155.6 * Na + 4.82 \times aridity$	58.28%	<550mm	6,695
$EC = 11.76 - 3.749 \times pH_{water} + 1.612 \times Ca + 67.56 \times Na + 10.68 \times aridity$	38.66%	>550mm	12,320

Table 3.11 Multiple linear regression relationships to predict ESP for different rainfall classes

Equation of the fitted model	R^2	Rainfall class	Sample size
$ESP = 2.214 + 5.607 \times Na + 0.01615 \times EC + 0.1895 \times aridity - 0.3308 \times pH_{water}$	71.76%	All	18,207
$ESP = 0.05158 + 6.733 \times Na + 0.01028 * EC + 0.2161 \times aridity - 0.03307 \times pH_{water}$	85.04%	<550mm	6,726
$ESP = 3.306 + 1.156 \times Na + 0.06509 \times EC - 0.8513 \times aridity - 0.2284 \times pH_{water}$	52.04%	>550mm	11,300

and for >550mm rainfall class pH_{water} and exchangeable Ca have the highest *p*-value (Table 3.10).

Since the *p*-value is less than 0.05, there is a statistically significant relationship between the variables for the different rainfall classes at the 95% confidence level for ESP. The R^2 statistic indicates that the model as fitted explains a high 85.04% of the variability in ESP for <550mm rainfall class, only 52.04% for >550mm rainfall class, and 71.76% if no rainfall distinction is made. The highest *p*-value for the independent variables was found for exchangeable Na and EC for all the rainfall classes (Table 3.11).

There is a statistically significant relationship between the variables for the different rainfall classes at the 95% confidence level for pH_{water} since the *p*-value is less than 0.05. The R^2 statistic indicates that the model as fitted explains 34.4% of

Table 3.12 Multiple linear regression relationships to predict pH_{water} for different rainfall classes

Equation of the fitted model	R^2	Rainfall class	Sample size
$pH_{water} = 7.799 + 0.08394 \times Mg - 0.002368 \times rain + 0.03244 \times Ca + 0.08664 \times Na - 0.004184 \times clay$	55.80%	All	18,834
$pH_{water} = 8.118 + 0.08887 \times Mg - 0.002991 \times rain + 0.0371 \times Ca + 0.05102 \times Na - 0.006469 \times clay$	34.40%	<550mm	6,390
$pH_{water} = 7.112 + 0.08067 \times Mg - 0.001592 \times rain + 0.02846 \times Ca + 0.1961 \times Na - 0.003634 \times clay$	46.25%	>550mm	12,443

the variability in pH_{water} for <550mm rainfall class, 46.25% for >550mm rainfall class, and 55.80% if no distinction is made between rainfall classes. The highest *p*-value for the independent variables is for exchangeable Mg and annual rainfall for all the rainfall classes (Table 3.12).

3.4 Conclusions

The effect of rainfall, evaporation, and aridity on salt accumulation in the soil, on a national scale, is not straightforward, and other factors such as geology, position in the landscape, and previous climatic conditions should be accounted for. It should further not be assumed that all salt-affected soils will always show definite and predictable associations with present day climate. The relationship between climate and salt-affected soils is made more difficult to determine because practically all areas have suffered climates in the past different from those prevailing at present.

The opening of the Drake Passage is probably the geological event in the recent past that has the most dominant effect on salt-affected soils and climate in southern Africa. This gave rise to the Benguela upwelling system that radically changed the climate in southern Africa.

There is a clear decrease in EC, as indicated by the average values, but not always when using the median values, from the lowest annual rainfall class to the highest annual rainfall class; an increase in EC from the lowest annual evaporation class to the highest annual evaporation class; and a drastic decrease in EC from the hyper-arid to the humid aridity zones. This is an indication of the importance of rainfall and evaporation on the leaching or accumulation of salts in an environment.

There is a decrease in ESP as indicated by the average and median values from the lowest annual rainfall class of <100mm to 801–1,000mm annual rainfall class. The maximum potential amount of Na leaching occurs between 801 and 1,000mm annual rainfall classes, with no further decrease in ESP above an annual rainfall of 1,000mm. There is no clear indication of an increase in ESP as indicated by the average and median values from the lowest annual evaporation class to the highest annual evaporation class. There is, however, an increase in average ESP from 1,401 to 1,600mm annual evaporation class to >2,401 class and as in the median ESP from 1,801 to 2,000mm to >2,401 class. There is a drastic decrease in ESP values from the hyperarid to the humid aridity zones as indicated by the average value and to a lesser degree when the median values are considered.

There is a clear decrease in pH_{water} as indicated by the average and median values from the lowest annual rainfall class of <100mm to the highest rainfall class of >1,000mm. There is an increase in pH_{water} as indicated by the average and median values from the lowest annual evaporation class to the highest annual evaporation class. There is also a clear decrease in pH_{water} as indicated by the average and median values from the hyperarid to the humid zone.

The accuracy with which EC, ESP, and pH_{water} were predicted with stepwise multiple linear regression relationships on a national scale is surprising considering that the various models included all "outlier" values. The R^2 statistic indicated that the models as fitted explained the variability in EC and ESP much better for the low rainfall class (<550mm annual rainfall), than for the high rainfall class (>550mm annual rainfall). For EC, <550mm annual rainfall class in the model explains 58.28% of the variability and for >550mm annual rainfall class 38.66% of the variability. Values for ESP are 85.04% for <550mm annual rainfall class and 52.04% for >550mm annual rainfall class. Multiple linear regression relationships were unable to predict pH_{water}, an indication that it would be better to log-transform the pH_{water} values or to use curvilinear models for the prediction.

Good decisions for the management of salt-affected soils on a national scale require good information, derived from raw data. Such data must be generated with specific goals in mind, and it must be stored properly in a format that is easy to access and process. Like any basic resource, the data environment must be managed meticulously.

References

ARC-ISCW (2004) Overview of the status of the agricultural natural resources of South Africa. ARC-ISCW report no. GW/A/2004/13, Pretoria

Balba AM (1995) Management of problem soils in arid ecosystems. CRC Press, Boca Raton

Beckman RJ, Cook RD (1983) Outliers. Technometrics 25:119–163

Birkeland PW (1984) Soils and geomorphology. Oxford University Press, Oxford

Bühmann C, Nell JP, Samadi M (2004) Clay mineral associations in soils formed under Mediterranean-type climate in South Africa. S Afr J Plant Soil 21(3):166–170

Ellis F (1973) Soil studies in the Duiwenhoks river catchment area. MSc Agric thesis, University of Stellenbosch, Stellenbosch

Ellis F, Lambrechts JJN (1994) Dorbank, a reddish brown hardpan of South Africa: a proto-silcrete?. In: Poster presented at the 15th World Congress of Soil science, Acapulco, Mexico

Francis ML (2008) Soil formation on the Namaqualand coastal plain. DPhil Agric thesis, University of Stellenbosch, Stellenbosch

Gerrard J (1992) Soil geomorphology: an integration of pedology and geomorphology. Chapman and Hall, London

Land Type Survey Staff (1987) Land types of the maps 2526 Rustenburg, 2528 Pretoria. Memoirs on the Agricultural Natural Resources of South Africa, No 8, Pretoria

McCarthy T, Rubidge B (2005) The story of earth and life: a southern Africa perspective on a 4.6-billion-year journey. Struik Publishers, Cape Town

Non-Affiliated Soil Analysis Working Committee (1990) Methods of soil analysis. SSSSA, Pretoria

Peech M (1965) Chemical and microbiological properties. In: Black CA, Evans DD, White JL, Ensminger LE, Clark FE (eds) Methods of soil analyses – Part 2. American Society of Agronomy, Madison

Scher HD, Martin EE (2006) Timing and climatic consequences of the opening of Drake Passage. Science 312(5772):428–430

Schulze RE (1997) South African atlas of agrohydrology and climatology. Report TT82/96, Water Research Commission, Pretoria

Statgraphics (2005) Statgraphics Centurion XV user manual. Statgraphics, Maryland

Summerfield MA (1983) Silcrete as a paleoclimatic indicator: evidence from southern Africa. Paleogeogr Paleoclimato Palaeoecol 41:65–79

Szabolcs I (1989) Salt-affected soils. CRC Press, Boca Raton

UNEP (2009) Global humidity index from GRID and UEA/CRU http://www-cger.nies.go.jp/grid-e/griddoc/hindtgeoe.html. Accessed 12 Aug 2009

Van Zyl D (2003) South African weather and atmospheric phenomena. Briza, Pretoria

Vogel C (2000) Climate and climatic change: causes and consequences. In: Fox R, Rowntreen K (eds) The geography of South African in a changing world. Oxford University Press, Oxford

Walling DE (1996) Hydrology and rivers. In: Adams WM, Goudie AS, Orme AR (eds) The physical geography of Africa. Oxford University Press, New York

Chapter 4
Soil Salinization Assessment and Monitoring at Boe Klue District, Nan Province, Northern Thailand

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Abstract Thailand is an agrarian country with a total land area of 51.4×10^6 hectares (ha), of which 38% are farm land, 25% are forests, and the remaining 37% cover urban area, public area, sanitation, swamp land, railroad, highways, real estate, and others. Thailand has been changed in the last five decades due to rapid population increase and land use pattern change. The encroachment of natural forests, use of marginal lands, and mismanagement of soil and water resources have degraded soil and water resources. It is estimated that degraded soils cover 31×10^6 ha or 60% of the total land area of the country, comprising six major soil problems, that is, acid sulfate soils, peat soils, sandy soils, eroded soil, mined soils, and saline soils. Saline soils are the oldest and represent one of the most important environmental problems to humanity. In Thailand, they occupy 3.5×10^6 ha area. These soils reduced the agricultural productivity in the northern region, northeastern region, the Central Plain, and along the coastal areas of the country. It is therefore important to assess and monitor soil salinization in these areas for better management of agricultural soils. This has been accomplished in Boe Klue District, Nan Province, Northern Thailand. The methodologies used are geophysical method, ground-based surveys

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using EM38 measurement and laboratory analysis of soil and water samples. The result showed the occurrence of salt on soil surface being derived from soil salinization as a natural phenomenon. The source of salts is found to be from strike slip of Boe Klue formation. Salinized soils have been found to coincide with shallow saline groundwater or exposure of Boe Klue formation.

Keywords Agricultural productivity • Boe Klue • Geophysical method • Ground-based surveys • Soil salinization assessment and monitoring • Thailand

4.1 Introduction

Thailand is well endowed with diverse natural resources. As an agrarian country, its economy is dominated by the agricultural sector in terms of gross domestic product (GDP), employment, and food security. The total land area of the country is approximately 51.4×10^6 ha, comprising 38% farmland, 25% forests, and the remaining 37% are public area, municipality area, water bodies, swamp land, railroads, highways, real estate, and other areas. Climate of Thailand is tropical savannah (the Central Plain, north, northeast, and some part of eastern part), tropical monsoon (west side of southern and eastern part), and tropical rainforest (east side of southern part). The average annual temperature is about 27°C, while the annual rainfall varies in the range of 824–5,248 mm (Center for Agricultural Information 2005).

The study area, Boe Klue District, Nan Province, is located in Northern Thailand adjoining Laos. The geographical characteristic of the area is mountain range and hill, while small lowland areas are scattered in the valley. Land elevation above the mean sea level of Boe Klue District is in a range of 700–1,890 m. The average annual rainfall is 1,300 mm. Land use, according to historical annals, stories, and evidences, shows that this area had been a place for human settlement from 5,000 to 1,500 years ago. Ancient salt wells were found in this area and have been used to produce salts for consumption and commerce. In the past, Nan City was a great supplier, producing table salt from salt well for the northern region of Thailand as well as for neighboring countries. In 1550, King Tilokaraj of Chiangmai City-State seized Nan with the hopes of providing salt for his kingdom. Agricultural land area is totally 4,557 ha and has been used for growing rice, corn, tobacco, tea, vegetables, and fruit trees (Agricultural Office Boe Klue District 2009). Agriculture, however, is an important sector for people in this area.

4.2 Land Use of the Country in Recent Decades

Land resources have been extensively used to increase agricultural production to meet food demand of rapidly increasing population, which has been increased from 8×10^6 in 1911 to 66×10^6 at present. This has resulted in constant expansion of land

Table 4.1 Criteria for classifying salinity of soils (Land Development Department 1993)

Salinity class	ECe (dS m^{-1}) at 25°C	Salt percentage
Non-saline	<2	<0.10
Slightly saline	2–4	0.10–0.20
Moderately saline	4–8	0.20–0.40
Highly saline	8–16	0.40–0.80
Very highly saline	>16	>0.80

for agriculture and increase of marginal lands, and the encroachment of national forests. Besides that, many areas are usually cultivated, with inappropriate activities causing land degradation.

It is estimated that degraded soils cover 31×10^6 ha or 60% of the total land area of the country. Degraded soils comprise six major soil problems, that is, acid sulfate soils, peat soils, sandy soils, eroded soils, mined soils, and saline soils. Among these, marginal saline soils are the oldest and represent one of the most important environmental problems of humanity. They cover a total area of 3.5×10^6 ha. It is a form of degraded land that has become causative factor for low agricultural productivity in the northern region, northeastern region, the Central Plain, and along the coastal areas of the country.

Land degradation has been recognized as a major global problem. Saline soil is one of the oldest problems for mankind which has affected the ecosystem structure and functions. It is a major factor that has turned high quality lands to marginal quality. The assessment, quantification, and monitoring of the nature, extent, severity, impacts, and classification of salt-affected soils would help to understand the problem and help plan and implement mitigation for these soils and establish management practices for sustainable land use.

4.3 Salt-Affected Soils

The soil containing excess soluble salts can affect the growth and yield of most plants. This is indicated by its ECe (electric conductivity of soil saturation extract) when it is higher than 2 dS m^{-1} at 25°C (Land Development Department 1993).

Salt-affected soils are formed from different salification intensities and chemical composition, occurring in different formations and environmental conditions. It is the criteria of saline soils that certain amount of salts in the root zones has impeded the plant growth or has degraded soil properties. The gradation of saline soils and alkaline soils can be determined by salinity and alkalinity levels. The classification of soil salinity is divided as shown in Table 4.1.

According to Thailand classification of salt-affected soils (Land Development Department 1993), these soils are divided into four classes, non-saline, saline,

saline-sodic, and sodic. Non-saline soil presents ECe < 2 dS m^{-1} and ESP < 15; saline soil has ECe > 2 dS m^{-1} and ESP < 15; saline-sodic soils have excessive soluble salts (ECe > 2 dS m^{-1}) and soil sodicity (ESP > 15). Sodic soil has ECe < 2 dS m^{-1} and ESP > 15.

In Thailand, salt-affected soils occupy approximately 3.5×10^6 ha area in the northeastern part, in the Central Plain, and along the coastal belt. The salt-affected lands comprise only 16% of cultivated lands; however, it is a major and increasing problem, affecting the agricultural production. These are inland saline soils and coastal saline soils.

4.3.1 Inland Saline Soils

They are extended to 3.0×10^6 ha area covering in three parts of the country: (1) In the northeast region, they are recognized in the seasonal dry land area in dry season. Besides that, this region is constrained by shallow sandy soil with low fertility and deficiency of most plant nutrients, by limited irrigation facilities, and more critically, by poor soil and water management. Inland saline soils cover an area of 2.84×10^6 ha in 17 provinces of the northeast. (2) In the northern region, the salt-affected soils are found in three provinces: Nan, Uttaradit, and Phitsanulok. (3) In the Central Plain, these soils occur in three provinces of the Central Plain, that is, Nakhon Pathom, Ang Thong, and Suphan Buri, covering an area of 0.16×10^6 ha.

4.3.2 Coastal Saline Soils

They are extended along 2,600 km of the coastal belt in 24 provinces on both the Gulf of Thailand and the Andaman Sea, covering an area of 0.58×10^6 ha.

4.4 Soil Salinization and Sodication in the Country

Saline soils are usually formed through a natural process; they can also be formed through human impact.

4.4.1 Natural Process

The inland saline soils occur in the northeastern part of the country. It is a plateau land, with rolling or undulating topography, as has been uplifted from the sea. These are the major factors that the more the low-lying areas and precipitation are, the more severity of salinity level in the soils. Salts are derived from rock salt strata, from weathering of sandstone and shale impregnated with salts, and also from saline groundwater with high water table (Sinanuwong and Takaya 1974; Arunin 1985; Im-Erb and Pongwichian 2003).

In Northern Thailand, salts are derived from underground. Saline soils have been found to coincide with shallow saline groundwater or exposure of Boe Klue formation.

In the Central Plain, most salts in saline soils have been derived from underlain old marine sediments. These salts are chlorides, sulfates, and carbonates of Na, Ca, and Mg. The soil survey of the area revealed that this part of the country was under the influence of tidal flat condition since 4,000–8,000 years ago. Due to the expansion of agricultural areas to cope with the increased need of food, this has caused the inappropriate use of land and water resources in this region. The excavation of land (sand mining and using soil materials for construction), over-irrigation, shallow saline groundwater, use of saline groundwater for agriculture, and lack of drainage have resulted in soil salinization.

In the coastal zone, the land is under the influence of seawater. Most of these soils are derived from marine deposits. The salt in these areas is dominated by a high content of sodium chloride, with smaller amounts of sodium sulfate and calcium, magnesium and potassium chlorides, and sulfates.

4.4.2 Anthropogenic Causes

Human activities have also been responsible for soil salinization, as described below.

Deforestation and growing of shallow-rooted crops cause the consumptive use of rainwater by the vegetation to be much less, allowing excess water to percolate to the water table. The change of ground hydrology has resulted in the movement of the groundwater and its salinity level. This caused the high water table, and the movement of soluble ions through capillary rise and subsequent evaporation accumulated salts on the soil surface.

Salt making has usually been found in very strongly saline soil areas of the northeastern region. In the process, the producers pump the shallow concentrated saline groundwater to get evaporated on the earth pans to obtain salt afterward. This also results in the seepage of saline water to adjacent areas. The occurrence of saline soil due to the construction of reservoirs is usually related to its proximity to the sources of salt or in the area where saline groundwater is shallow. In that case, water in the reservoirs will attain high salinity level within a few years.

Shrimp farming is a big problem that has caused anthropogenic soil salinization. In the process, shrimp farmers transfer concentrated brine (and occasionally applied with salt granules) to the ponds and dilute it with freshwater to a salinity level of 3–10 parts per thousand (ppt), which is suitable for shrimp before their release into it. The intensive use of chemicals and antibiotics used for raising shrimps has severely affected the environment. Discharge of sludge, excess feeds, and saline

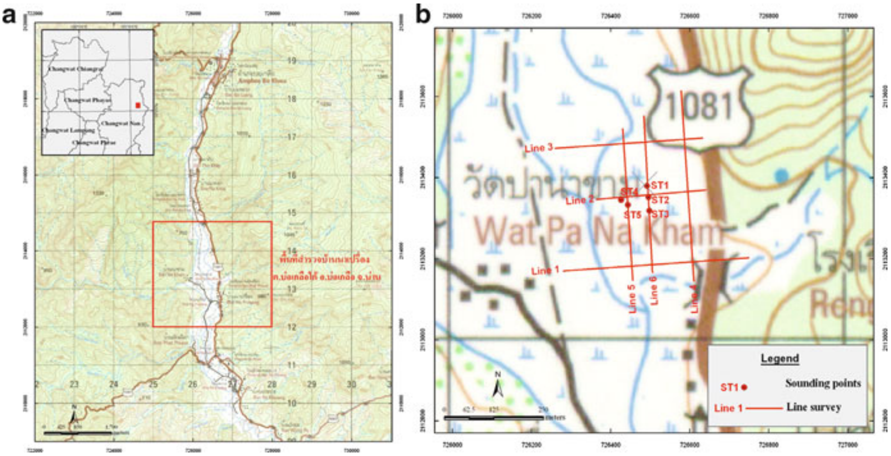

Fig. 4.1 Location map and survey lines of Na Pruang area, Bo Klue District, Nan Province, Thailand

water into nearby irrigation canals, including seepage of saline water to adjacent agricultural areas and underground water, has led to a significant buildup of toxicity and salinity. In some severe cases, large rice fields have gone out of production.

4.5 Study Area

The study area (salt-affected) is situated at Ban Na Pruang, Ban Bo Luang, and Ban Na Kwang in Boe Klue District, Nan Province, Thailand. This was surveyed between April 2008 and January 2010. The investigation area covers approximately 150 ha.

An area at Ban Na Pruang in Bo Klue District, Nan Province, was used to study salt source, covering an area about 50 ha, as shown in Fig. 4.1a. The geophysical surveys are made on six line surveys in N-S and E-W line directions (Fig. 4.1b).

4.5.1 Soils

Soils in these areas are formed from alluvium and weathering of sedimentary rocks and occur on lowland area of the valley. Relief is flat to nearly flat. Slopes are 0–5%. They are moderately deep to deep and moderately well-drained soils. The A horizon is 15–20 cm thick and silty loam in texture. Soil reaction is strongly acid to slightly acid (pH 4–5.7). The B horizon is sandy loam and fine clayey; gravels are found in some spots at the depth of 100 cm. Soils in these areas have low to moderate fertility. Areas are used mainly for rice production during rainy season.

4.5.2 Geology

Ban Na Pruang area is located on the Quaternary alluvial-filled basin surrounded by high topographic terrain and underlain by Cretaceous clastic rocks (Im Samut and Chuaedee 2005). The stratigraphic rocks in the study area are as follows: (1) Boe Klue formation (Late Cretaceous) consists of siltstone interbedded with mudstone, reddish brown, and some rock salt; (2) Sa Pun formation (Late Cretaceous) overlain on Bo Klue formation consists of reddish brown sandstone and siltstone; and (3) Quaternary alluvial consists of sand, silt, and clay.

Main structural geology of the study area is faults in three directions: NE-SW, N-S, and NW-SE. Major fault is Boe Klue fault in north–south trending. Many fractures are found in this area that parallel and crosscut with the nearby faults.

4.6 Methodology

The assessment and monitoring of soil salinization on arable land have been made during the dry season of 2008–2010. The methods are applied with integrated technologies on soil survey, measurement of electrical conductivity, and laboratory analyses of soil and water samples including the use of electromagnetic induction (EM38) surveys to measure bulk soil conductivity. Besides that, a vegetation survey in the study areas was conducted to determine the vegetation, diagnosis of plant symptom, and plant growth.

Moreover, geophysical survey has been made to search the source of salts in the study area, using resistivity meter (IRIS SYSCAL R1) and electromagnetic conductivity (EM34). Resistivity surveys were conducted with an automated multi-electrode switching system (IRIS SYSCAL R1 plus). The dipole-dipole array technique was also used in the study. A report on the use of dipole-dipole array technique showed a good resolution of fracture and caves with this configuration (Roth et al. 1999; Labuda and Baxter 2001). A total of 48 representative spots were fixed with electrodes, using a dipole spacing of 15 m. The apparent resistivity dipole-dipole data had been converted and interpreted, using the rapid two-dimensional (2D) resistivity inversion least-squares method (program RES2DINV, Ver. 3.3) (Loke 1998) to acquire a 2D "true" earth resistivity inversion solution, which is showing color grid. Ten points of resistivity deep sounding (RS) were made by using Schlumberger electrode configuration. RS curves had been interpreted by curve matching procedures using albums of theoretical curves and auxiliary point diagram. The accuracy of graphical interpretation was checked, referring computer model.

Electromagnetic conductivity (EM34) survey has been concurrently operated to measure the subsurface conductivity, measuring by electromagnetic method, which is opposed to the resistivity. The spacing of measurement is a fixed distance (10, 20, and 40 m) between an electromagnetic field transmitter (Tx) and a receiver (Rx). The separation of the Tx and Rx as well as the orientation (horizontal vs. vertical) determines the depth of investigation.

4.7 Results and Discussion

The results of the study on the soil salinization and its extent showed that there was a tendency of land units in the study areas having been affected from shallow saline groundwater, rising to soil surface, and resultant accumulation of salts in excess that can affect the growth and yield of most plants. A phenomenon on salinization in the northeast region is also reported which is caused from saline groundwater (Sinanuwong and Takaya 1974; Arunin 1985; Im-Erb et al. 2004). The salt-affected soils in these areas are extended in an area of 4 ha.

The chemical characteristics and composition of soils and water are shown in Tables 4.2 and 4.3. The results of soil sample analysis from Ban Na Pruang showed that in the areas where the salt crust was found, the electrical conductivity (ECe) is in a range of 11–35 dS m^{-1}, SAR 20–54, and pH 4.1–4.7, and where none of the salt crust was found, the ECe is in a range of 0.8–1.7 dS m^{-1}, SAR 0.1–2, and pH 4.8–5.0.

The soil sample analysis of the study area at Ban Na Kwang showed that the values of ECe are 1.3 dS m^{-1}, SAR 3, and pH 4.7.

The results of soil sample analysis from Ban Bo Luang showed that in the public zone area, the ECe values are high on a range of 31 dS m^{-1}, SAR 57, and pH 5.7. Saline groundwater in this area was rising on the surface, while in the rice field, the ECe is also high with the values in a range of 18 dS m^{-1}, SAR 53, and pH 5.8. For water sample from soil surface of this area, the ECw was 9.7 dS m^{-1} and pH 6.6.

The water sample from a canal closed to the rice field that farmers used for irrigation had ECw level of 0.1 dS m^{-1}, while in the water sample from salt well of the village where the villagers used to produce table salt, the ECw level was 192–>200 dS m^{-1}.

Table 4.2 Analyses of water samples

No.	Location	EC dS m^{-1}	pH	Remark
1	Water sample from salt well used for producing table salt (no. 1)	192.5	–	
2	Water sample from salt well used for producing table salt (no. 2)	>200	–	
3	Water sample from waterlogged area at Ban Bo Luang	9.79	6.6	
4	Water sample from rice field at Ban Bo Luang (no. 1)	3.6		Water sample from rice field during land preparation
5	Water sample from rice field at Ban Bo Luang (no. 2)	0.8		Water sample from rice field during land preparation
6	Water sample from rice field at Ban Bo Luang (no. 3)	2.3		Water sample from rice field during land preparation
7	Water sample from rice field at Ban Bo Luang (no. 4)	0.94		Water sample from rice field during land preparation.
8	Water sample from a canal at Ban Bo Luang	0.1		Water sample nearby rice field

Table 4.3 Analyses of soil samples

No.	Location	Depth cm	EC dS m^{-1}	pH	Soluble Ca mmol L^{-1}	Soluble Mg mmol L^{-1}	Soluble Na mmol L^{-1}	SAR
1	Soil sample from rice field at Ban Na Pluang no. 1	0–20	35.0	4.1	38.7	9.6	269.6	54
2		20–50	22.5	4.7	26.8	5.2	178.3	44
3		50–100	27.0	4.7	31.4	7.1	224.0	51
4	Soil sample from rice field at Ban Na Pluang no. 2 (0–20 cm)	0–20	11.0	4.7	21.0	5.7	73.9	20
5		20–50	8.0	4.7	17.3	4.0	54.3	16
6		50–100	8.2	4.7	16.8	4.1	56.5	17
7	Soil sample from rice field at Ban Na Pluang no. 3 (0–20 cm)	0–20	1.7	4.8	2.7	0.5	9.9	0.1
8		20–50	1.4	5.1	3.2	0.7	6.9	4
9		50–100	1.5	5.3	3.9	0.9	6.7	4.3
10	Soil sample from rice field at Ban Na Pluang no. 4 (0–20 cm)	0–20	0.8	5.0	2.7	0.6	3.4	2
11		20–50	0.8	5.6	2.7	0.6	3.3	2
12		50–100	0.4	6.5	1.4	0.2	1.3	1
13	Soil sample from rice field at Ban Na Kwang (0–20 cm)	0–20	1.3	4.7	3.8	0.8	2.8	3
14		20–50	0.3	5.8	1.4	0.2	1.0	1
15		50–100	1.2	5.6	3.4	0.7	4.8	6
16	Soil sample from public area (0–20 cm)	0–20	31.0	5.7	34.0	6.3	256.6	57
17		20–50	20.0	3.8	32.8	5.4	143.5	32
18		50–100	16.0	4.8	23.8	4.1	110.9	29
19	Soil sample from rice field at Ban Bo Luang (0–20 cm)	0–20	18.0	5.8	11.9	1.7	139.1	53
20		20–50	14.0	6.2	16.6	2.1	115.2	37
21		50–100	13.4	5.8	20.5	2.6	108.7	31

Result of the resistivity survey displayed as apparent vertical resistivity cross section. The traverse lines 1, 2, and 3 in NE-SW direction that show the existence of the saline soil anomalies are shown in Fig. 4.2. From these figures, three different resistivity layers are as follows:

A resistant cover (60–80 Ω·m): This layer includes alluvial sand bed and coarse-grained sediments representing thin (10 m) cap rocks on the surface.

A conductive complex (1–10 Ω·m): This layer represents clay and water. The ones with less than 1 Ω·m are correlated with salt water-bearing series, which lie just over rock salts located at the depth of approximately more than 80 m, corresponded to the result of resistivity sounding.

A resistant layer (40–60 Ω·m): They correspond to Paleozoic complex basement which consists of mudstone, siltstone, and sandstone.

Figure 4.2 illustrates that the shallow section is dominated by a local increase in resistivity representing the layer of sand and silt on topsoil alluvium. In the deeper section, this can be observed as an isolated low resistor in the middle of the line that indicates the saline soil zone. The low resistivity body extends in N-S direction from line 2 to line 3.

The structure of faulted basement with quaternary sedimentary overlain can be seen on this section. The low resistivity around the faulted basement may represent a resistivity drop caused by the salt water fluid in the fault zone. These zones were classified as saline anomalies for exploration drilling. Similarly, the change of ground hydrology has resulted in the movement of the groundwater and its salinity level. This caused high water table and the movement of the dissolved salts upward by capillary rise and the evaporation processes and accumulation of salts on the soil surface (Im-Erb et al. 2004).

The results of an EM survey are typically presented in map form, with qualitative interpretation. High conductivities are interpreted as saline soil, and low conductivities are interpreted as thin soils or shallow bedrock.

Electromagnetic terrain conductivity meter (EM34) surveys were conducted on the Boe Klue District area. The primary purpose of these surveys was to locate the saline soil areas. The result of one of these surveys using an EM34 with 10-m coil spacing and horizontal dipole configuration is shown in Fig. 4.3a. The extent of saline soil, as delineated by the EM (Fig. 4.3a) survey, is similar to the result of the resistivity survey (Fig. 4.2). The EM result can be shown in 3D of conductivity interpreted map to consider the shape of anomaly at different depths as shown in Fig. 4.3b. In the area where the two surveys overlap, the EM survey could operate considerably more extrapolate, which makes the area coverage more extensive than the resistivity survey.

4.8 Conclusion

The phenomenon on occurrence of soil salinization at Boe Klue District, Nan Province, is a result from the salt water from channel of the NE-SW faults on Boe Klue formation. The salt-affected soils in this area cover an area of approximately 4 ha. It is estimated that the rock salt is under the surface at depth of more than 100 m. The short- or long-term mitigation should apply to assist farmers in the affected areas.

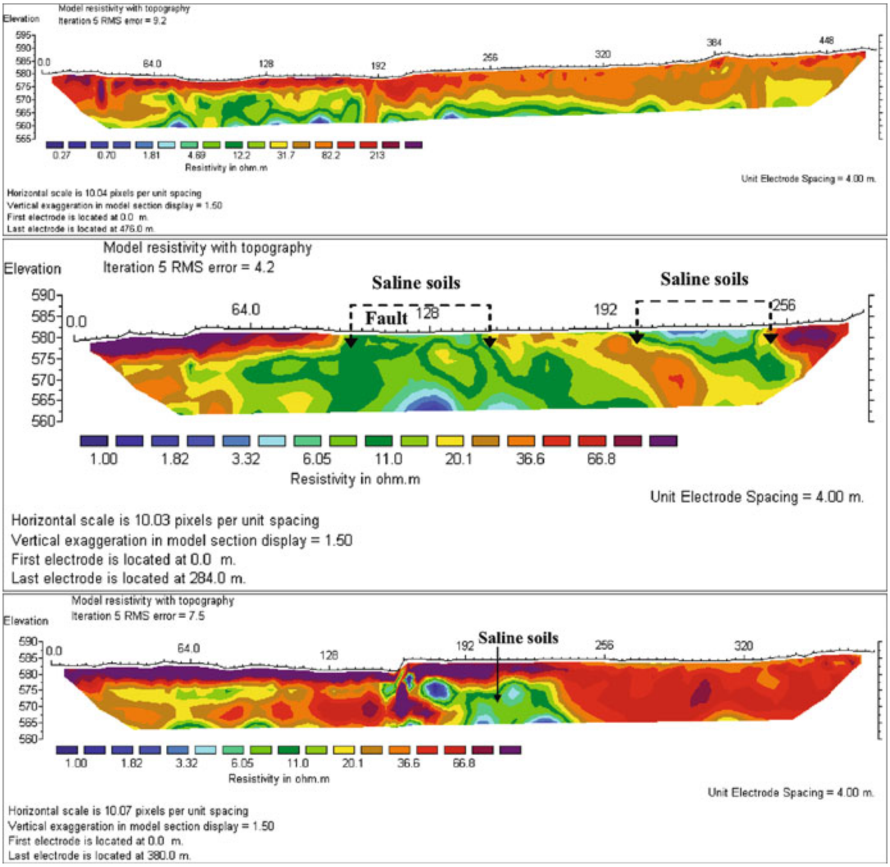

Fig. 4.2 Resistivity image of lines 1 (*top*), 2 (*middle*), and 3 (*bottom*) at Ban Boe Klue District

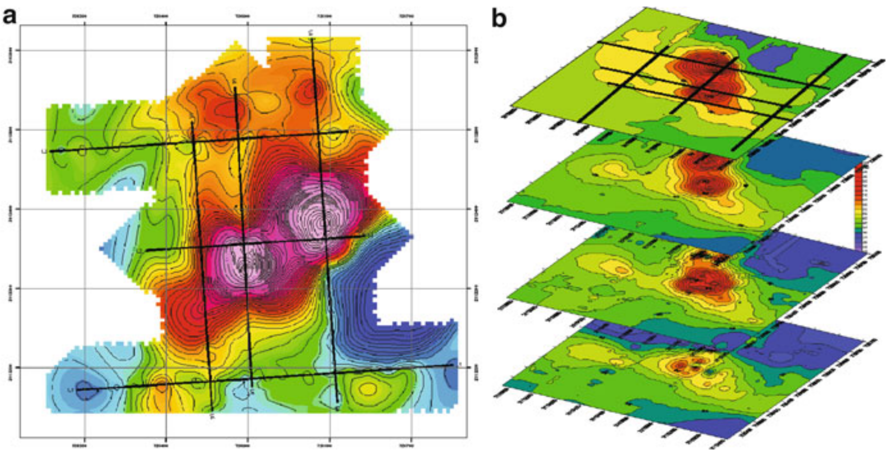

Fig. 4.3 Conductivity of the Boe Klue area. (**a**) Conductivity map at 0–5 m shows the direction of saline soil in NE trending, (**b**) 3D presentation of the result of conductivity interpret with slices of the underground with constant altitude (Im-Erb R et al.)

References

Agricultural Office Boe Klue District (2009) Agricultural information. Agricultural Office Boe Klue District, Nan Province

Arunin S (1985) Management of soil salinity in Northeast Thailand. The first KKU-USAID international seminar on soil, water and crop management systems for rainfed agriculture in Northeast Thailand. Proceedings of the workshop at Khon Kaen University, Khon Kaen, Thailand

Center for Agricultural Information (2005) Agricultural statistics of Thailand crop year 2004–2005. Office of Agricultural Economics, Bangkok, Thailand, p 142

Im Samut S, Chuaedee N (2005) Geological map, sheet Boe Klue (5247 III). Department of Mineral Resources, Thailand

Im-Erb R, Pongwichian P (2003) Salt-affected soils in Thailand. Workshop on the management of salt-affected soils. Department of Agriculture, Bangkok, Thailand, p 13

Im-Erb R, Yamclee P, Supanit T (2004) Integrated management for sustainable use of salt-affected soils/land degradation assessment in drylands in Thailand. Paper presented at regional workshop on integrated management for sustainable use of salt-affected soils/land degradation assessment in drylands “LADA” Harbin, Heilongjiang Province, People’s Republic of China, 11–14 June 2004

Labuda ZT, Baxter CA (2001) Mapping karst conditions using 2D and 3D resistivity imaging methods: In: Powers M (ed) Proceedings of the symposium on the application of geophysics to engineering and environmental problems, environmental and engineering geophysical society, CD-ROM, Paper GTV-1

Land Development Department (1993) Saline soils. Technical handbook. Land Development Department, Bangkok, p 343

Loke MH (1998) RES2DINV version 3.3: rapid 2D resistivity and IP inversion using the least-squares method. Computer disk and manual, Penang, Malaysia

Roth MJS, Mackey JR, Mackey C, Nyquist JE (1999) A case study of the reliability of multi-electrode earth resistivity testing for geotechnical investigations in karst terrains, In Beck BF, Pettit AJ, Herring JG (eds) Proceedings of the 7th multidisciplinary conference on sinkholes engineering and environmental impacts of karst, Balkema, pp 247–252

Sinanuwong S, Takaya Y (1974) Saline soil in Northeast Thailand: their possible origin as deduced from field evidence. Southeast Asia Study 12(1):105–120, Kyoto University, Japan

Chapter 5
Soil Salinity Mapping Using Multi-Temporal Satellite Images in Agricultural Fields of Syrdarya Province of Uzbekistan

Alexander Platonov, Andrew Noble, and Ramazan Kuziev

Abstract Almost 50% of the irrigated lands of Central Asia are affected by different levels of salinity. In extreme cases, the most severely affected lands are abandoned, while moderately saline lands produce low crop yields. Rehabilitation of the saline lands could have significant implications on productivity of irrigated lands as well as positive impacts on the environment. The assessment of the trend and the scale of salinity are crucial element in the development of a remediation/rehabilitation strategy. The traditional approach for soil salinity mapping is extremely costly and has low level of precision. The chapter discusses the approach in developing the soil salinity maps by analysis of vegetation stress from multi-temporal remote sensing data for irrigated areas.

Keywords NDVI • Remote sensing • Satellite images • Soil salinity • Vegetation stress

5.1 Introduction

In Central Asia, approximately 50% of the irrigated lands are affected by salinity – ranging from as high as 96% in Turkmenistan to about 12% in Kyrgyzstan (Bucknall et al. 2003). Anthropogenic soil salinity in the region is among the highest in the world, where about 25% of irrigated areas have been affected by salinity.

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Consequently, there is an urgent need to prevent further degradation of soils along with mitigating and reversing the extent of this insidious land degradation. In this context, the assessment and monitoring of salinity, both spatially and temporally, is an important step in the rehabilitation of degraded lands.

In the past, an extensive network of salinity monitoring and assessment systems of Central Asian countries was established in mid-1960s, when the Former Soviet Union (FSU) started its irrigation expansion program in Central Asia. The information on the scope and scale of salinity in the irrigated areas was presented through the preparation of annual salinity maps at 1:25,000 and 1:50,000 scales. For the monitoring of salinity within the irrigated areas, soil samples were collected (one soil sample being representative of 100–150 ha area) and their chemical attributes were determined. Declines in funding for soil salinity monitoring after the collapse of Soviet Union led to the decline in this monitoring program both in scale and scope of salinity in the irrigated areas of Central Asia, resulting in a coarse assessments of the extent of the problem.

There is growing confidence among researchers that the application of remote sensing and geographical information system (RS/GIS) tools for assessing and monitoring of soil salinity can be a reliable cost-effective means for soil salinity monitoring. Rao et al. (1998) demonstrated this capability using the Indian Remote Sensing (IRS) images through visual interpretation of the image elements (color, texture, shape, pattern, associations, etc.). For Jodhpur district of Rajasthan, India, the Landsat TM images were applied to distinguish saline-alkaline wastelands. They appear as whitish gray to yellowish gray, whitish gray to dull red, and milky white to dull white and light blue tones on TM false color composites (Singh et al. 1992).

In Cochabamba, Australia, the spectral similarity of reflectance from satellite images and the ground-based reflectance were used for identification of soil salinity (Metternich 1998). In Western Australia, salinity was mapped using the multitemporal Landsat TM satellite images and digital elevation models; areas of low vegetation intensity for several seasons were classified as likely to be saline areas (McFarlane and Williamson 2002). Soil salinity maps were prepared in western Yamuna Canal command area and Uttar Pradesh, India (Dwivedi 1994), through application of the Landsat TM images and extensive ground-truth data. Spectral planetary reflectance of TM bands for various land features (using ground-truth data) was retrieved and plotted; salinity mapping was based on the fact that crops in waterlogged areas had a lower reflectance than crops under non-waterlogged conditions, whereas crops in the salt-affected areas had a higher reflectance than crops in normal areas except in the near-infrared band. For Northeast Thailand, soil salinity was detected using Landsat 7 imagery combined with GIS soil layers and landforms (Sukchan and Yamamoto 1999). Metternich (2001) has proposed to map soil salinity distribution, using an integrated approach, which includes the multitemporal classification of remotely sensed data, physical and chemical soil properties, and land attributes.

This chapter presents the results of research conducted during the period 2005–2006 on the application of remote sensing and GIS tools for soil salinity mapping at field scale. The results acquired from remote sensing were cross-checked through intensively collected ground-truth data.

Table 5.1 Soil salinity classification based on ECe

Soil salinity classification	ECe (dS m^{-1})
Non-saline	<2
Low	2–4
Moderate	4–8
High	8–16
Very high	>16

5.1.1 Soil Salinity Measurements and Gradation

The term "soil salinity" is linked to the presence of soluble and readily dissolvable salts (mainly Na^+, Mg^{2+}, Ca^{2+}, K^+, Cl^-, SO_4^{2-}, HCO_3^-, NO_3^-, and CO_3^{2-}) within the soil in amounts that result in a decline in soil fertility and lead to the reduction of crops yield. In the Former Soviet Union countries, soil salinity was assessed on the basis of total dissolved salts (TDS) in aqueous soil extracts and/or the concentration of Cl^-, which is most harmful to crop growth. In other countries, soil salinity is quantified through a range of electrical conductivity measurement determined in different media: soil-water sample (ECw), saturated soil-paste extract (ECe), saturated soil-paste (ECp), and apparent or bulk soil electrical conductivity (ECa).

The classification of soil salinity (Bunbury and Pinjarra 2006), based on electrical conductivity of saturated soil-paste extract (ECe), is presented in Table 5.1.

5.2 Research Question and Methodology

A review of methodologies on salinity mapping through the application of remote sensing tools indicated two main approaches: analysis of reflectance from bare soil and analysis of vegetation stress by soil salinity. The first approach is widely used in many applications; in our investigation, the second approach was used, based on analysis of maximum multi-annual vegetation condition. Besides soil salinity and fertility, many other factors influence vegetation condition (amount of applied fertilizers, irrigation and precipitation, surface and groundwater availability, quality of seeds and depth of seeding, etc.). Consequently, the use of multi-annual satellite images for analysis of crops stress would tend to minimize the contribution of these factors.

The research question posed in this study is as follows: Does the values of maximum multi-annual Normalized Difference Vegetation Index (NDVI) reflect the degree of soil salinity within agricultural fields of Syrdarya province in Uzbekistan?

In order to assess the efficacy of remote sensing data in mapping soil salinity, the following steps were undertaken:

- Preprocessing of multi-annual seasonal satellite images (Landsat)
- Extensive ground-truth data collection (soil salinity measurements)

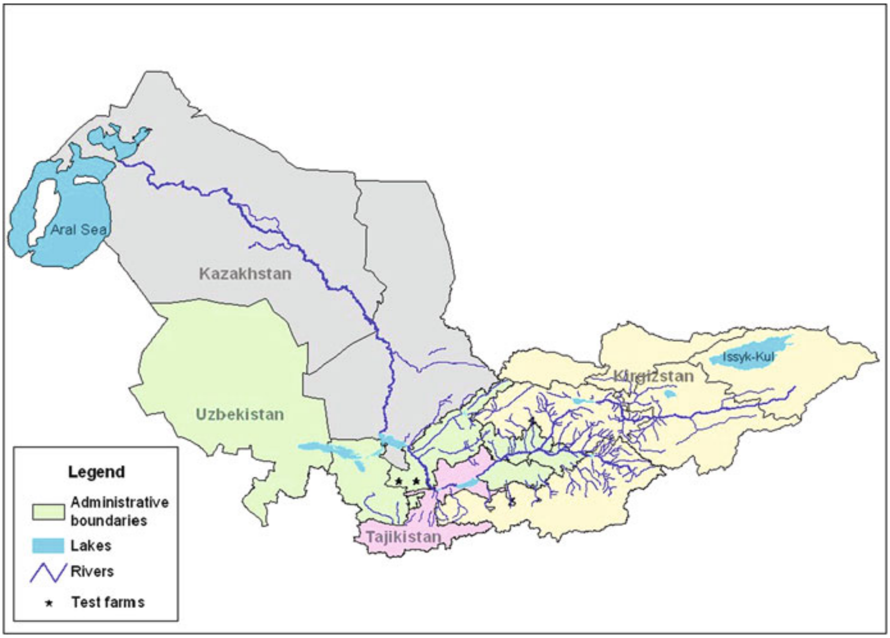

Fig. 5.1 Location of test farms within the Syrdarya river basin

- Calculation of NDVI raster layers from seasonal Landsat satellite images over the period 1998–2001 years
- Analysis of correlation between maximum multi-annual NDVI values and soil salinity measurements
- Creation of soil salinity maps, based on maximum multi-annual NDVI values

5.2.1 Study Area

The study area includes the fields of "Gafur Gulyam" (2000 ha) and "Galaba" (3200 ha) farms located in the western and central parts of Syrdarya province, situated in the middle reach of Syrdarya river (Fig. 5.1). The soils of the study area are mostly light and moderate loams of low fertility. According to data from the Hydro-Ameliorative Expedition, the soils are mainly low to moderately saline with patches of high salinity. The climate of the target area is sharply continental, with a maximum air temperature (up to 40°C), occurring in June–August, with the coldest month being January (up to −24°C). Mean annual precipitation (300 mm) falls during autumn-winter-spring time, and there is almost no rain during summer.

5.2.2 *Satellite Images Processing*

Seasonal Landsat 5 TM and Landsat 7 ETM satellite images of 1998–2001 representing the maximum development stage for main crops in Central Asia, winter wheat in April (L5_1998_0410, L5_1999_0429, L7_2000_0407, L7_2001_0427) and cotton in July–August (L5_1998_0816, L7_1999_0827, L7_2000_0829, L7_2001_0731), were used in this study. From each image, a subset for the test farm areas was made, and each subset was precisely georeferenced by using the reference points (intersection of roads, canals and collectors with roads) coordinate, measured by Garmin-12 GPS device. The multi-temporal satellite images were normalized by conversion of pixel's digital number (the raw solar energy, collected by sensor) to the radiance and at-satellite reflectance. For each satellite image, the Normalized Difference Vegetation Index (NDVI) raster layers were calculated using the following formula:

$$\text{NDVI} = (\text{Band4} - \text{Band3})/(\text{Band4} + \text{Band3})$$

On the basis of seasonal NDVI for each year, the annual maximum NDVI and the maximum for all annual NDVI raster layers were calculated. The range of annual maximum NDVI values was divided into 5 classes, linked to the soil salinity classification (non-saline, low, moderate, high, and very high salinity).

5.2.3 *The Ground-Truth Data*

The ground-truth data were collected within the fields of two farms, "Gafur Gulyam" (in 2005) and "Galaba" (in 2006), using two methods:

(a) Soil samples were collected in 2005 from 28 points within 26 fields of "Gafur Gulyam" farm from three depth intervals (0–30, 30–70, and 70–100 cm) for chemical analysis that included cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), anions (CO_3^{2-}, HCO_3^{-}, Cl^{-}, SO_4^{2-}), and TDS in the soil laboratory of the Scientific Research Institute of Irrigation in Central Asia.
(b) EM38 measurements were made in 2005 at 110 points within the same 26 fields of "Gafur Gulyam" farm and at 532 points within 38 fields of "Galaba" farm in 2006.

The selection of soil sampling and EM38 measurement points was based on a preliminary analysis of multi-temporal Landsat images within zones with different vegetation conditions (no, low, moderate, high, and very high vegetation).

The EM38 equipment has two modes for measurements of bulk soil electrical conductivity using electromagnetic induction: horizontal (average for 0–75 cm) and vertical (average for 0–150 cm soil horizon). Values of EM38 readings (mS m^{-1}) were divided by 100 to convert to ECa in units of dS m^{-1}, according to the EM38 manual (Geonics 1992).

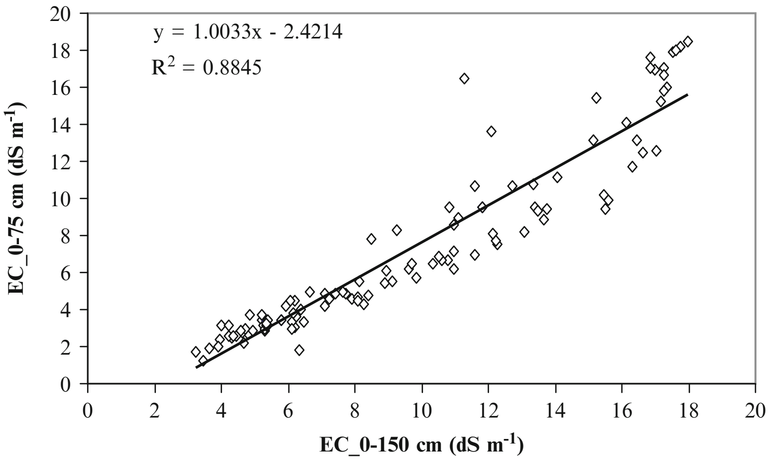

Fig. 5.2 Correlation between soil EC measurements by EM38 made in the vertical (0–150 cm) and horizontal (0–75 cm) modes

Table 5.2 The linear correlation coefficients between NDVI_Max, TDS, SumTS, and EM_h

	NDVI_Max	TDS	SumTS
TDS	0.185		
SumTS	0.309	0.878	
EM_h	0.277	0.517	0.502

A strong positive linear correlation was observed between EC measurements by EM38, made in vertical and horizontal modes (Fig. 5.2); hence, further analysis was confined to values obtained from the horizontal mode (0–75 cm), as this mode is representative for the maximum root depth (50 cm) of main crops in the target area.

5.3 Results and Discussion

5.3.1 Soil Sample Data, 2005 and NDVI Values

Based on chemical analysis of soil samples, the quantity of total dissolved salts (TDS) and sum of toxic salts (SumTS) was determined. The coefficients of linear correlation between multi-annual NDVI_Max, TDS, and SumTS at 0–70 cm soil depth and EC values, measured by EM38 in horizontal mode, are presented in Table 5.2.

All measured soil salinity parameters have low correlation coefficients with NDVI_Max.

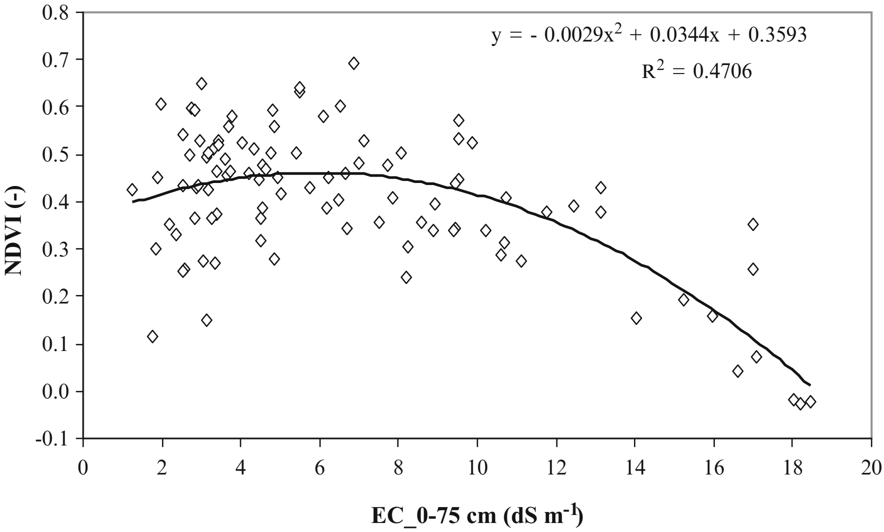

Fig. 5.3 The correlation between NDVI and EM38 measurements at 0–75 cm soil horizon

The spatial overlay of the GIS layer of points, where soil EC was measured by EM38 m, on the raster layers of maximum NDVI from multi-annual satellite images resulted in a polynomial relationship between NDVI and EM38 measurements (Fig. 5.3).

While the correlation between NDVI and soil EC measurements by EM38 is low, the following plausible explanation is put forward:

- Other factors (soil fertility, water availability, etc.) had an influence on maximum multi-annual NDVI values, especially in the range of low salinity (<4 dS m^{-1}).
- Incompatibility of spatial dimension of EM38 measurements on area of 1–2 m^2 with NDVI values that are calculated on 30×30 m pixel size.
- Very high spatial variability of soil salinity.

5.3.2 Analysis of Ground-Truth Data, 2006

5.3.2.1 Spatial Variability of Soil Salinity

To assess the spatial variability of soil, salinity fields with high salinity (visible patches of salt crust on the soil surface) and good vegetation condition were selected at “Galaba” farm. Within these fields, EM38 measurements were undertaken at several points (10–15 m distance between points). Figure 5.4 demonstrates the high spatial variability within fields in soil salinity measurements using EM38.

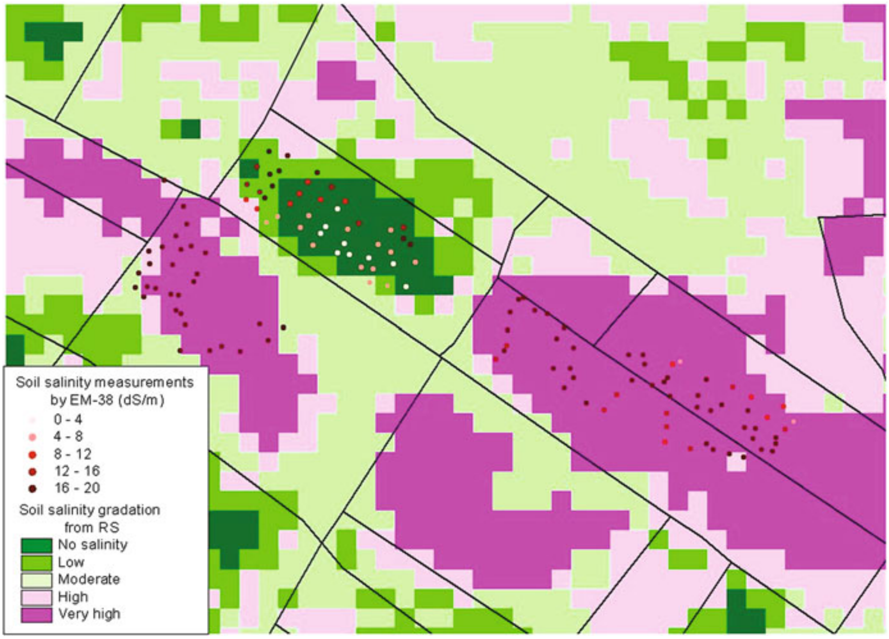

Fig. 5.4 The variability in soil salinity measurements using EM38

5.3.3 *The Field-Based Approach*

One way to resolve the problem of within-field soil salinity variability and to make it spatially compatible with NDVI from satellite images is to aggregate the values from both sources and then to use an average value as input for analysis. This approach was evaluated on fields of "Gafur Gulyam" farm (data of 2005 year). For each test field, the average EM_h (0–75 cm) was calculated and analyzed along with associated NDVI values. The coefficient of linear correlation between EM38 measurements and NDVI, average for field (Fig. 5.5) was slightly improved ($r^2 = 0.5825$). The number of measurement points within each test field of "Gafur Gulyam" farm (approximately 4 points per field) could be viewed as too low.

The same approach was applied in the calculation of an average for field values using 532 EM38 measurement points in 2006 year, within 38 fields of "Galaba" farm. Figure 5.6 indicates the more improved relationship between EM38 measurements and NDVI, average for test fields of "Galaba" farm.

5.3.4 *Soil Salinity Maps for Test Farms*

Soil salinity maps for "Gafur Gulyam" (Fig. 5.7) and "Galaba" (Fig. 5.8) farms are created by using (a) the traditional method of soil sampling and chemical analysis of

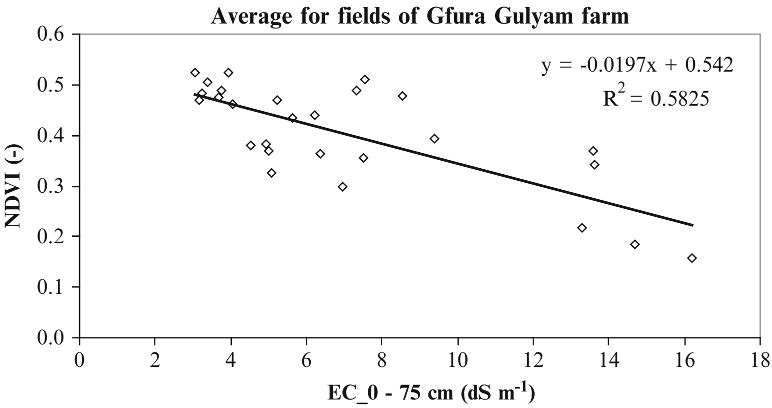

Fig. 5.5 Correlation between EM38 measurements at 0–75 cm (EM_h) and NDVI, average for fields of Gafur Gulyam farm

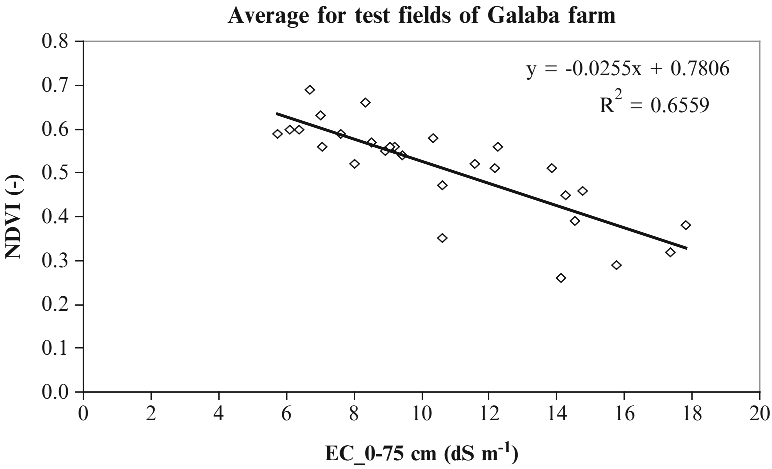

Fig. 5.6 Correlation between EM38 measurements at 0–75 cm (EM_h) and NDVI, average for fields of Galaba farm

soil samples, and (b) the maximum NDVI from multi-temporal Landsat satellite images demonstrates the different result of these methods. Using a limited number of sampling points by traditional method resulted in a generalized soil salinity map that often does not reflect the real situation. By calculating the maximum multi-annual NDVI values from satellite images, one can create more spatially detailed soil salinity maps using two methods: the pixel-based (Fig. 5.7b) and the average for fields (Fig. 5.8b). The spatial resolution of Landsat images is 30×30 m (approximately 11 pixels per ha).

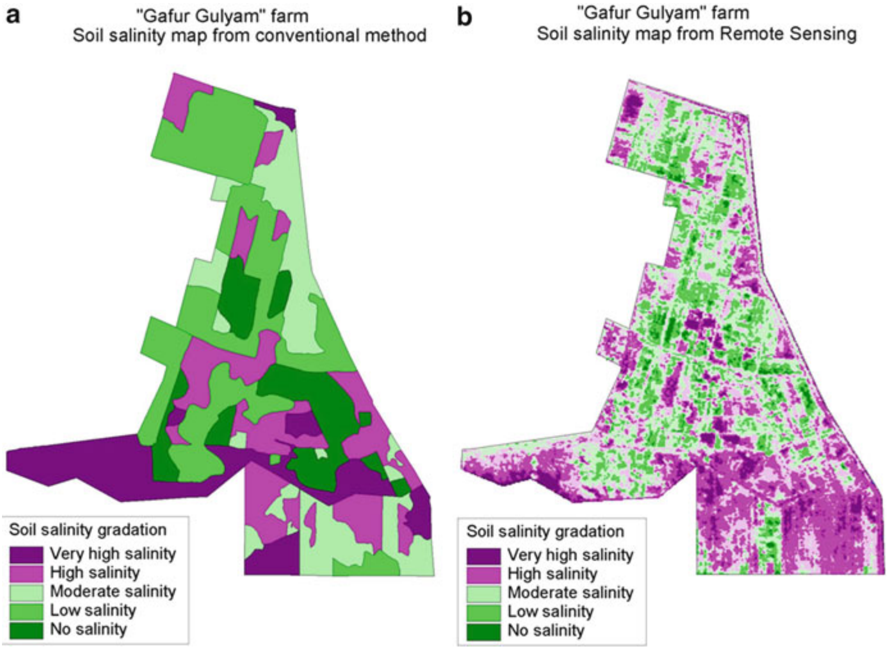

Fig. 5.7 Soil salinity maps of "Gafur Gulyam" farm created by (**a**) conventional method and (**b**) RS/GIS application

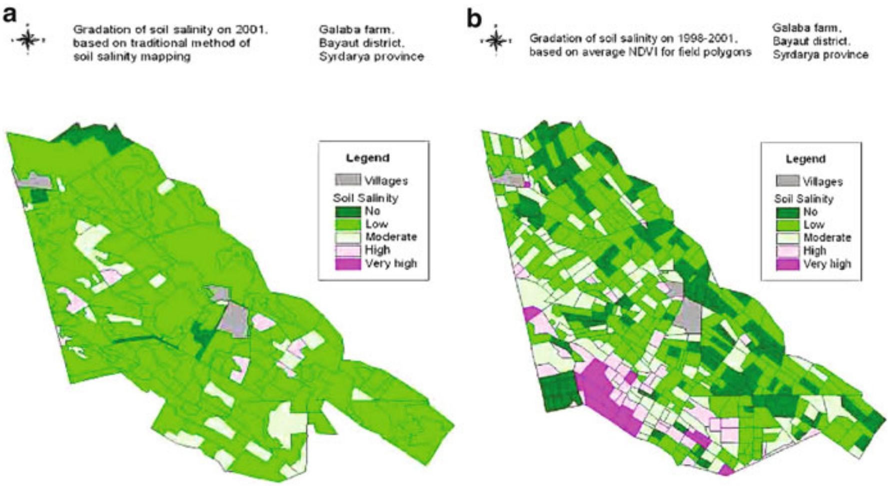

Fig. 5.8 Soil salinity maps of Galaba farm created by (**a**) conventional method and (**b**) RS/GIS application

5.4 Conclusion and Recommendations

Soil sampling is a costly, time- and labor-consuming activity with the average norm for soil sampling being 15–20 points per day by one soil specialist and two workers. The average cost of chemical analysis per sample is US$ 1.5; for the Galaba farm (3200 ha), it would require US$ 4800 and 160 days of fieldwork to undertake a survey of soil salinity.

The Landsat satellite images are freely available now from Internet (http://glovis.usgs.gov/).

Consequently, using GIS and RS for soil salinity mapping is extremely cost-effective with a higher degree of spatial accuracy.

To reduce the cost of soil salinity mapping for irrigated areas, the recommendations are:

- To use the multi-temporal satellite images for creation of soil salinity map
- To collect the soil samples from limited amount of points inside the fields with different gradation of soil salinity from soil salinity map

Use of this approach will increase the accuracy of soil salinity map with minimum expenditures on soil sampling.

Acknowledgments This study was carried out within the scope of an Asian Development Bank (ADB)-funded RETA project “Enabling Communities in the Aral Sea Basin to Combat Land and Water Resource Degradation Through the Creation of ‘Bright’ Spots.” The project was implemented jointly by International Water Management Institute (IWMI), International Center for Agricultural Research in the Dry Areas (ICARDA), and International Center for Biosaline Agriculture (ICBA) in Kazakhstan, Turkmenistan, and Uzbekistan.

References

Bucknall J, Klychnikova I, Lampetti J, Lundell M, Scatasta M, Thurman M (2003) Irrigation in Central Asia. Social, economic and environmental considerations. The World Bank, Washington, DC. (http://www.worldbank.org/eca/environment)

Bunbury RG, Pinjarra RD (2006) Estimating the extent of salinity. http://www.agric.wa.gov.au/PC_92353.html?s=0

Dwivedi RS (1994) Study of salinity and waterlogging in Uttar Pradesh (India) using remote sensing data. Land Degrad Rehabil 5:191–199

Geonics (1992) EM 38 operating manual. Geonics Limited, Mississauga

McFarlane DJ, Williamson DR (2002) An overview of waterlogging and salinity in Southwestern Australia as related to the “Ucarro” experimental catchment. Agric Water Manag 53:5–29

Metternich GI (1998) Analyzing the relationship between ground-based reflectance and environmental indicators of salinity processes in the Cochabamba. Int J Ecol Environ Sci 24:359–370

Metternich GI (2001) Assessing temporal and spatial changes of salinity using Fuzzy logic, remote sensing and GIS. Ecol Model 144:163–179

Rao BRM, Dwivedi RS, Sreenivas K, Khan QI, Ramana KV, Thammappa SS, Fyzee MA (1998) An inventory of salt-affected soils and waterlogged areas in the Nagarjunsagar Canal command area of Southern India, using space-borne multi-spectral data. Land Degrad Dev 9:357–367
Singh N, Singh S, Sharma KD (1992) Identification and mapping saline-alkali wastelands in Jodhpur district, Western Rajasthan, using remote sensing techniques. Ann Arid Zone 31(4):247–254
Sukchan S, Yamamoto Y (1999) Classification of salt affected areas using remote sensing and GIS. JIRCAS Work Rep 30:15–19

Chapter 6
The New Map of Soil Salinity and Regularities in Distribution of Salt-Affected Soils in Russia

Ye. I. Pankova, A.F. Novikova, and A. Kontoboytseva

Abstract Among the numerous adverse processes related to the soil and the environment is the soil salinization, which affects more extended areas posing a real global problem. This chapter presents a new soil salinity map, which was compiled with the aim of specifying the information on geographical distribution and peculiar features of soil salinization in the vast areas of the Russian Federation. The new map of soil salinity as well as the map of chemical composition in salinization at a scale of 1:2,500,000 allowed identifying the main regularities in geographical distribution and genesis of salt-affected soils in Russia. This information helps to give the comparative characteristics of soil salinization in different regions of the country.

Keywords Geographical distribution • New map • Regularities • Russia • Soil salinity

6.1 Introduction

Salt-affected soils and their mapping have acquired primary importance in soil research of Russia. The salt-affected soils of different genesis are widely distributed in the south of Russia within semidesert, dry steppe, steppe zones and in the forest-steppe zone to a lesser extent (Fig. 6.1). They occur also less frequent in northern coastal areas of the White Sea, Kara Sea, Laptev Sea, etc.

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Fig. 6.1 Schematic map of the distribution of salt-affected soils in Russia (1)

In 1946, the first schematic map has been published to show the current salt accumulation in the soils of Russia (Kovda 1946); the map of soda salinization appeared in 1963 (Kondorskaya 1965). The small-scale map (1:2,500,000) of soil salinity types at the territory of the former Soviet Union was published on Kovda's initiative within the framework of FAO/UNESCO project in 1976. This project was implemented under the guidance of Prof. Szabolcs as a chairman of International Subcommission on Soil Salinization of the International Society of Soil Science (ISSS) with the aim of compiling the maps of salt-affected soils in different regions of the world. The obtained results were published in a monograph (Szabolcs 1989) that provided information on the global distribution of salt-affected soils and peculiar features of soil salinity throughout the world.

The above map allowed studying the main regularities in the distribution of salt-affected soils in Russia. It was established that the soil salinization is often associated with the solonetz (sodicity) process. The vast areas of deeply (100–200 cm) saline soils were shown on this map for the first time, because this fact has not been taken into account in cadastre surveys. The regions were identified as dominated by a definite type of salt chemical composition; at the same time, it was shown that the soils of different salinization occur in the same region (Fig. 6.1).

However, this map demonstrated the chemical composition of soil salinization in a general way, thus reflecting peculiar features of salinization in the main soil types of different country's regions only on qualitative level. It was impossible to estimate the percentage of areas covered by salt-affected soils using this map. Some data were given in a very schematic form. For example, solonetz soils have not been differentiated according to their percentage in the soil cover; the soil salinization degree was not indicated.

Lately, new results have been obtained on salt-affected soils; new mapping materials and data of remote monitoring have made it imperative to compile a new map of salt-affected soils in Russia.

6.2 Materials and Methods

The creation of new soil salinity map was aimed to obtain more accurate data about geographical distribution and specific features of soil salinity not only in the total area of the country but also in all the natural zones and economic and administrative regions. This problem has received attention because the process of secondary salinization became accelerating due to human-induced soil degradation especially in southern arid regions of Russia. Moreover, this map can be considered as a set of soil-ecological maps, reflecting properties and processes that have restricted the soil productivity and fertility of croplands. In compiling the new map, various cartographic materials obtained in the 1980s–1990s, original and literature data were used. The soil map of the Russian Federation at a scale of 1:2,500,000 (1988) was applicable as a contour base for the map under consideration. Herewith, the contours of salt-affected soils were specified using the map of soil reclamation at a scale of 1:500,000 compiled in 1987. In some cases, the pattern configurations were changed and being added by new information on saline soils. In regions where the soils are not affected by salinization, the soil contours were partially generalized. Under use were also the soil, lithologic-geomorphological maps, the maps of soil geographical and natural regionalization, characterized the complex of natural conditions and factors responsible for the development of salt-affected soils.

To the salt-affected soils identified on the map, we relate all the soils of different genetic types, which contain the water-soluble salts in the amount exceeding the toxicity threshold for crops characterized by moderate salt tolerance at least in one horizon of 2-m-thick profile. According to analytical data about the soil/water extracts (1:5), this threshold is >0.3 meq/100 g soil for Cl^- ion, >1.7 meq/100 g soil for SO_4^{2-} ion (bonded to Na^+ and Mg^{2+}), and >1 meq/100 g soil for HCO_3^- ion (bonded to Na^+ and Mg^{2+}).

The salt-affected soils are grouped into proper saline and saline-solonetz ones. The salt-affected soils delineated on the map are distinguished according to (1) the depth of the upper boundary of the salt-bearing horizon, (2) the percentage of soils with salts in the upper 1-m layer in the soil contour, (3) the chemical composition of salts and the percentage of moderately and strongly saline soils in the soil cover, and (4) the percentage of solonetzes and solonetzic soils in the soil contour.

The above information cannot be shown clearly on a single map, so it was decided to compile a set of maps comprising (1) a map of saline, deeply saline, and potential saline soils indicating their percentage in the soil contour; (2) a map of the salt chemical composition taking into account the percentage of moderately and strongly saline soils in the soil cover structure; and (3) a map of solonetzes and solonetzic soils. The soil map was taken as a basis for all the maps of salt-affected soils. Every contour delineated on the map shows the soil cover structure represented by the percentage of different soils. The soil nomenclature is well agreed with classification and diagnostics of soils adopted in Russia in 1977 and shown in the soil map (1:2,500,000) of the Russian Federation (1988). In the final version of the map, the synonyms of soil names are given according to the new Classification of Russian Soils (2004).

The new map of soil salinization in Russia reflects the percentage of soils containing salts in the upper 1-m layer and the areas of deeply and potential saline soils. As a rule, the soil contours, containing saline soils, reveal their heterogeneity being composed of two or three different soils; their percentage in the area is shown by dots under the soil index: 3 dots indicate 50–25% of salt-affected soils, two dots for 25–10%, and one dot for 10–1%. When saline soils occupy very small areas, they are not included in the soil index being shown by the out-of-scale symbols.

The sandy-loamy and sandy soils as well as sands and stony soils are identified in the soil map; loamy and clay texture does not show on it. Soils of mountain areas are given by traditional diagonal hatching.

6.3 Results and Discussion

The main information presented in the soil salinity map is the percentage of soils affected by salt accumulation in the upper 1-m layer as well as the areas occupied by deeply and potential saline soils.

Depending on the depth of the upper boundary of the salt-bearing horizon, saline soils are divided into the following way: (1) saline soils containing the salts in the upper 1-m layer; (2) deeply saline soils, in which the upper boundary of salinization is within the 100–200-cm soil layer; and (3) potential saline soils (the upper boundary of salt-bearing horizon is in the 200- to 500-cm-deep layer). The latter may be not assigned to the group of saline soils properly at the moment due to their observation; however, the salt-bearing bedrocks serve as evidence of possible occurrence of the secondary salinization. Saline soils and namely those containing the salts in the upper 1-m layer are divided into solonchak (surface saline) and solonchak-like soils (saline in the middle of the soil profile). Saline soils may comprise more than 75, 75–50, 50–25, 25–10%, or less than 10% of the soil contour. Local occurrence of soil salinization is shown by conventional symbols. Deeply and potential saline soils are not specified with respect to their percentage in mapping areas.

This map reflects only the soils affected by salts within the upper 1-m layer, that is, solonchak and solonchak-like soils. The percentage of moderately and strongly saline soils in every soil contour is also given (more than 50, 50–25, 25–10, and <10%). The soil contours revealing no moderately and strongly saline soils are identified; the percentage of slightly saline soils (more than 10%) is given on the map.

The map provides the information on chemical composition of salts in soils. The soil salinization degree with respect to chemical composition of salts is estimated according to indices presented in Table 6.1.

The maps compiled in such a way allowed identifying regularities in distribution of the salt-affected soils within the natural zones of different regions in Russia.

6.3.1 Zonal Regularities in the Distribution of Salt-Affected Soils

In Russia, the salt-affected soils are widespread in the south of the European part of the country, in the Ural, in Western and Eastern Siberia. Every region is characterized

Table 6.1 Classification of soils according to the degree and type of salinization (in numerator, toxic salts[a] in denomerator); data in parentheses correspond to salinization degree in gypsum-bearing soils ($CaSO_4 2H_2O > 1\%$); water extract (1:5)

Soil salinization degree	Chemical composition of salts (ion ratios, meq/100 g soil)					
	Neutral salinization, pH < 8.5		Alkaline salinization, pH > 8.5		Bicarbonate-alkaline salinization	
	Chloride, sulfate-chloride	Chloride-sulfate	Sulfate	Soda and soda-chloride	Sulfate-soda and soda-sulfate	Sulfate-chloride-bicarbonate
	$Cl:SO_4 > 1$	$Cl:SO_4$ 1–0.2	$Cl:SO_4 < 0.2$	$Cl:SO_4 > 1$; $HCO_3 > Ca + Mg$; $HCO_3 > Cl$	$Cl:SO_4 < 1$; $HCO_3 > Ca + Mg$; $HCO_3 > Cl$	$HCO_3 > Cl$; $HCO_3 > SO_4$; $HCO_3 < Ca + Mg$
Toxicity threshold (non-saline soils)	< 0.1 / < 0.05	< 0.2 / < 0.1	< 0.3(1.0) / < 0.15	< 0.1 / < 0.05	< 0.15 / < 0.15	< 0.2 / < 0.15
Slight	< 0.1 – 0.2 / 0.05 – 0.12	0.2 – 0.4(0.6) / 0.1 – 0.25	0.3(1.0) – 0.6(1.2) / 0.15 – 0.3	0.1 – 0.2 / 0.05 – 0.15	0.15 – 0.25 / 0.15 – 0.25	0.2 – 0.4 / 0.15 – 0.3
Moderate	0.2 – 0.4 / 0.12 – 0.35	0.4(0.6) – 0.6(0.9) / 0.25 – 0.5	0.6(1.2) – 0.8(1.5) / 0.3 – 0.6	0.2 – 0.3 / 0.15 – 0.3	0.25 – 0.4 / 0.25 – 0.4	0.4 – 0.5 / 0.3 – 0.5
Strong	0.4 – 0.8 / 0.35 – 0.7	0.6(0.9) – 1.0(1.4) / 0.5 – 1.0	0.8(1.5) – 1.5(2.0) / 0.6 – 1.5	0.3 – 0.5 / 0.3 – 0.5	0.4 – 0.6 / 0.4 – 0.6	Not found
Very strong	> 0.8 / > 0.7	> 1.0(1.4) / > 1.0	> 1.5(2.0) / > 1.5	> 0.5 / > 0.5	> 0.6 / > 0.6	-``-

[a]Sum of toxic salts is equal to the sum of toxic ions given in percent: Σ tox. salts (%) = ($Cl + Na + Mg + SO_4$ tox + HCO_3 tox), %. Ions of Cl, Na, Mg are toxic; HCO_3 tox = HCO_3 total – Ca; SO_4 tox = SO_4 total – (Cl – HCO_3). Calculation of the sum of toxic ions is performed in mmol; data are transformed into percentage and summed up. In the map the soils are shown as affected predominantly by chloride and sulfate salts and soda. There is also a group of soils, containing chlorides and sulfates with soda. This group includes (1) soils with soda traces only in the solonetz horizon (according to data of water extract 1:5) and neutral salinization in the other parts of the soil profile and (2) soils with a small content of soda throughout the soil profile against the background of chloride and sulfate salinization

by different natural conditions providing a clear evidence of provincial features, which are rather peculiar for the development of salt-affected soils (Pankova et al. 2006).

In European Russia, the percentage of salt-affected soils is increasing south- and eastwards. Within the forest-steppe zone, the local salinization occurs predominantly under semi-hydromorphic and hydromorphic conditions, being caused by close depth of salt-bearing clays in flat areas and close level of slightly saline groundwaters under conditions of weakly expressed drainage. Sodium sulfates frequently with soda are dominant in the composition of water-soluble salts. The salt-affected and moderately saline soils are represented by meadow chernozems and solonetzes accounting for 1–10 to 25% in soil contours.

In the steppe zone of European Russia, the salinization is developed under automorphic conditions. The salt-affected soils are estimated as 1–25% and represented by solonetzic chernozems and meadow-chernozem moderately saline soils. Dominant is the sulfate type of salinization. The strongly saline soils are observed under hydromorphic conditions in the Kuban and Don deltas. The chemical composition of salinization varies from sulfate-chloride to chloride-sulfate. In the Don Valley, the salinization is sodium-sulfate and sulfate-sodium. The huge areas are occupied by deep and potential saline soils. The basic source of salinization is the close depth of saline parent materials or groundwaters. The human-induced factor is also responsible for soil salinization – the secondary hydromorphism and irrigation. In the Kuban delta, the hydromorphic salt-affected soils have been developed as resulted from periodical flooding by seawaters.

Widespread are such soils within the dry steppe and semidesert zones, where all the soils are practically affected by salinization at different depths. They are estimated as 25–75% in the soil contour being represented by soils of solonetz complexes. In these zones, soils are developed not only moderately saline but also surface saline containing the salts in the upper 0–30-cm layer. Peculiar features of natural conditions in these zones are the climate aridity and rather wide distribution of saline soil-forming rocks frequently covered by saline loess-like loams. The majority of soils are affected by salinization in the above zones, where the strongly saline soils are confined to Ergeni and Manych depressions and the Pre-Caspian lowland. Among the salt-affected soils, dominant are automorphic soils of chloride-sulfate and sulfate-chloride salinization often with soda in the middle part of the soil profile. The semi-hydromorphic and hydromorphic strongly saline soils are widely spread in Manych depression, at the territory of Tersko-Kumskaya lowland, in plains of Terek and Sulaka, Volga deltas, and in the coastal zone of the Caspian Sea.

In the Pre-Caspian lowland within the semidesert zone, the strongly saline soils with chloride chemical composition prevail; in Terek and Sulaka floodplains, the chemical composition of salinization varies from sodium to sulfate and chloride. The surface saline soils occupy about 50% of the total area in steppe and dry steppe zones and 70–90% in the Pre-Caspian lowland. Within the steppe zone in the south of European Russia, the deeply and potential saline soils are predominant.

Widespread are the salt-affected soils in the Trans-Ural region. They are also met in the Pre-Ural region, the latter being considered as a transitional zone between the Russian plain and the Ural Mountains. The soil cover pattern and peculiar distribution of salt-affected soils and their chemical composition are determined by geographical location and the development history of this territory. Like as in European part, the soil salinization is increasing here from the north to the south and eastwards.

In the steppe zone of the Pre-Ural region, the percentage of salt-affected soils and solonetzes makes up 1–10 and 10–25%, respectively, and only in the south within the dry steppe zone, they occupy over 75% of the total area being represented by automorphic and semi-hydromorphic solonetzes. The soil salinization is associated with distribution of saline neogenic-paleogenic clays and the salt redistribution at the soil surface under conditions of weakly expressed drainage.

In the steppe zone of ordinary and southern chernozems as well as in the zone of dry steppes represented by dark-chestnut and chestnut soils, the sulfate salinization is prevailing, and only in the south, it is by chloride type.

At the territory of the Trans-Ural region and West-Siberian lowland, the salt-affected soils are widely spread in the forest steppe and especially in steppe and dry steppe zones. The salinization is resulted from saline neogenic soil-forming rocks covered frequently by fluvial-alluvial deposits as well as from the close groundwater level in non-drained and slightly drained areas. Within the forest-steppe zone in flat almost non-drained interfluve areas, the hydromorphic and semi-hydromorphic saline soils are predominated and characterized by sodium together with soda and sulfate salinization. They occupy 1–10 and 10–25% of the total area, respectively.

The soil salinization is increasing in the steppe zone and especially in dry steppe zone occupying an insignificant part of the southwestern Trans-Ural region. In the steppe zone, the salt-affected soils are developed under hydromorphic and semi-hydromorphic conditions and estimated as 1–10 and 10–25% in the northern part to 50–70% in southern and eastern part of this region. The salinization is predominantly chloride and sulfate; in the eastern part of the Trans-Ural region, it is sodium with participation of soda. In the dry steppe zone of the extreme southwestern Trans-Ural region, the salt-affected soils occupy more than 75% of the total area. Their salinization is mainly sulfate.

Among the salt-affected soils in the Pre- and Trans-Ural regions, widespread are moderately saline soils; deeply and potential saline soils take place as well.

Western Siberia is a natural region characterized by manifestation of recent salt processes. The hydromorphic saline soils with sodium chemical composition occur. The soil salinization is frequently associated with the solonetz process and conditioned by salt accumulation for a long period of time in depressions. At present, the salt redistribution takes place in landscape. Under hydromorphic conditions, soda appears as a result of recent soil-forming processes – sulfate reduction. According to investigation data obtained in the latest years, the aeolian process is recognized as a main salt source in Western Siberia.

The salt-affected soils of Western Siberia are confined to insufficiently wet parts of the forest-steppe and steppe zones. They account for 50–75% of the total area being represented by hydromorphic moderately and surface saline soils in depressions. Under automorphic conditions, the salt-affected soils make up not more than 20%, and their salinization degree is significantly lower. Widespread are the potential saline soils represented by a great variety of chernozems. At the territory under moistened conditions – in the southern taiga zone, in Pre-Altai steppes, and in the piedmont area – the salt-affected soils occupy the river floodplains and closed territories accounting for 20% in soil contours.

Within the dry steppe zone of Western Siberia, the salt-affected soils are estimated as more than 75% being prevailed by surface and moderately saline soils. In elevated relief elements, dark-chestnut potential saline soils are concentrated. The degree, depth, and the chemical composition of soil salinization are determined both by recent geomorphological conditions and the history of the landscape development.

The salt-affected soils in the southern taiga that has been considered as a slightly elevated area of salt accumulation in the past contain an insignificant amount of water-soluble salts in the topsoil now. Their salinization is hydrocarbonate-sodium. In depressions, the soils are developed as characterized by chloride and sulfate salinization frequently with soda.

In central forest-steppe and steppe zones of West-Siberian lowland, the salt accumulation is conditioned by peculiar features of relief and the moisture regime. Being in autonomous position, they are characterized by slightly sodium or sodium-sulfate chemical composition. The deeply saline soils are met in such landscapes. In trans-accumulative (gently sloping) landscapes, the relief is responsible for soil chemical composition. In upper parts of slopes, the salinization is sodium and sulfate-sodium, whereas in middle and lower parts, it varies from sodium to chloride. The salt-affected soils confined to depressions within accumulative landscapes in the southern part of the steppe zone are characterized by chloride and sulfate salinization. In the dry steppe zone, the soils have neutral salinization with soda; in rare cases, their salinization is chloride or sulfate.

At the current stage of the development taking place at the territory of Western Siberia, there is a tendency toward dissolution of automorphic and salinization of accumulative landscapes.

Special attention should be paid to the salt-affected soils of Eastern Siberia and the Far East (Pre-Baikal, Trans-Baikal regions, and Yakutia). These soils are developed in depressions of steppe and dry steppe landscapes under conditions of semi-arid and arid climate. Their distribution is limited being associated with hydromorphic and semi-hydromorphic conditions. Such soils occupied the zones of tectonic faults; groundwater outcrops are mainly represented by moderately saline soils of different genesis. Their area exceeds 75% of soil contours. The deeply and potential saline soils such as southern solonetzic chernozems and chestnut soils are widely spread especially in the southern part of this region. The sulfate salinization is dominant in the Pre-Baikal region. The soils with different chemical composition including sodium salinization are met at the territory of Trans-Baikal region. However, the soil salinization has been so far examined insufficiently in the given region.

The salt-affected soils of Yakutia attract special attention. This is the most northern region where the salt-affected soils found their distribution. Their genesis and geography are mainly associated with climatic, hydrogeological, and lithologic-geomorphological conditions as well as the permafrost and the impact rendered by southern seas on coastal areas. The salt-affected soils are predominantly concentrated within Central-Yakutia plain and confined to closed depressions on the Lena river terraces and its tributaries. They are represented by frost solonchaks, solonetzes, meadow-chernozem, meadow, and alluvial soils of chloride-sulfate and rare chloride-sodium and sodium-sulfate salinization.

The marsh soils of Northern Yakutia are observed in coastal areas of the Arctic Ocean and characterized by chloride salinization.

There exists a local distribution of salt-affected soils in the Far East. They are predominantly developed in the southern part of this region (in Pre-Khanka lowland, in river valleys and lake terraces, in coastal areas and terraces of the Japan and Okhotsk Seas). The genesis of soil salinization is quite different there. The continental soils have the hydrocarbonate-sodium salinization due to outcrops of salt-bearing rocks. The salinization of coastal marsh soils is chloride being affected by seawaters and salt impulverization.

Apart from Yakutia, the salt-affected soils are also developed in the coastal zone of Northern Seas particularly on seashores of the White and Karsk Seas within the Northern Dvina delta. They are rarely met in coastal plains of the Barents, Chukotsk, and Laptev Seas.

Thus, the coastal plain zones of Northern Seas reveal the presence of salt-affected soils; however, like the soils of the Far East, they have been so far studied insufficiently.

The genesis and chemical composition of soil salinization (chloride) in coastal plains are determined by shore relief, composition of seawaters, and climatic parameters of the given territory. Not only marsh soils but also the soils of coastal meadows and terraces are affected by salinization resulting from groundwaters and salt impoverization.

The maps under discussion are exemplified by fragments for Kalmyk Republic and Astrakhan region, situated in the southeast of European Russia (Figs. 6.2 and 6.3).

As is evident from Fig. 6.2, the major part of the area suffers from salinization. The salt-affected soils in the north of Pre-Caspian lowland are referred to a group of solonchak soils; huge areas of Ergeni upland are occupied by solonchak-like soils; in the south (Chernosemelskaya and Astrakhan plains), the sands with traces of salt-affected soils are observed. The legend used in Fig. 6.2 is described as saline soils (the upper boundary of salt-bearing horizon is in the 0–1-m-deep layer): (1) The share of saline soils is >75%; the upper boundary of salt-bearing horizon is at a depth of less than 30 cm. (2) The share of saline soils is >75%; the upper boundary of salt-bearing horizon is in the 30–100-cm-deep layer. (3) The share of saline soils is 75–50%; the upper boundary of the salt-bearing horizon is at a depth of less than 30 cm. (4) The share of saline soils is 50–25%; the upper boundary of salt-bearing horizon is at a depth of less than 30 cm. (5) The share of saline soils is 50–25%; the upper boundary of the salt-bearing horizon is in the 30- to 100-cm-deep layer. (6) The share of saline soils is 25–10%; the upper boundary of the salt-bearing horizon is at a depth of less than 30 cm. (7) The share of saline soils is 25–10%; the upper

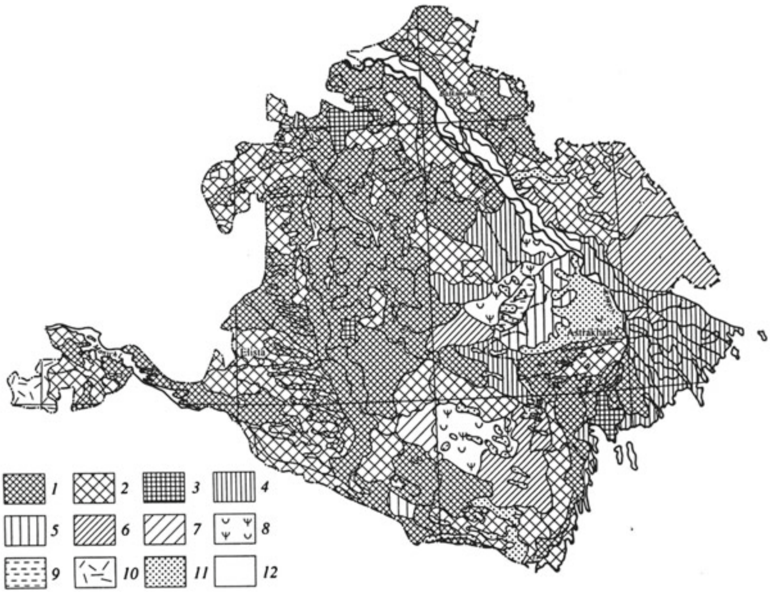

Fig. 6.2 Map of deep and potentially saline soils in the Kalmyk Republic and Astrakhan oblast

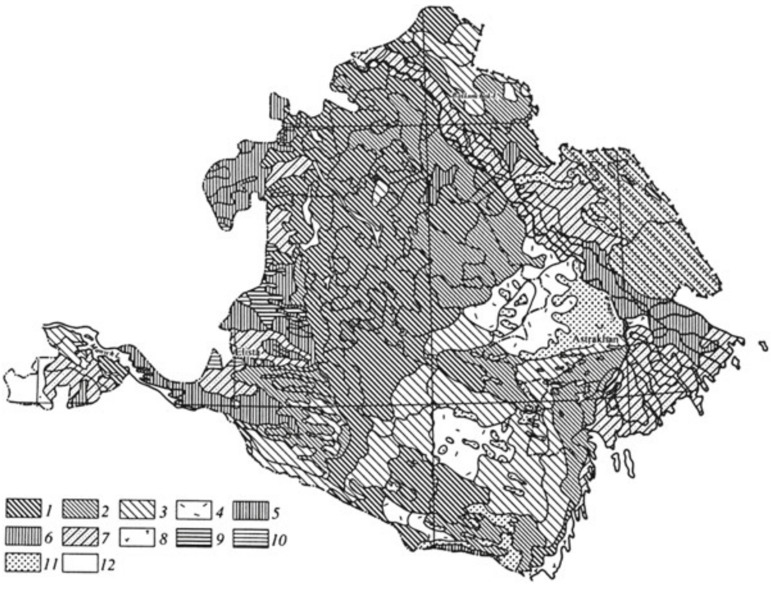

Fig. 6.3 Map of salt composition and the ratio of moderately and strongly saline soils in the soil cover of the Kalmyk Republic and Astrakhan oblast

boundary of salt-bearing horizon is in the 30- to 100-cm-deep layer. (8) The share of saline soils is <10%; the upper boundary of salt-bearing horizon is in the 0–30- or 30–100-cm-deep layer. (9) In deeply saline soils, the upper boundary of the salt-bearing horizon is in the 100–200-cm-deep layer without taking into consideration their percentage in the area. (10) In potentially saline soils, the upper boundary of the salt-bearing horizon is in the 200–500-cm-deep layer without taking into consideration their percentage in the area; Mainly non-saline soils: (11) sands and (12) non-saline soils of various textures.

In Fig. 6.3, the soil grouping is given according to chemical composition of salts and percentage of moderately and strongly saline soils at the territory of Kalmykia and Astrakhan region. The soils are highly affected by chloride salinization. In Ergeni upland, the sulfate saline soils sometimes with soda are dominant.

The legend used in Fig. 6.3 is described as: Soils of predominating chloride salinization ($Cl > SO_4$; $HCO_3 < Ca + Mg$); shares of moderately and strongly saline soils, (1) >50, (2) 25–50, (3) 25–10, (4) <10% (or slightly saline soils >10%). Soils of predominating chloride-sulfate and sulfate salinization ($SO_4 < Cl$; $HCO_3 < Ca + Mg$); shares of moderately and strongly saline soils, (5) >50, (6) 50–25, (7) 25–10, (8) <10% (or slightly saline soils > 10%). Soils with predomination of chlorides or sulfates but with soda ($HCO_3 > Ca + Mg$; $Cl > HCO_3$ or $SO_4 > HCO_3$); shares of moderately and strongly saline soils, (9) >50, (10) 50–25%. Mainly non-saline soils: (11) sands and (12) non-saline soils of various textures.

Figure 6.4 illustrates the distribution of solonetz and solonetzic soils. The solonetz soils are not divided according to zonal features in soil classification and diagnostics adopted in Russia; however, they occur in composition of zonal soils being regarded as chernozem solonetzes in the steppe zone, chestnut solonetzes in the dry steppe zone, and brown desert-steppe solonetzes in the semidesert zone. Moreover, in the map, the solonetz soils are divided according to the hydromorphism degree including automorphic, semi-hydromorphic, and hydromorphic ones. But the map provides the main information – the percentage of solonetz soils: >50, 50–25, 25–10%, and less than 10%. Thus, solonetz soils are widely spread at the territory under consideration, and their percentage varies from more than 50% to less than 10% being automorphic and semi-hydromorphic by nature. It is interesting to stress that these soils display peculiar salinization. They are different according to the depth of salinization and the salt composition. Among them are met the chloride or sulfate saline soils; frequently, the solonetz and subsolonetz horizons reveal the presence of soda.

The legend used in Fig. 6.4 is described as: Chernozemic zone: (1) chernozems with participation of meadow-chernozemic solonetzic soils (<10%). Zone of chestnut soils: (2) automorphic solonetzes (>50%), (3) automorphic solonetzes (50–25%), (4) automorphic solonetzes (25–10%), (5) automorphic solonetzes (<10%), (6) semi-hydromorphic solonetzes (>50%), (7) semi-hydromorphic solonetzes (50–25%), (8) semi-hydromorphic solonetzes (25–10%), and (9) hydromorphic solonetzes (meadow solonetzes) (>50%). Zone of brown desert-steppe soils: (10) automorphic solonetzes (>50%), (11) automorphic solonetzes (50–25%), (12) automorphic solonetzes (25–10%), (13) automorphic solonetzes (<10%),

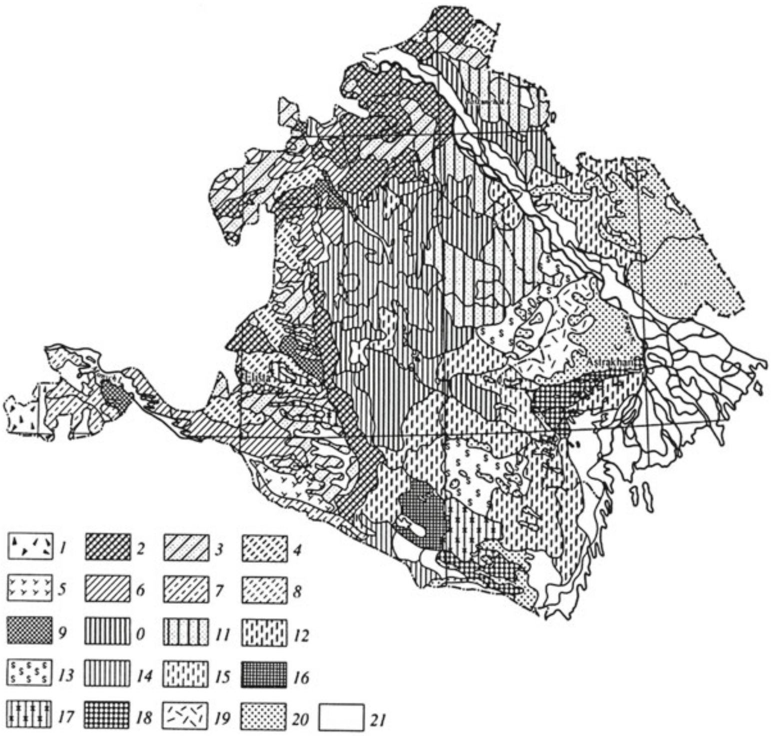

Fig. 6.4 Map of solonetzes and solonetzic soils in the soil cover of the Kalmyk Republic and Astrakhan oblast

(14) semi-hydromorphic solonetzes (>50%), (15) semi-hydromorphic solonetzes (50–25%), (16) hydromorphic solonetzes (>50%), (17) hydromorphic solonetzes (25–10%), and (18) hydromorphic solonetzes (<10%). Non-solonetzic and slightly solonetzic soils with local solonetzes: (19) slightly solonetzic and non-solonetzic soils with local solonetzes, (20) sands, and (21) areas without solonetzes and solonetzic soils.

6.4 Conclusion

The new soil salinity map as well as the map of chemical composition in salinization at a scale of 1:2,500,000 allowed identifying the main regularities in geographical distribution and genesis of salt-affected soils in Russia.

The electronic version of the map for the entire territory of European Russia made it possible to estimate the areas covered by salt-affected soils including those occupied by solonetzes (chernozem, chestnut, semidesert, automorphic, semi-hydromorphic, and hydromorphic ones) and solonetzic soils of different genesis. The saline soils as affected by salts within the upper 1-m layer are estimated as 23.3×10^6 ha in European Russia. This information helps to give the comparative characteristics of soil salinization in different regions of the country. It may be very useful for typification of lands affected by salinization, for monitoring of salt-affected soils with the aim at specifying genetic problems and those related to soil improvement, prediction, and prevention of soil salinization.

References

A series of soil-reclamation maps of the USSR at a scale of 1:500 000 (1987). Soyuzvodproekt, Moscow

Classification and diagnostics of soils of the USSR (1977). (Egorov VV (ed)). Kolos, Moscow, p 221

Kondorskaya NI (1965) Geographical distribution of soils with sodic salinization in the USSR. Soil Sci 9:10–16

Kovda VA (1946) The origin and regime of salt-affected soils, vol 1. Academy of Science USSR, Moscow

Pankova YI, Vorobieva LA, Gadjiev IM, Gorokhova IN, Elizarova TN, Korolyuk TV, Lopatovskaya OG, Novikova AF, Reshetov GG, Skripnikova MI, Slavniy YA, Chernousenko GI, Yamnova IA (2006) Salt-affected soils of Russia. Moscow, Akademkniga, p 854

Shishov LL, Tonkonogov VD, Lebedeva II, Gerasimova MI (eds) (2004) Classification and diagnostic of soils of Russia. Oikumena, Smolensk, p 342

Szabolcs I (1989) Salt affected soils. CRC Press, Boca Raton, p 274

The soil map of Russian federation at a scale of 1:2,500,000 (1988). (Fridland VM (ed)). Moscow

Chapter 7
Soil Salinity Mapping in the Sinai Peninsula of Egypt Using Geographic Information System and Remote Sensing Techniques

Hala M. Ibrahim and Assia A. El Falaky

Abstract Soil salinity in the arid and semiarid environments is a major concern for the sustainability of agriculture and water management. Salinity problem does exist in Egypt as well. In this study, we attempted to map soil salinity in a narrow strip in Sinai Peninsula. This was accomplished by analyzing surface soil samples for electrical conductivity (EC dS m^{-1}) and using Landsat TM image acquired in 1991 with a 30-m resolution that covered the study area to measure the mean reflectance pixel values at these specific samples' ground locations. Landsat TM data was preprocessed (geometrical and radiometrical). Forty bands ratios were developed from the 6 TM original bands to select the bands required for this particular need. A correlation matrix was developed to select the best regression model to represent a soil salinity map. Significant correlation was shown between the inverse of 3 reflectance TM bands and the premeasured EC values ($r=0.82$, 0.79, 0.62 at 0.01 level for inverse of TM1, TM2, TM7, respectively). Linear regression model, $y=c1+c2(1/\text{TM1})+c3(1/\text{TM2})+c4(1/\text{TM7})$, with correlation of determination $r^2=0.72$ was developed for soil salinity mapping. Thus, by applying this equation to the inverse of Landsat bands 1, 2, and 7, a soil salinity map was prepared. It is concluded that remote sensing is useful technique and can be considered a reliable, cost-effective, and timely method needed to determine the extent of soil salinity.

Keywords Egypt • GIS • Landsat TM • Remote sensing • Sinai • Soil salinity

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7.1 Introduction

Soil salinization is becoming an increasing problem, especially in the arid and semiarid regions where crop water requirement is offset through irrigation using low-quality saline/brackish water. Worldwide population is growing rapidly, and the same is the case with Egypt; this requires to increase the agricultural production to meet food demand of the local population. This can be achieved either by bringing new soils to production or through reclamation of marginal saline lands, which are either giving low production or are set aside due to poor economic resources and technical know-how of the farmers in dealing such soils. It is prerequisite to have sufficient good quality water to achieve useful results from the reclamation of marginal saline lands.

The planet earth consists of land surface of about 13.2×10^9 ha, of which 7×10^9 ha is arable and only 1.5×10^9 ha is cultivated (Massoud 1981). Of the cultivated lands, about 0.34×10^9 ha (23%) is saline and another 0.56×10^9 ha (37%) is sodic. Older estimates (Szabolcs 1989) suggest 10% of the total arable land to be affected by salinity and sodicity, extending over more than 100 countries and almost all continents occupying different proportions of their territory (Shahid and Rahman 2011; Tabet et al. 1997).

It is therefore essential to assess and monitor soil salinity in the degraded irrigated agricultural lands to check the efficiency of irrigation systems and soil management practices.

Sinai Peninsula represents a major area for potential expansion of agricultural land in Egypt; this is due to the fact that the fresh water can be brought in the area from the River Nile through El-Salam canal. The classical soil salinity survey methods (soil sampling and analyses in the analytical laboratories) especially in large areas are relatively expensive and time-consuming; as a compromise to the cost and other requirements, the remote sensing has proved to be an efficient tool to overcome these problems and to aid in salinity mapping in a relatively lesser time and resources (Robbins and Wiegand 1990). On contrary to ancient methods, nowadays, advanced methods (remote sensing/geographic information systems) are currently in use for the assessment of natural resources (Zobeiry and Maid 2000). The use of RS/GIS techniques to delineate saline soils has been proved efficient in many recent studies (Sharma and Bhargawa 1988; Rao et al. 1991; Dwivedi 1992; Srivastava et al. 1997; Dwivedi and Sreenivas 1998; Khan and Sato 2001; Shahid et al. 2010). Landsat TM and JERS-1SAR data (visible and infrared regions) are the best to distinguish saline, alkaline, and nonsaline soils (Metternicht and Zink 1997). Singh and Dwivedi (1989) and Dwivedi (1992) used Landsat MSS and TM data for more detailed mapping and monitoring of the salt-affected soils in the frame of the reconnaissance soil map of India.

The integration of remotely sensed data, geographic information system, and spatial statistics provides useful tools for modeling variability to predict the distribution, tools presence and pattern of soil characteristics (Kalkhan et al. 2000). Also, De Dapper et al. (1996) indicated the development of GIS and remote sensing for monitoring and predicting soil salinity in the Nile Delta fringes of Egypt.

Indian experience of the application of satellite remote sensing (Howari et al. 2002; Stohlgren et al. 2000) for the study of saline soils is based mostly on data acquired from Landsat 1, 2, 3, 4, 5, and 7, IRS series, and SPOT. Northrop (1982) concluded that Landsat could be used to detect salinity features when incorporating extensive ground data. Csillag and Biel (1993) used a modified stepwise principle component analysis to access the effectiveness of individual bands for discriminating salinity status from high resolution spectra provided by narrow absorption band.

The present study is, therefore, carried out to investigate a proper and possible model for mapping salt-affected soils in part of Sinai using TM 5 satellite image and potential data obtained from field observations using GIS and remote sensing software.

7.2 Materials and Methods

7.2.1 Site Description

The studied site (Fig. 7.1) lies in a narrow strip in Sinai Peninsula that extends along a part of the Suez Gulf. The surveyed area is approximately 39 km^2 lying between latitude 29° 52 and 29° 58 north and longitude 32° 36 and 32° 42 east.

7.2.2 Ground Salinity Map

In order to prepare a spatial salinity map, the average soil salinity expressed as EC in mmohs cm^{-1} (dS m^{-1}) from the 0–30-cm layer for each of the 33 polygons (1 km × 1 km) of the study area was inserted into attribute table in ArcGIS environment with its corresponding coordinate (Figs. 7.2 and 7.6).

7.2.3 Satellite Data Acquiring and Geometrical Correcting

One scene of Landsat TM 5 image (8/1990) was adopted in this research. The image data was acquired from the Internet in GeoTIFF format using URL link (http://earthexplorer). The satellite data was geometrically corrected to the Universal Transverse Mercator Projection with a 30-m grid. Several well-distributed geographic control points obtained from 1:50,000-scale topographic map were used to calculate the geometric transformation. The Table 7.1 illustrates satellite data characteristic.

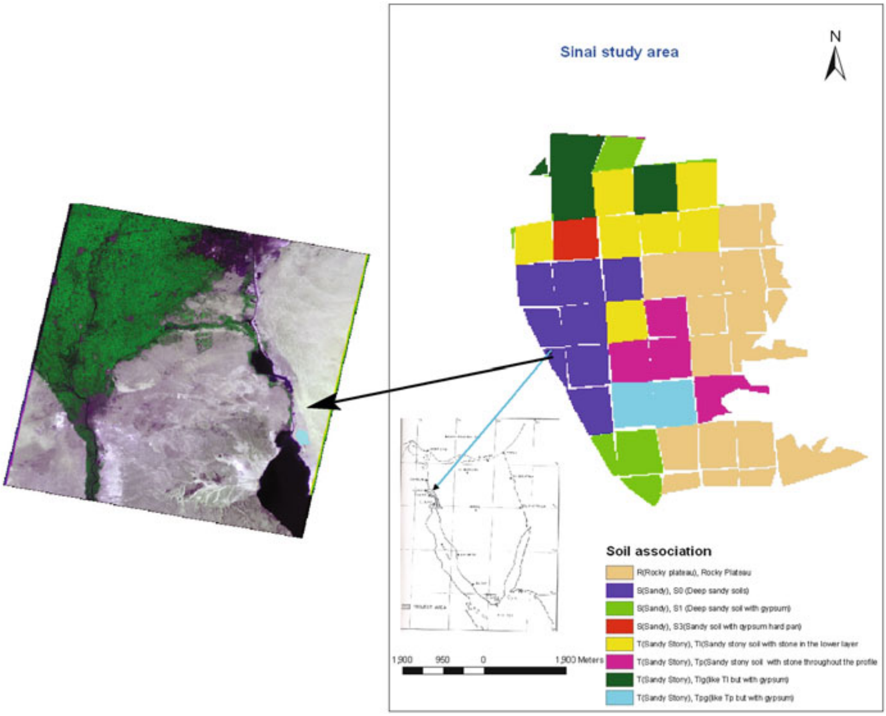

Fig. 7.1 Study area showing soil–soil associations

7.2.4 Radiometric Correction and Image Normalization

7.2.4.1 Conversion of the Digital Number (DN) to Spectral Radiance (Lλ)

The spectral radiance ($L\lambda$) is calculated using the following equation (USGS, 2001):

$$L\lambda = \left(\frac{LMAX - LMIN}{QCALMAX - QCALMIN}\right) \times (QCAL - QCALMIN) + LMIN, \tag{7.1}$$

where the LMINs and LMAXs are the spectral radiances for bands at digital numbers 1 and 255, respectively, and QCAL = digital number (Chander et al. 2009).

7.2.4.2 Conversion of this Radiance Image to Surface Reflectance

Howari (2003) indicated that salt-affected soils were often associated with higher reflectivity. The following equation was applied to the previous deduced radiance band:

Fig. 7.2 Study area with soil sampling polygons

Table 7.1 Details of acquired data

Sun elevation angle	Cloud (%)	Sun azimuth	Pixel size	Band combination	Path/row	Sensor ID	Acquisition date
56.7088856	0	105.2522262	30 m	1,234,567	176/39	TM_5	1990-08-04

$$\rho = \frac{\pi . L_\lambda . d^2}{\text{ESUN}_\lambda . \cos(\text{SZ})}$$

where

ρ = planetary TOA reflectance [unitless] (Chander et al. 2009)

L_λ = spectral radiance at the sensor's aperture in [W m^{-2} sr^{-1} µm^{-1}]

d^2 = the square of the Earth-Sun distance in astronomical units = [1 − 0.01674 cos(0.9856 (JD-4))]^{2,} where JD is the Julian Day (day number of the year) of the image acquisition

ESUN_λ = mean solar exoatmospheric irradiance in [W m^{-2} µm^{-1}]

SZ = sun zenith angle in radians when the scene was recorded

7.2.5 Development of Regression Models for Soil Salinity Estimated from TM Data

The mean value of pixels per each polygon for each of the six reflected energy bands (TM1-5 and 7) was used using ERDAS Imagine and ArcGIS software. These average values and other deduced spectral ratio (TM1/TM4, TM2/TM1, TM3/TM2, TM3/TM4, TM4/TM2, TM4/TM3, TM7/TM5, 1/TM1, 1/TM2, 1/TM7, …), PCA, and 1/NDVI were used as independent variables in the regression models. The regression model of dependent soil variable (EC) and independent deduced band variables was introduced to SPSS system, and the best independent variables were decided.

To estimate the degree of interrelation between bands, bands ratio, PCA, 1/NDVI, and EC, the correlation coefficients are used. Table 7.2 demonstrates correlation matrix for some of the developed bands ratio.

Different models from different bands ratio combination (bands inverse and bands cubic inverse, different salinity indices, bands rationing, PCA, inverse of vegetation index) were developed and tested. These models were compared based on high values of correlation of determination (r^2), high value of *F*-ratio, adjusted R^2, and low values of standard error of the estimate. The combination of inverse spectral band (visible and middle infrared bands) 1/TM1.1/TM2.1/TM7 shows the best correlation with the soil EC land data (Table 7.3).

Dimensional model between EC and spectral values:

$$Y = c1 + c2x1 + c3x2 + c4x3$$

$$Y = \mathrm{EC},\ x1 = \frac{1}{\mathrm{TM1}},\ x2 = \frac{1}{\mathrm{TM2}},\ x3 = \frac{1}{\mathrm{TM7}}$$

$$c1 = -61.142,\ c2 = 35.941,\ c3 = -18.494,\ c4 = -11.269$$

where *a* is predictors: (constant) $1/t7$, $1/t2$, $1/t1$.

Unsupervised classification and accuracy assessment were performed for this developed soil map from the satellite bands to stand for salt distribution accuracy using ERDAS Imagine (Fig. 7.3).

7.3 Results and Discussion

There was an approximation for the ground truth EC values that is used in this work. The electric conductivity (EC) of the soil samples was calculated on average basis for each of the 33 polygons of the studied areas (1 km × 1 km), being not at specific

Table 7.2 Correlation matrix for some of independent variables

Correlations		EC	*t*1	*t*2	*t*4	*t*7	1/*t*1	1/*t*2	1/*t*3	1/*t*4	1/*t*5	1/*t*7
EC	Pearson correlation	1	–0.806**	–0.789**	–0.749**	–0.600**	0.817**	0.796**	0.784**	0.769**	0.707**	0.622**
	Sig. (2-tailed)	–	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
	N	33	33	33	33	33	33	33	33	33	33	33
*t*1	Pearson correlation	–0.806**	1	0.974**	0.968**	0.884**	–0.997**	–0.972**	–0.975**	–0.978**	–0.945**	–0.904**
	Sig. (2-tailed)	.000	–	.000	.000	.000	.000	.000	.000	.000	.000	.000
	N	33	33	33	33	33	33	33	33	33	33	33
*t*2	Pearson correlation	–0.789**	0.974**	1	0.966**	0.825**	–0.976**	–0.997**	–0.992**	–0.977**	–0.896**	–0.844**
	Sig. (2-tailed)	.000	.000	–	.000	.000	.000	.000	.000	.000	.000	.000
	N	33	33	33	33	33	33	33	33	33	33	33
*t*4	Pearson correlation	–0.749**	0.968**	0.966**	1	0.925**	–0.956**	–0.953**	–0.983**	–0.997**	–0.964**	–0.932**
	Sig. (2-tailed)	.000	.000	.000	–	.000	.000	.000	.000	.000	.000	.000
	N	33	33	33	33	33	33	33	33	33	33	33
*t*7	Pearson correlation	–0.600**	0.884**	0.825**	0.925**	1	–0.857**	–0.804**	–0.858**	–0.911**	–0.978**	–0.997**
	Sig. (2-tailed)	.000	.000	.000	.000	–	.000	.000	.000	.000	.000	.000
	N	33	33	33	33	33	33	33	33	33	33	33
1/*t*1	Pearson correlation	0.817**	–0.997**	–0.976**	–0.956**	–0.857**	1	0.979**	0.975**	0.971**	0.926**	0.881**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	–	.000	.000	.000	.000	.000
	N	33	33	33	33	33	33	33	33	33	33	33

(continued)

Table 7.2 (continued)

Correlations

		EC	*t*1	*t*2	*t*4	*t*7	1/*t*1	1/*t*2	1/*t*3	1/*t*4	1/*t*5	1/*t*7
1/*t*2	Pearson correlation	0.796**	–0.972**	–0.997**	–0.953**	–0.804**	0.979**	1	0.989**	0.969**	0.882**	0.827**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	–	.000	.000	.000	.000
	N	33	33	33	33	33	33	33	33	33	33	33
1/*t*3	Pearson correlation	0.784**	–0.975**	–0.992**	–0.983**	–0.858**	0.975**	0.989**	1	0.991**	0.918**	0.873**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	–	.000	.000	.000
	N	33	33	33	33	33	33	33	33	33	33	33
1/*t*4	Pearson correlation	0.769**	–0.978**	–0.977**	–0.997**	–0.911**	0.971**	0.969**	0.991**	1	0.959**	0.922**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	–	.000	.000
	N	33	33	33	33	33	33	33	33	33	33	33
1/*t*5	Pearson correlation	0.707**	–0.945**	–0.896**	–0.964**	–0.978**	0.926**	0.882**	0.918**	0.959**	1	0.986**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000	–	.000
	N	33	33	33	33	33	33	33	33	33	33	33
1/*t*7	Pearson correlation	0.622**	–0.904**	–0.844**	–0.932**	–0.997**	0.881**	0.827**	0.873**	0.922**	0.986**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	–
	N	33	33	33	33	33	33	33	33	33	33	33

**Correlation is significant at the 0.01 level (2-tailed)

Table 7.3 Model summary

Model	r	r^2	Adjusted r^2	Std. error of the estimate
1	0.849(*a*)	0.721	0.693	2.353363

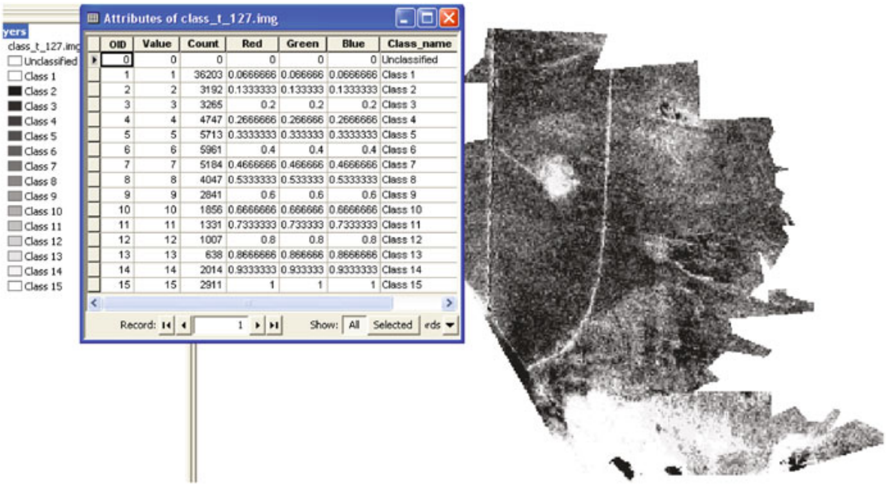

Fig. 7.3 Classification processing scheme

x, *y* coordinates points, and accordingly the calculated standard error (SE) of the estimate was relatively high (2.35), the adjusted R square, and the coefficient of determination (r^2) between dependent variable (EC) and the independent bands variables was not strong enough ($r^2 = 0.72$), (adjusted $r^2 = 0.693$) for this developed regression model.

The model deduced from the inverse of reflective TM bands visible and middle infrared bands (TM1, TM2, TM7) gains better output statistics parameters relative to other output developed models.

On a Thematic Mapper (TM) image, the highly salinized area is that in which the soil's reflectance rate is high for each band that appears white. Of course, the nonsalinized area, in which the plants are growing well, appears red (in natural color image). Only in the moderately and weakly salinized areas there is little chromatic difference, and the soil condition is difficult to distinguish. In this case study, EC values can be grouped approximately into 2 groups: high salinity in the lower part of the study area (EC in dS $m^{-1} \geq 16$) and low salinity though the remaining area (EC in dS m^{-1} fluctuate from 0.25 to 3) (Fig. 7.4).

Figure 7.5 demonstrates some of the developed saline maps which are produced by combining different bands ratio using raster calculator tool under ArcGIS environment. It was clear from the figure that the harmony relation between the two

Fig. 7.4 Natural color and the developed principle component analysis images overlaid by the developed saline map of the study area

groups of EC as ground truth and the white tone trend of bands combination models, also the opposite tone trend between bands combination $(1/t1+1/t2+1/t7)$ and $(t4-t3)/(t4+t3)$ for NDVI index.

Unsupervised classification was performed with 15 classes and followed by accuracy assessment processing which produced accuracy = 53% only due to using average values of EC for each of the 33 (1 km × 1 km) polygons.

The developed salinity map from satellite data (Fig. 7.6) shows that the white colored areas are of high salinity, while the gray area which represents most of the studied soil was of low salinity. On the other hand, the small black spots represent vegetative areas in the ground truth (see the black spot areas in Figs. 7.4 and 7.5).

7.4 Conclusion

Remote sensing appears to offer several advantages over conventional ground truth methods used to map and monitor soil salinity. Landsat TM data was adopted in this study. About forty band ratios, indices, and PCA were developed from the 6 TM original bands to select the best bands required for this particular need. A correlation matrix was developed to select the best regression model to represent a soil salinity map. Significant correlation was shown between the inverse of 3 reflectance TM bands and the premeasured EC values, and finally a soil salinity map was prepared. Some aspects must be taken into consideration: First, the soil sampling must be related to specific *x*, *y* location points, and second, these points must be uniformly distributed to cover all the study area for best correlation results and true representation of developed salinity map. Finally, it can be concluded that this remote sensing technique is useful and can be considered as reliable, cost-effective, and timely method needed to determine the extent of soil salinity.

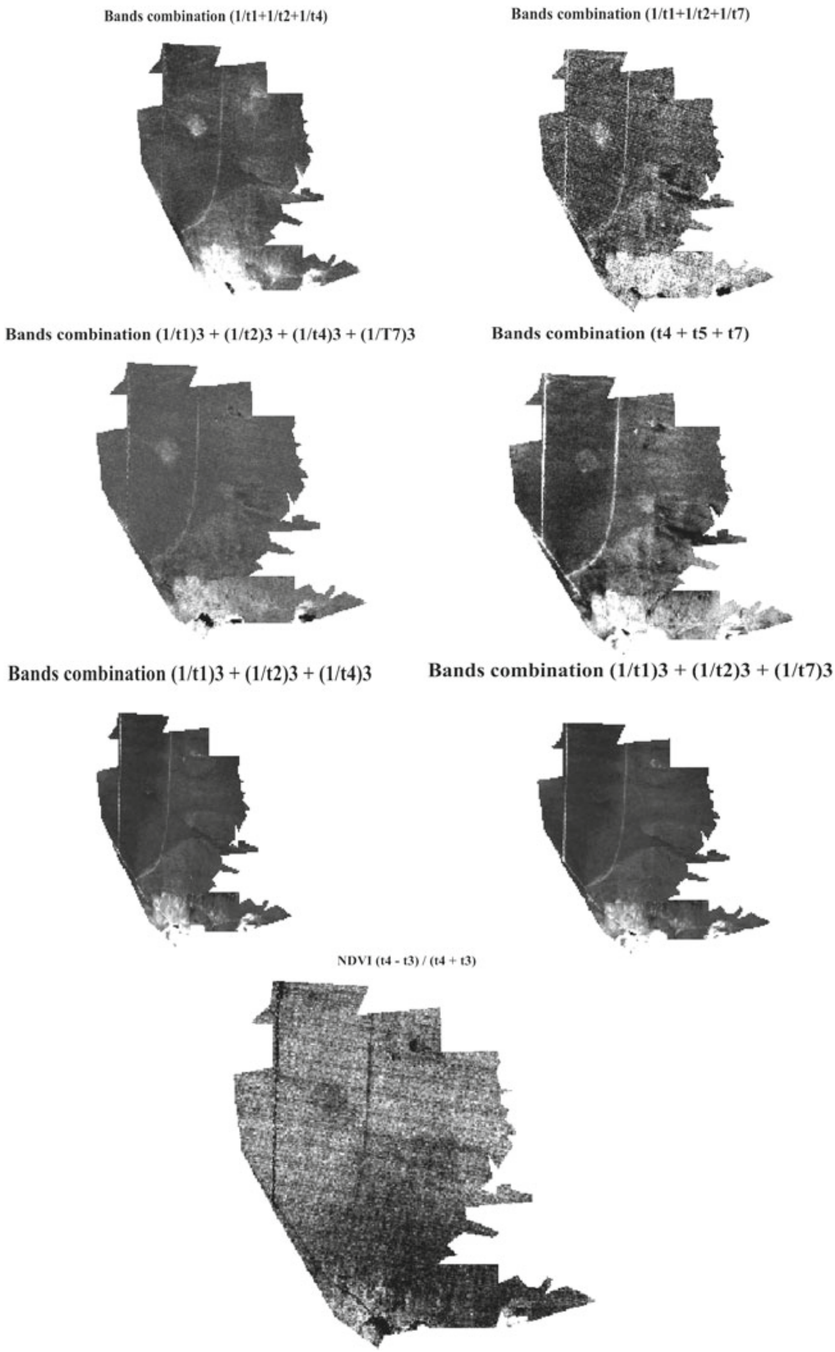

Fig. 7.5 NDVI and different developed saline map models

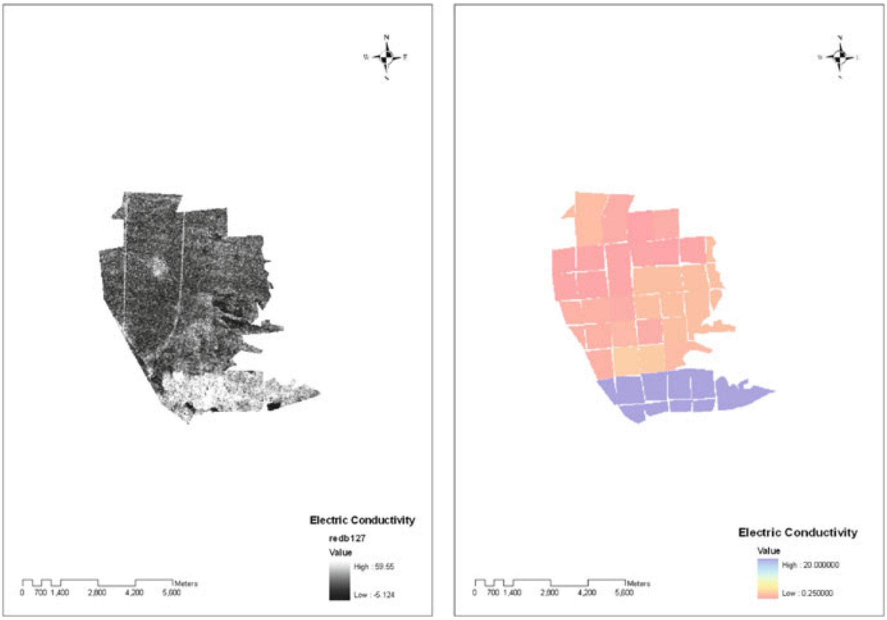

Fig. 7.6 Saline map developed from the satellite data and the ground truth salinity map

References

Chander GD, Markham BL, Helder DL (2009) Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. Rem Sens Environ 113:893

Csillag FA, Biel LL (1993) Spectral band selection for the characterization of salinity status of soil. Rem Sens Environ 43:231–242

De Dapper M, Goossen R, Gad A, Al-Badawi M (1996) Modeling and monitoring of soil salinity and waterlogged hazards in desert delta fringes of Egypt, based on geomorphology, remote sensing and GIS. In: Geomorphic hazards Olov S (ed) J Wiley-New York-Brisbane-Torronto-Heidelberg, pp 169–182

Dwivedi RS (1992) Monitoring and the study of the effect of image scale on delineation of salt-affected soils in the Indo-Gangentic plains. Int J Rem Sens 13:1527–1536

Dwivedi RS, Sreenivas KL (1998) Delineation of salt-affected soils and waterlogged areas in the Indo-Gangetic plains using IRS-1C LISS-III data. Int J Rem Sens 19:2739–2751

Howari FM (2003) The use of remote sensing data to extract information from agricultural land with emphasis on soil salinity. Aus J Soil Res 4:1243–1253

Howari FM, Goodell PC, Miyamoto SA (2002) Spectral properties of salt crust formed on saline soils. J Environ Qual 31:1453–1461

Kalkhan MA, Stohlgren TJ, Chong GW, Lisa D, Reich RM (2000) A predictive spatial model of plant diversity. Integration of remotely sensed data, GIS, and spatial statistics report of the World Bank, Washington, DC

Khan NM, Sato YS (2001) Monitoring hydro-salinity status and its impact in irrigated semi-arid areas using IRS-1B LISS-II data. Asian J Geoinf 1(3):63–73

Massoud FI (1981) Salt-affected soils at a global scale and concepts of control. FAO Land and Water Development Division, Technical Paper, Rome, p 21

Metternicht GB, Zink JA (1997) Spatial discrimination of salt and sodium affected soil surfaces. Int J Rem Sens 18:2571–2586

Northrop LJ (1982) Landsat detection of irrigation area salinity. Occasional paper series no 4. Department of National Development and Energy, Australian Water Resources Council

Rao BR, Dwivedi RS, Venkataratnam LM, Thammappa SS, Bhargawa GP, Singh AN (1991) Mapping the magnitude of sodicity in part of the Indo-Gangetic plains of Uttar Pradesh, Northern India using Landsat-TM data. Int J Rem Sens 12(3):419–425

Robbins CW, Wiegand CL (1990) Chapter 10: Field and laboratory measurements. In: Tanji KK (ed) Agricultural salinity assessment and management. American Society of Civil Engineers, New York, pp 201–219

Shahid SA, Rahman K (2011) Chapter 2: Soil salinity development, classification, assessment and management in irrigated agriculture. In: Pessarakli M (ed) Handbook of plant and crop stress. CRC Press, Boca Raton, pp 23–39

Shahid SA, Abdefattah MA, Omar SAS, Harahsheh H, Othman T, Mahmoudi H (2010) Mapping and monitoring of soil salinization-remote sensing, GIS, modeling, electromagnetic induction and conventional methods – CASE Studies. In: Ahmad M, Al-Rawahy SA (eds) Keynote paper published in the proceedings of the international conference on soils and groundwater salinization in arid countries, vol 1. Sultan Qaboos University, Muscat Sultanate of Oman, pp 59–97

Sharma RC, Bhargawa GP (1988) Landsat imagery for mapping saline soils and wetlands in northwest India. Int J Rem Sens 9:69–84

Singh AN, Dwivedi RS (1989) Delineation of salt-affected soils through digital analysis of landsat MSS data. Int J Rem Sens 10:83–92

Srivastava AD, Tripathi NK, Gokhale KV (1997) Mapping groundwater salinity using IRS-1B LISS II data and GIS techniques. Int J Rem Sens 18:2853–2862

Stohlgren MT, Chong GW, Lisa DS, Reich RM (2000) A predictive spatial model of plant diversity: integration of remotely sensed data, GIS and spatial statistics. Paper presented at the eighth biennial remote sensing application conference, ASPRS-Publication, Washington, DC, 22–26 May

Szabolcs I (1989) Salt-affected soils. CRC Press, Boca Raton, p 274

Tabet DA, Vidal A, Zimmer DB, Asif SL, Aslam M, Kuper M, Strosser P (1997) Soil salinity characterization in SOPT images-a case study in one irrigation system of the Punjab, Pakistan. In: Guyot G, Phulpin T (eds) Physical measurements and signatures in remote sensing book. A.A. Balkema, Rotterdam, pp 795–800

USGS (2001) Landsat 7 science data user's handbook. USGS, Reston

Zobeiry M, Maid AR (2000) An introduction to remote sensing technology and application in natural resources. University of Tehran, Tehran

Chapter 8
Spatial Variability of Soil Salinization as Judged from the Comparison of Soil Maps and Remote Sensing Materials for Different Years in Uzbekistan

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Abstract Quantitative assessments of the temporal variability in soil salinity are discussed in this chapter. Currently such assessments are based on the comparison of point-size data for several years (regular observations and sampling in the same point) or on the comparison of soil salinization maps developed in different years. Both methods have drawbacks. In the case of point-size data, it is difficult to extrapolate them on large territories. In the case of comparison of two soil maps obtained in different times, the problem of temporal extrapolation of the data arises. We estimated the dynamics of soil salinization on the basis of remote sensing materials with ground-truth calibration for the territory of the Usman Yusupov farm in the Golodnaya Steppe of Uzbekistan. Remote sensing materials on this territory were obtained for years 1983, 1985, 1986, 1988, 1989, 1990, 2000, and 2008. On their basis, eight separate soil salinity maps were developed for the area of 80 km^2. A comparison between them made it possible to develop a series of the maps of soil salinization dynamics. Separation of the areas with a stable soil salinity status upon the comparison of the maps for different years proved to be very informative. Such areas comprised no more than 1.5% of the farm area for the whole period (25 years) and about 25% of the farm area for two consecutive years. Quantitative data on soil salinization dynamics made it possible to outline certain drawbacks in soil reclamation procedures and to suggest the ways of their optimization.

Keywords Salinization dynamics • Spatial variability • Soil maps • Temporal variability • Uzbekistan

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8.1 Introduction

The high variability of soil salinity is a well-known fact (Pankova and Mazikov 1985). Various methods are used to assess the salt status of particular territories for the given time. These are field surveys and sampling, soil mapping, and remote sensing. The methods of quantitative assessment of the temporal variability of soil salinity have yet to be developed. At present, they are based on the comparison of point-size data for several years (regular observations and sampling in the same point) or on the comparison of soil salinization maps developed in different years (Pankova and Solov'ev 1993).

Both methods have their drawbacks. In the case of point-size data, it is difficult to extrapolate them on large territories (Pankova and Mazikov 1976); Zonn et al. 1980). In the case of comparison of two soil maps obtained in different times, the problem of temporal extrapolation of the data arises.

To reduce these drawbacks, we have developed the method based on the comparison of several maps of soil salinization (Pankova and Rukhovich 1999). These maps are produced from remote sensing materials with ground-truth calibration. A system of such maps was developed for the territory of the Usman Yusupov farm in the Golodnaya Steppe of Uzbekistan. Remote sensing materials on this territory were obtained for the years 1983, 1985, 1986, 1988, 1989, 1990, 2000, and 2008. On their basis, eight separate maps of soil salinization were developed for the area of 80 km^2.

8.2 Materials and Methods

The maps of soil salinization were developed according to a common methodology of interpretation of remote sensing data (aerial photos for the years 1983, 1985, 1986, 1988, and 1989) with a separation of four classes of soil salinization according to the average content of Na^+ ions in the upper soil meter: (1) <2, (2) 2–4, (3) 4–6, and (4) >6 meq/100 g soil (Table 8.1).

To study the dynamics of soil salinity with the use of statistical methods, 20 derivative maps were compiled. Overall, 25 maps were analyzed:

1. The map of soil salinization for 1983 (Fig. 8.1).
2. The map of soil salinization for 1985.
3. The map of soil salinization for 1986.
4. The map of soil salinization for 1988.
5. The map of soil salinization for 1989.
6. The map of the direction of salinization–desalinization processes based on the comparison of the maps of soil salinity for 1983 and 1989.
7. The map of the direction of salinization–desalinization processes based on the comparison of the maps of soil salinity for 1983 and 1985 (Fig. 8.2a).
8. The map of the direction of salinization–desalinization processes based on the comparison of the maps of soil salinity for 1985 and 1986 (Fig. 8.2b).

Table 8.1 Areas (ha) of farmland with different degree of soil salinity (the Usman Yusupov farm, Uzbekistan) in 1983–1989

	Water-extractable Na^+ concentration (meq/100 g soil)			
Year	>6	6–4	4–2	<2
1983	470.9	846.9	1,587.1	2,515.1
1985	650.8	1,630.4	1,988.1	1,098.5
1986	485.4	864.6	1,725.5	1,833.4
1988	710.3	1,408.5	1,733.7	1,142.8
1989	820.7	1,622.9	1,632.8	893.7

Fig. 8.1 Soil salinity map in the upper meter as estimated from data on the content of water-extractable Na^+ ions (meq/100 g soil)

9. The map of the direction of salinization–desalinization processes based on the comparison of the maps of soil salinity for 1985 and 1986.
10. The map of the direction of salinization–desalinization processes based on the comparison of the maps of soil salinity for 1986 and 1989.
11. The map of trends in salinization–desalinization processes based on the analysis of the five maps of soil salinity for 1983–1989 (Fig. 8.3).
12. The map of averaged soil salinity for 1983 and 1985.
13. The map of averaged soil salinity for 1985 and 1986.
14. The map of averaged soil salinity for 1986 and 1989.
15. The map of averaged soil salinity for 1983–1989.
16. The map of stable soil salinity in 1983 and 1985 (Fig. 8.4a).
17. The map of stable soil salinity in 1985 and 1986.

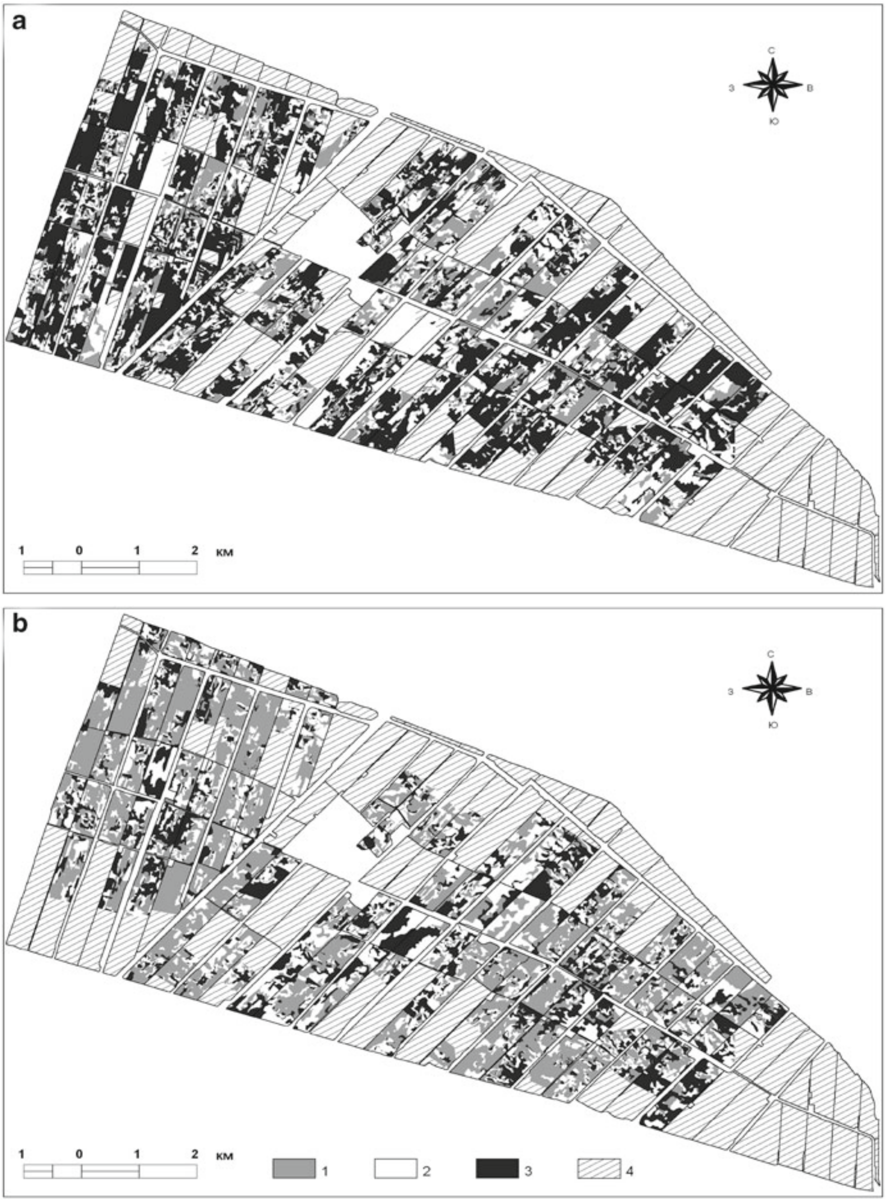

Fig. 8.2 Traditional soil salinity dynamics maps as estimated from data on (**a**) 1983 and 1985 and (**b**) 1985 and 1986: (1) decreasing salinity, (2) stable salinity, (3) increasing salinity, and (4) regular surveys were not performed

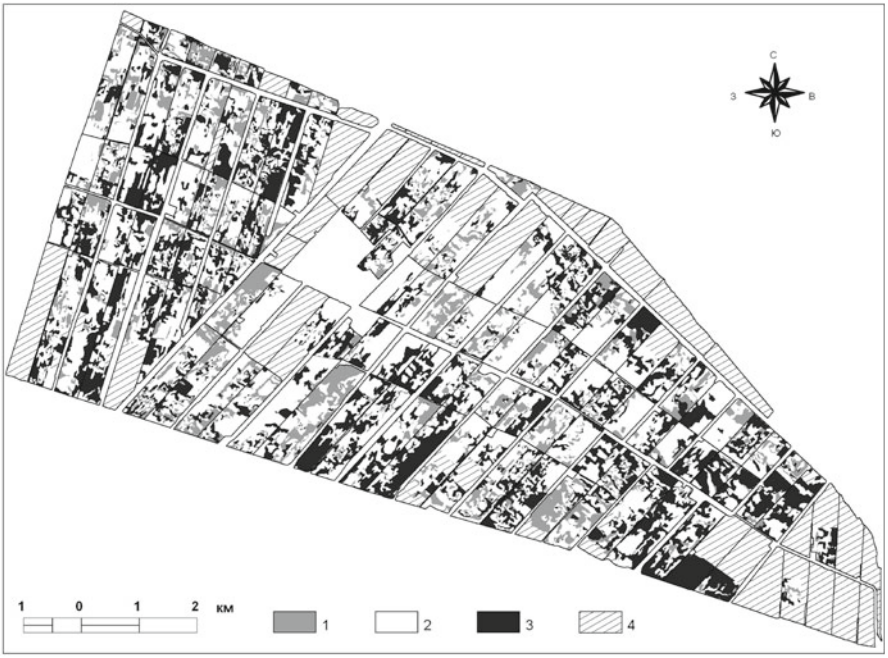

Fig. 8.3 Map of the trends of soil salinization–desalinization as obtained from the analysis of the maps of soil salinity for 1983–1989: (1) desalinization, (2) no definite trend, (3) salinization, and (4) regular surveys were not performed

18. The map of stable soil salinity in 1986 and 1988.
19. The map of stable soil salinity in 1988 and 1989.
20. The map of stable soil salinity in 1983–1989 (Fig. 8.4b).
21. The map of maximum changes in the degree of soil salinity.
22. The map of soil salinity dynamics.
23. The map of maximum distribution of strongly saline soils.
24. The map based on the comparison of soil salinity dynamics in 1983–1985 and 1985–1986.
25. The map of concordance of the direction of soil salinization–desalinization processes in 1983–1985, and 1985–1986.

8.3 Results and Discussion

The average degree of salinization in the upper soil meter (as judged from concentrations of water-extractable sodium) within the farm calculated according to maps 1–5 comprised 2.7 meq/100 g soil in 1983, 3.8 meq/100 g soil in 1985, 3.0 meq/100 g soil in 1986, 3.7 meq/100 g soil in 1988, and 3.9 meq/100 g soil in 1989. Thus, in

Fig. 8.4 Maps of stable soil salinity (dS m^{-1}) status as judged from the comparative analysis of the maps for (**a**) 1983 and 1985 and (**b**) 1983, 1985, 1986, 1988, and 1989

general, no clear tendency for salinization or desalinization of the territory was observed during those 7 years; the soils had a moderate degree of salinization according to the content of water-extractable sodium.

Maps of the direction and intensity of salinization–desalinization processes (maps 6–10) based on the pairwise comparison of maps 1–5 are considered as traditional maps of soil salinization dynamics. Their analysis showed that the average area of farmland, on which the degree of soil salinity does not change between any 2 compared years, reaches 33%. On 43% of the area, the degree of soil salinity changed by one grade, on 19% by two grades, and on 5% area by three grades. The change of the degree of soil salinity by two and more grades means that nonsaline and moderately saline soils are transformed into strongly and very strongly saline soils, respectively, and vice versa, i.e., such changes indicate the high intensity of salinization–desalinization processes. In the studied case, the degree of soil salinity changed by two and more grades on about a quarter of the farmland (20–27.6%) (Table 8.2).

If two maps of soil salinization for two different dates are compared, we can definitely judge the direction of soil salinization or desalinization processes in any given point. The degree of soil salinization may increase, decrease, or remain stable. However, this does not mean that the same tendency is preserved in some other time interval. For example, map 7 (based on the comparison of the maps for 1983 and 1985) indicates the well-pronounced salinization processes on a larger part of the territory, whereas map 9 (based on the comparison of the maps for 1985 and 1986) indicates the desalinization process.

The assessment of applicability of traditional maps of the salinization–desalinization processes (maps 6–10) for judging the general direction of these processes was based on the comparison of two maps for neighboring time intervals. Thus, we took the maps showing the dynamics of soil salinization from 1983 to 1985 (map 7) and from 1985 to 1986 (map 9) (Fig. 8.2). The comparison of these maps via the method of superposition was made, so that we obtained two comparative maps of soil salinization dynamics (maps 24 and 25), on which the areas with similar and opposite trends of salinization–desalinization processes were shown.

The analysis of these maps showed that opposite trends (salinization–desalinization) were observed in 1983–1985 and 1985–1986 on 38.6% of the whole territory; on approximately the same area (38.7% of the whole territory), the trends were dissimilar, i.e., the stable state of soil salinity in one of these periods was replaced by salinization or desalinization in the other period. Similar trends (salinization or desalinization) in both periods were only observed on 8.44% of the whole territory. Finally, on 14% of the whole territory, the degree of soil salinity remained stable during both periods.

Thus, the direction of salinization–desalinization processes may change with time, and the extrapolation of the trends observed in the given period onto some other period may lead to considerable (40–80%) errors. Hence, it is incorrect to predict the dynamics of soil salinization on the basis of observations at two given terms.

Table 8.2 The direction of salinization–desalinization processes as judged from the comparison of the maps of soil salinization for different years from 1983 to 1989 for the Yusupov farm

Map no.; compared years	Total mapped		Changes in the degree (grade) of soil salinization													
			Salinization decrease by						Stable salinization		Salinization increase by					
	Area		3 grades		2 grades		1 grade		0		1 grade		2 grades		3 grades	
	a	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*
Map 6; 1983 vs 1989	39.34	6,704	0.3	174	1.44	508	4.93	1,155	11.27	1,677	11.22	1,567	6.89	111.	2.27	518
Percent	**100**	**100**	**0.8**	**2.6**	**3.7**	**7.6**	**12.5**	**17.2**	**28.6**	**25.0**	**28.5**	**23.4**	**17.5**	**16.6**	**5.8**	**7.7**
Map 7; 1983 vs 1985	44.33	7,759	0.22	139	1.61	727	6.35	1,442	14.76	1,980	13.07	1,749	6.75	1,241	1.56	481
Percent	**100**	**100**	**0.5**	**1.8**	**3.6**	**9.4**	**14.3**	**18.6**	**33.3**	**25.5**	**29.5**	**22.5**	**15.2**	**16.0**	**3.5**	**6.2**
Map 8; 1983 vs 1986	38.34	6,704	0.61	330	2.36	776	6.96	1,227	14.72	1,691	9.09	1,356	3.91	825	1.12	347
Percent	**100**	**100**	**1.6**	**4.9**	**6.2**	**11.6**	**18.2**	**18.3**	**38.4**	**25.2**	**13.7**	**20.2**	**10.2**	**12.3**	**2.9**	**5.2**
Map 9; 1985 vs 1986	42.03	7,395	1.33	391	5.32	1,114	12.36	1,720	13.62	1,942	6.89	1,336	2.08	689	0.44	203
Percent	**100**	**100**	**3.2**	**5.3**	**12.7**	**15.1**	**29.4**	**23.3**	**32.4**	**26.3**	**16.4**	**18.1**	**4.9**	**9.3**	**1.0**	**2.7**
Map 10; 1986 vs 1989	36.79	6,401	0.3	154	1.65	560	6.12	1,116	11.36	1,606	10.19	1,503	5.82	1,011	1.35	451
Percent	**100**	**100**	**0.8**	**2.4**	**4.5**	**8.7**	**16.6**	**17.4**	**30.9**	**25.1**	**27.7**	**23.5**	**15.8**	**15.8**	**3.7**	**7.0**

(*a*) Area in km^2 and (*b*) number of polygons

Table 8.3 Areas and number of polygons of different saline soils and their percentages in the total mapped area and in the total number of polygons, respectively, as estimated from the maps of averaged soil salinity for 1983–1989

	Non saline and slightly saline		Moderately saline		Strongly saline		Very strongly saline		Total mapped	
Map no; compared years	Area (km^2)	Number of polygons	Area (km^2)	Number of polygons	Area (km^2)	Number of polygons	Area (km^2)	Number of polygons	Area (km^2)	Number of polygons
Map 12; 1983 vs 1985	5.61	545	31.00	592	4.07	1,254	3.42	832	44.10	3,223
Percent	**12.7**	**16.9**	**70.3**	**18.4**	**9.2**	**38.9**	**7.6**	**25.8**	**100**	**100**
Map 13; 1985 vs 1986	4.12	510	29.15	612	4.72	1,391	3.94	46	41.93	2,974
Percent	**9.8**	**17.1**	**69.5**	**20.6**	**11.3**	**46.8**	**9.4**	**15.5**	**100**	**100**
Map 14; 1986 vs 1989	3.21	403	25.09	1,070	4.54	1,090	4.06	503	36.91	3,066
Percent	**8.7**	**13.1**	**68.0**	**34.9**	**12.3**	**35.6**	**11.0**	**16.4**	**100**	**100**
Map 15; 1983 vs 1989	2.32	542	19.65	997	4.01	1,524	1.12	432	27.14	3,495
Percent	**8.7**	**15.5**	**72.4**	**28.5**	**14.8**	**43.6**	**4.1**	**12.4**	**100**	**100**

A more correct way to predict soil salinization is to develop the maps of the trends of salinization–desalinization processes on the basis of data for several years of observations (map 11, Fig. 8.3). For the entire period (1983–1989), the category of soil salinity remained unchanged on 27.6% of the entire territory (the areas with stable salinity); on 25.2% of the territory, the soil salinity decreased; and on 47.2% of the territory, the soil salinity somewhat increased.

This map is obtained via superposition of five separate maps of soil salinity for the period from 1983 to 1989. The resulting map contains 48,760 polygons with 625 different variants of soil salinization dynamics. For each of these variants, the dynamics of soil salinization can be shown on the plot with the years of observation on the abscissa axis and the degree of soil salinity on the ordinate axis. Such plots can be approximated by linear functions $y = ax + b$, where y denotes the degree of soil salinity, x is the year of observation, and a and b are coefficients. Coefficient a is equal to the tangent of the slope and can be interpreted as the trend of salinization–desalinization. A separate legend was developed on the basis of the trends of salinization–desalinization calculated for the period from 1983 to 1989.

The absence of clear trends in the direction of salinization–desalinization processes for 1983–1989 is also confirmed by the maps of averaged soil salinity (maps 12–15). During the five terms of observations, moderate salinity was observed on 70% of the total area (Table 8.3). Moderately saline soils were relatively stable in time, i.e., their salinity was preserved for 1–2 years and for the entire period. According to maps 1–5, the percentage of moderately saline soils in each year varied from 29 to 35%, i.e., it was two times lower than the percentage of moderately saline soils averaged for the entire period. This attests to the high dynamism of salinization–desalinization processes. The maps of averaged salinity were obtained via superposition of the maps of salinity for separate years. The sum of the degrees of soil salinity observed on a given plot observed during several years was divided into the number of these years to obtain the average characteristic. The years without observation (e.g., 1987) were not taken into account.

To estimate the portion of the area with a stable soil salinity status, the maps of stable soil salinity (maps 16–20, Fig. 8.4) were obtained. They showed that the maximum percent of stable soil salinity within a given grade (e.g., soils with stable moderate salinity) did not exceed 11–13% for two neighboring years; for the entire range of soil salinity classes, stable soil salinity was observed on 28–33% of the territory (Table 8.4). However, if all the maps for several years were compared (map 20, Fig. 8.4), the areas with stable soil salinity were much smaller; for the entire period (1983–1989), stable soil salinity of a given grade was observed on just 0.5–2.2% of the territory; for all the grades (classes) of soil salinity, stable conditions were observed on 5.3% of the territory. The statistical analysis showed that, with 95% probability, the grade of soil salinity remains unchanged from year to year on about 25% of the territory.

A different problem is related to the delineation of the most dynamic plots with respect to their salinity status. For this purpose, the map of maximum changes in the degree of soil salinity (map 21) was obtained via superposition of five basic maps of soil salinity for years 1983, 1985, 1986, 1988, and 1989. For each of the

Table 8.4 Areas and number of polygons of different saline soils as estimated from the maps of stable salinity status for 1983–1989

Map no; compared years	Total mapped		Non saline and slightly saline		Moderately saline		Strongly saline		Very strongly saline		Total area with stable soil salinity (km^2)
	Area (km^2)	Number of polygons	Area, (km^2)	Number of polygons	Area, (km^2)	Number of polygons	Area, (km^2)	Number of polygons	Area, (km^2)	Number of polygons	
Map 16; 1983 vs 1985	44.1	2,247	5.61	608	5.5	819	2.27	589	1.27	231	14.65
Percent	***100***	***100***	***12.7***	***27.1***	***12.5***	***36.4***	***5.1***	***26.2***	***2.9***	***10.3***	***33.2***
Map 17; 1985 vs 1986	41.93	2,173	4.12	594	5.6	792	2.65	612	1.21	175	13.6
Percent	**100**	**100**	**9.8**	**27.3**	**13.4**	**36.4**	**6.3**	**28.2**	**2.9**	**8.1**	**32.4**
Map 18; 1986 vs 1988	40.5	1,795	3.39	371	4.53	665	2.07	540	1.19	219	11.18
Percent	**100**	**100**	**8.4**	**20.7**	**11.2**	**37.0**	**5.1**	**30.1**	**2.9**	**12.2**	**27.6**
Map 19; 1988 vs 1989	45.73	2,387	2.54	345	5.5	789	4.24	954	2.05	299	14.33
Percent	**100**	**100**	**5.6**	**14.5**	**12.0**	**33.1**	**9.3**	**40.0**	**4.5**	**12.5**	**31.3**
Map 20; 1983 vs 1989	24.14	699	0.45	147	0.6	379	0.14	124	0.23	49	1.43
Percent	**100**	**100**	**1.7**	**21.0**	**2.2**	**54.2**	**0.5**	**17.1**	**0.8**	**7.0**	**5.3**

obtained polygons, the lowest and the maximum salinity grades were compared, and the difference between them was calculated.

The analysis of this maps showed that salinization–desalinization processes during the entire period (1983–1989) were active on 90% of the territory; on about 50% of the territory, changes in the soil salinity status were considerable, i.e., soil salinity changed by two grades and more.

The map of soil salinity dynamics (map 22) is based on superposition of the five basic maps and illustrates the average amplitude of changes in the salt status of given polygons during the studied period. For each polygon, the coefficient of salinization dynamics was calculated according to the following equation: $k = (|a - b| + |b - c| + |c - d| + |d - e| + |e - a|)/5$, where k is the coefficient of salinization dynamics and a, b, c, d, and e are the degrees of soil salinity observed within the polygon in 1983, 1985, 1986, 1988, and 1989, respectively. The analysis of this map demonstrated that soil salinity changed by more than one grade each year on more than 50% of the territory.

To determine the areas with the maximum (very strong) salinization, the map of distribution of strongly saline soils (map 23) was obtained via superposition of five basic maps. During the entire period, soils on more than 25% of the territory had the strong salinization degree at least during 1 year. Most often, strongly saline soils were confined to the areas adjacent to irrigation channels, which is quite logical.

Thus, in general, the territory of the studied farm in the period from 1983 to 1989 had the moderate degree of salinity in the upper soil meter; a weakly pronounced tendency for an increase in the degree of salinity was observed. On more than 59% of the territory, the state of soil salinity was highly dynamic; salinization–desalinization processes changed the status of soil salinity each year. Definite changes in the degree of soil salinity were observed on relatively small plots; the average size of soil polygons with changing soil salinity was about 0.1 ha. For the entire period (1983–1989), the direction of such changes in each particular polygon was not definitely pronounced and had a probabilistic character.

In other words, the territory of the farm had unstable conditions for crop growing despite the ameliorative measures applied in 1983–1989 and earlier. There may be several reasons for this negative phenomenon: the initial maps of salt reserves in the soils could be incorrect, which led to miscalculation of salt reserves and the norms of water applied to wash the soils; this could also be due to the improperly functioning drainage system or due to the violation of recommended irrigation technologies.

8.4 Conclusions

The dynamics of soil salinity on irrigated territories cannot be described with the use of a given criterion or a single map of salinization dynamics. The widely applied method of assessing the dynamics of salinization of irrigated soils based on the comparison of the maps of soil salinity obtained in two different time moments (survey periods) gives a biased estimate of the intensity and direction of salinization–desalinization processes and cannot be used for long-term forecasts. It is necessary to apply the entire set of the maps of soil salinity dynamics to reveal real processes of redistribution of salts on such territories.

References

Pankova EI, Mazikov VM (1976) Assessment of the salt status of irrigated soils of cotton fields on the basis of aerial images (with the Golodnaya Steppe as an example). Pochvovedenie 5:55–65 (in Russian)

Pankova EI, Mazikov VM (1985) Methodological recommendations on the use of aerial imagery for assessing soil salinity and salt surveys of irrigated areas in the cotton-growing zone on large and medium scales. VV Dokuchaev Soil Science Institute, Moscow, p 73 (in Russian)

Pankova EI, Rukhovich DI (1999) Monitoring of salinization of irrigated soils in arid regions by remote sensing methods. Eurasian Soil Sci 32:225–235

Pankova EI, Solov'ev DA (1993) Remote-sensing monitoring of salinization in irrigated soils. V.V. Dokuchaev Soil Science Institute, Moscow, p 187 (in Russian)

Zonn SV, Mazikov VM, Gorina MA, Lobov RA (1980) Prospects of using aerial and satellite imagery for soil cover studies. Pochvovedenie 4:37–45 (in Russian)

Chapter 9
Soil Salinity in the Central Arid Region of Iran: Esfahan Province

Mojtaba Fathi and Moslehedin Rezaei

Abstract Soil salinity in the central arid region of Iran is mainly due to dry climate, salt-rich parent materials, insufficient or lack of drainage and use of saline groundwater for irrigation. Esfahan province is located in the central arid region of Iran. Of 105,000 km^2 total area, an area of 5,000 km^2 is used for crop and fruit production. Soil and water salinity is the major limitation to achieve optimum crop yields. The soils are classified as Entisols and Aridisols. Soil salinity is distributed in nine physiographic land forms, namely, mountains, hills, plateau, piedmont plain, alluvial plain, lowland, flood plain, colluvial fan and alluvial fan. In this study, salinity data were obtained from soil survey project reports conducted in the last decade. The data showed the ECe varied to a large extent. The highest and lowest average salinities were 38.3 dS m^{-1} in the lowland (high evaporation and ground water table) and 0.6 dS m^{-1} in the mountainous area, respectively. High precipitation over evaporation in the mountainous area of west leached salts from soil profile. The ECe values are moderately high to extremely high in the east part of Zayandeh-Rud river plain due to fine soil texture and poor drainage. In the river plain, irrigation often causes secondary soil salinization. More work is required to establish real causes of soil salinization and spatial distribution in the province. However, it is evident that salinity distribution is highly variable in the central arid region of Iran and in different physiographic unit of land area. Future development of agriculture and industry in each landform should consider the present and future soil salinity potential. Given the importance of irrigated agriculture and the shortage of water supply, more ground-based soil and groundwater salinity monitoring schemes are needed as a prerequisite of land use in the region.

Keywords Central Iran • Esfahan • Land resources • Physiographic units • Soil salinity

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9.1 Introduction

The continued population growth and subsequent urban and industrial development in Iran have intensified the competition between agricultural, urban and industrial sectors for the available freshwater recourses. To meet the ever-increasing demand for food and agricultural products and due to the scarce freshwater resources, the marginal quality water is used for irrigation purposes. Soil and water salinity causes soil degradation and decreased crop yield, compared with nonsaline soils (Ghassemi et al. 1995; Hillel 2000).

The soil salinity could be natural and human-induced salinity due to the shallow saline water table or use of low-quality water for irrigation. In both cases, the growth of plants and microbial population is affected leading ultimately to low yields (Hillel 2000). In Iran, about 235,000 km^2 (or 14.2% of the total area of the country) area is salt-affected, which is equivalent to about 50% of irrigated lands in Iran (Pazira 1999). It is, therefore, highly likely that salinization may pose serious threats to sustainable irrigated agriculture in Iran (Siadat 1998). Except for the Gulf and Gulf of Oman watersheds, the hydrology of Iran is characterized by internal drainage. Mineralized runoff from channel, sheet and groundwater flow dissipates into saline marshes, salt flats and salt-crusted playas, where salts accumulate by evaporation of stagnant surface water or groundwater occurring close to the land surface.

These salt-rich areas cover vast depressions of the central plateau. Bordering these depressions, large areas are covered by weakly to strongly saline soils (Fig. 9.1). Other major occurrences of saline soils are in the delta regions and coastal lowlands along the Gulf and the Caspian Sea, where high groundwater tables and seawater intrusion promote the enrichment of salts. In the interior basin, intrusion of saline groundwater might also be caused by excessive groundwater utilized for irrigation purposes (Banaei et al. 2005).

Regular inventory and soil salinity monitoring is essentially needed for the sound utilization and sustainable management of the land resources of any country. However, the classical soil survey methods of field sampling, laboratory analysis and interpolation of these field data for mapping, especially in large areas, are relatively expensive and time-consuming. In an early country-wide assessment, Dewan and Famouri (1964) estimated the extent of saline soils in Iran at about 250,000 km^2 including saline alluvial soils, solonchak and solonetz, salt marsh soils and saline desert soils. According to the recently published soil map at the scale of 1:1,000,000 (SWRI 2000), slightly and moderately saline soils occupy approximately 255,000 km^2, and strongly saline soils cover about 85,000 km^2 (FAO 2000). In Esfahan province, soil survey data was collected by Esfahan Agricultural and Natural Resources Research Centre (weather, semi-detailed and detailed soil survey); of the total 100,000 km^2 area, the data is available only for 13,000 km^2 consisting of mostly agricultural land; however, it is apparent that a systematic study on the extent of salinity in the whole province is currently not available. Especially in the central and eastern part, large areas covered by saline soils are not used for agricultural purposes due to shortage of water.

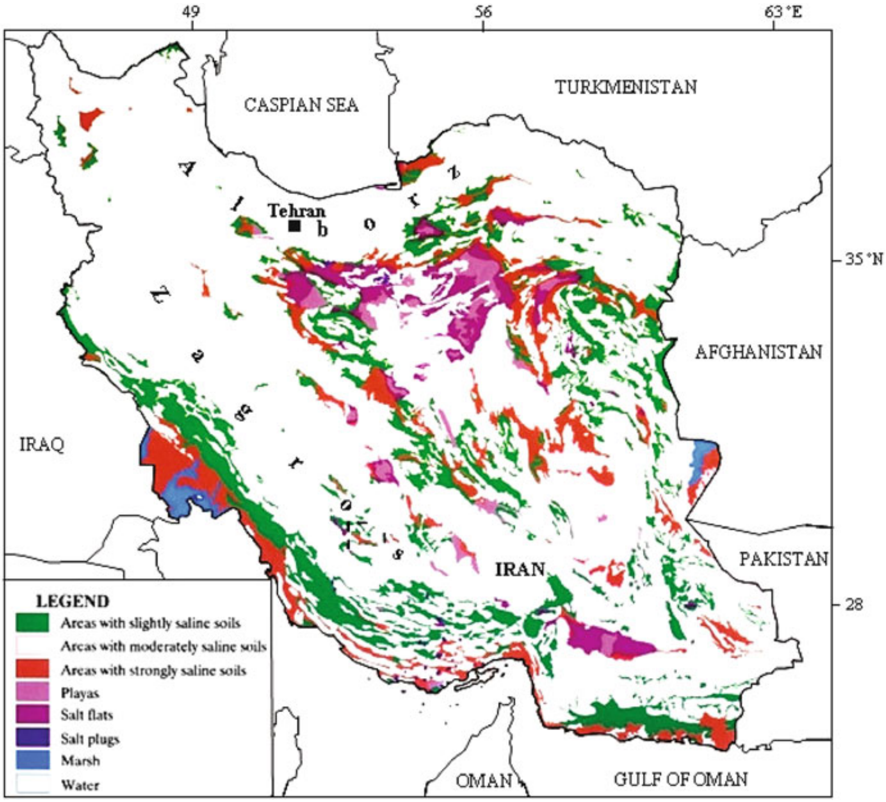

Fig. 9.1 Distribution of salt-affected soils in Iran (From SWRI 2000)

Development of soil salinity in the Esfahan province is mainly related to a dry climate, salt-rich parent materials of soil formation, and insufficient drainage. However, increase in the use of poor quality groundwater resources for irrigation purposes intensifies the development of saline soils. The growing water scarcity due to drought and the increasing water demands of industries, households and environment are major threats to sustainable agricultural development in Esfahan (Kalbasi and Mousavi 1995). In many areas, primarily salt-affected soils are used for irrigated agriculture, which causes secondary soil salinization in Iran (Ministry of Agriculture of Iran 1992). This chapter reviews and discusses the properties of natural and secondary saline soils in Esfahan province.

9.1.1 Climate of Esfahan Province

Esfahan province approximately occupies 107,027 km^2, and the elevation is about 1,800 m. It is located in the centre of Iran in a predominantly arid or semiarid

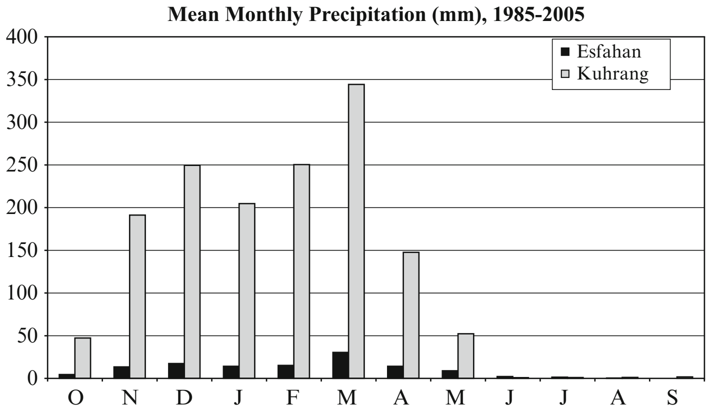

Fig. 9.2 Precipitation comparisons of Esfahan City and Kuhrang

climate condition. Average annual rainfall is 130 mm, occurring mostly in the winter months (December to April). During the summer, there is no effective rainfall. Temperature is hot in summer, reaching an average of 30°C in July; the winter is cooler with an average minimum temperature of 3°C in January. Annual evapotranspiration is 1,500 mm, and for feasible crop production, reliable irrigation water supply is needed.

The weather data from Kuhrang which lies just to the west of the Zayandeh-Rud basin have shown (Fig. 9.2) the climatic conditions are markedly different in various topographic positions compare with the rest of the province. Kuhrang elevation is about 2,300 m, with an average annual precipitation of 1,500 mm. Most of the precipitation is in the form of snow, which remains on the ground throughout the winter, only melting when temperatures warm up from April onwards. Winter temperature stays below freezing for weeks, although summers are pleasant with average maximum temperatures of 22°C in July. Esfahan province faces widespread droughts regularly, causing large economical and social damages (Murray-Rust et al. 2002).

9.1.2 Water Uses in Esfahan Province

Irrigation of agricultural lands and municipal water use in the Esfahan province are mainly relied on water resources from Zayandeh-Rud river. The Zayandeh-Rud is the most important river in Esfahan province in the central Iran and mainly fed by snowmelt from the Zagros Mountain ranges. It flows through Esfahan City which is one of the main and historical municipal eras in central Iran. Spring flood waters from the mountains snow melt onto flat alluvial plains during the warm spring months provide an environment for irrigated agriculture. Although some of the gross shortfalls in water are met through trans-basin diversions from other catchments in the Zagros Mountains, these will not automatically reverse the trends towards less water, and water of lesser quality, for both agricultural and nonagricultural uses. Zayandeh-Rud is a closed basin; the river terminates in the Gavkhuni Swamp which is a natural salt pan. This condition of salt leaching by good quality water from Zayandeh-Rud river and secondary soil salinity by drainage combining with inherent diversity of salt content of soil parent material led to a wide range of soil salinity condition on different land units (Mohammadi 1994).

Dominated soil salinity class of soil profiles in each land recourses unit was chosen as the reprehensive of the unit, and the thematic map of soil salinity was delineated for studied areas. The ILWIS3 (ITC 2003) was used as the main GIS package for raster and vector data input, output, analysis and processing.

In a second part, properties and salinity of eight selected soils from the main irrigation regions in the Zayandeh-Rud basin were described. Zayandeh-Rud river basin is the most important crop production region in arid centre of Iran.

Soil horizon and it's depth, weighted mean of pH, TNV%, gypsum, sum of cations, organic carbon, sand, silt, clay, soil texture, saturation percentage, EC of saturated soil pasted extract (ECe), total calcium and magnesium, sodium, sulphate, carbonate and ESP (exchangeable sodium percentage) and soil colour were determined (Abrol et al. 1988).

9.2 Results

Soils of the Esfahan province have been developed in various situations and are classified as Entisols and Aridisols (Soil Survey Staff 2003). Given the diverse nature of soils and climatic zones subject to salinity, there are significant differences in soil salinity between and within land resources units.

Arable land covers about 5% of the total land area of Esfahan province. The extent of arable land is limited by the availability of water and could be considerably increased, if water storage and distribution is improved. Some soils are heavily affected by salinization as indicated by salt efflorescence on soil surfaces, presence of halophytic vegetation and poor growth of agricultural crops. These salt-rich areas cover vast depressions in the east of the province. Bordering these depressions, large areas are covered by strongly saline soils. These natural saline soils occur in the east and north-east of the province; however, they have not been studied in detail because of their low agricultural potential. They are deep and heavy-textured soils and occur where high saline groundwater tables promote the enrichment of salts and are located in a lower elevation, which collect runoff from surrounding land. Such salinized soils are typically developed on the alluvial and lacustrine sediments along drainage lines and around salt lake systems under the influence of rising saline groundwater. Other major occurrences of saline soils are in levelled flood plain with heavy texture and poor drainage condition. In alluvial river plain, some of deep heavy-textured soils are moderately saline and suitable for irrigated agriculture after drainage establishment and desalinization process. In irrigated area, intrusion of

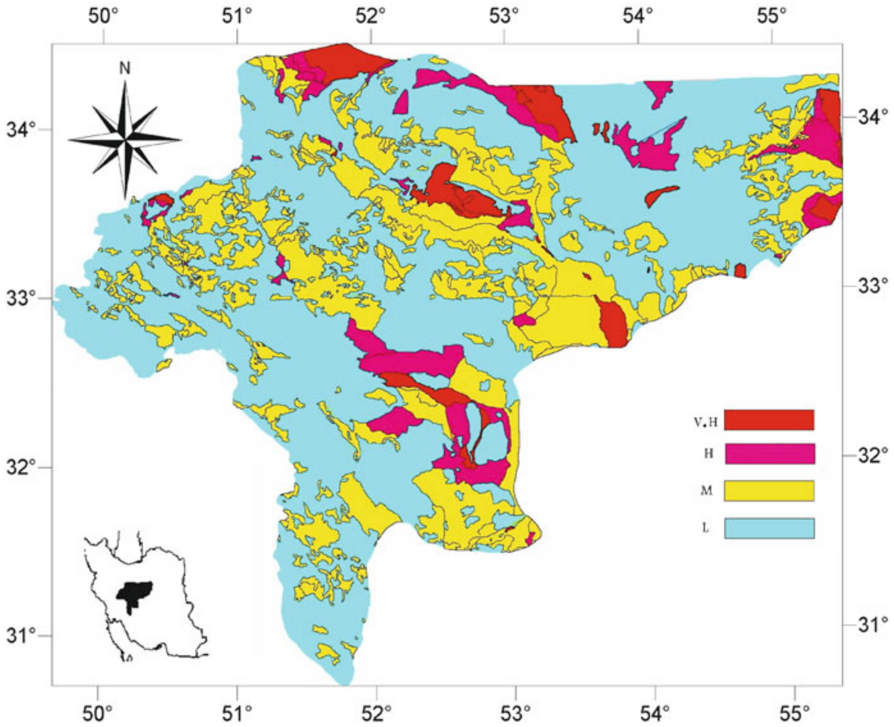

Fig. 9.3 Distribution of salt-affected soils in the Esfahan province: *L* nonsaline (<3 dS m^{-1}), *M* moderately saline (3–12 dS m^{-1}), *H* highly saline (12–16 dS m^{-1}); *V.H* very highly saline (>16 dS m^{-1})

saline groundwater might also be caused by excessive groundwater extraction for irrigation purposes.

In mountains and hill land units, soils are nonsaline, except small area which are formed from Miocene gypsiferous marls and limestone parent materials, especially in eastern part of the province where precipitation and soil leaching are low; however, the level of salinity even at depth would not be severely limiting to plant growth (Fig. 9.3). Some statistics about the data for ECe distribution in nine land resources units, namely, mountains, hills, plateau, piedmont plain, alluvial plain, low land, flood plain, colluvial fan and alluvial fan, are given in Table 9.1. Table 9.1 illustrates that there is a considerable difference between land units and the extreme values (minimum and maximum) in each land unit.

The highest and lowest average salinities were 38.3 dS m^{-1} in lowland and 0.59 dS m^{-1} in mountains area, respectively. The lowland area in the south-east of the province with higher evaporation rate and high groundwater tables is more susceptible to salt accumulation. High precipitation in mountain area of west, low temperature and evaporation rate cause higher salt leaching from soil profile. The saline soils in some hills and plateau land units in different parts of the province are due to

Table 9.1 Average, maximum, minimum and mode of soil salinity (dS m^{-1}) in different land resources map units

Land unit	Average	Maximum	Minimum	Mode
Mountains	0.59	3.0	0.2	0.4
Hills	2.38	16.6	0.4	0.5
Plateau or upper terraces	5.17	62.5	0.2	0.5
Piedmont alluvial plain	1.22	7.31	0.2	0.4
River alluvial plain	3.87	19.7	0.4	0.7
Lowland	38.33	48.0	26.5	38.0
Flood plain	15.52	120.0	0.5	1.0
Gravelly colluvial fans	1.79	11.6	0.2	0.5
Gravelly alluvial fans	1.34	3.6	0.5	0.9

salt-rich parent material including gypsiferous marls and limestone in east part of Zayandeh-Rud basin (NIOC 1975–1978). The ECe values are moderately high to extremely high due to fine soil texture and poor drainage. In river plain, irrigation often causes secondary soil salinization, depending on a variety of factors including the amount of salt content and composition of irrigation waters, shallow water table results from excessive irrigation and seepage from irrigation canals, poor natural drainage of heavy-textured alluvial deposits and recent terraces, conveyance losses and insufficient drainage or water scarcity hampering effective leaching. It is apparent from the available data that there is limited knowledge on the chemical, physical and biological properties of soils and spatial variability in arid central region of Iran. More data on the salinity status of soils in Esfahan province and salinization are needed to further identify the causes and spatial extent of the salinity problem. This would help to differentiate between primary and secondary salinization and to adequately address the problem of soil salinization in the area.

The use of reconnaissance maps followed by site observations and detailed soil survey is a useful tool in detecting soil salinity at a regional scale that could serve as the basis for improved decision making or highlight areas for further investigation. More work is needed to develop a flexible, generic framework for soil salinity mapping at different scales and in different environments of the province. In a second part, the properties and salinity of selected soils from the main irrigation regions in the Zayandeh-Rud river basin were described (Fig. 9.4).

Soils of the region are classified according to US soil taxonomy method as Fluventic Haplocambids (S1, S2), Typic Aquisalids (S3, S6, S8), Typic Torrifluvents (S4), Typic Torriorthents (S5) or Typic Aquicambids (S7) (Soil Survey Staff 2003). All soils are slightly alkaline as indicated by pH (H_2O) values between 7.0 and 8.5 (Table 9.2). The soils are calcareous with total calcium carbonate ($CaCO_3$) equivalent levels ranging from 18 to 45%. Small quantities of gypsum ($CaSO_4{\cdot}2H_2O$) are detected in all sites, whereas samples of S3, S4, S6 and S8 show elevated gypsum contents with maximum values of 12.6% in S6. However, the reported soil gypsum content is highly underestimated (Toomanian et al. 2001). Texture at the soil surface varied from sandy loam in the Ghohab Typic Torrifluvents to clay in the Dargan

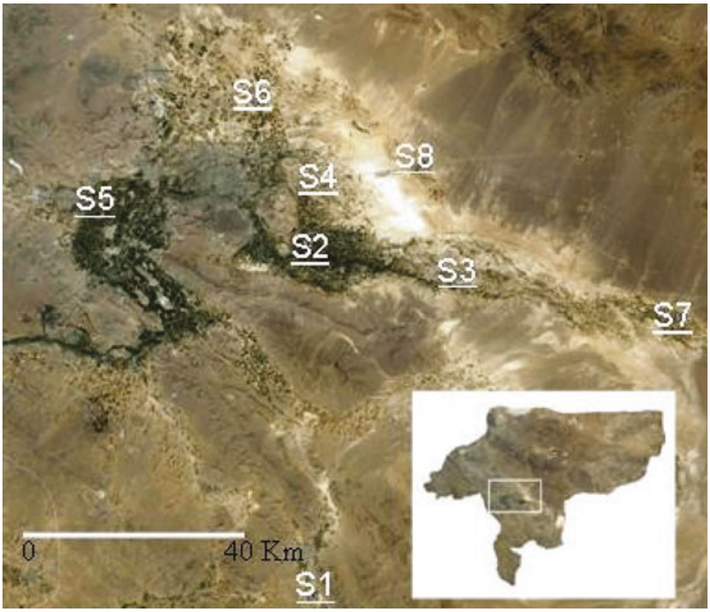

Fig. 9.4 Location of selected soil profile in Zayandeh-Rud irrigation region

Typic Aquicambids; S1, S2, S3 and S8 profiles had an increase in clay levels with depth (Table 9.3). Soil particle size of S1, S2, S3 and S7 in A horizon is dominated by the silt fraction (39–63%). The S1, S2, S5 and S7 are rich in clay with maximum clay contents of 36%. In soil S7, significant variations in clay content within soil profile result from layering of sediments (stratification process when alluvium settled from water). The texture, structure and sodicity of the profile will be significant in determining how easily entrained salt is leached.

ECe values are extremely variable, ranging from 0.76 to 137 dS m^{-1}. Topsoil ECe values decreased with depth except in S2. The common ions are calcium (Ca), magnesium (Mg) and sodium (Na). Concentrations of cations and anions in the soil saturation extract of different horizons and soils vary to a large extent. Sodium is the main cation in S3, S6, S7 and S8, whereas calcium and magnesium are dominated in S1, S2, S4 and S5. Exchangeable Na levels varied in the topsoil but were generally low in the subsoil. The Exchangeable Sodium Percentage (ESP) decreased with depth in S3, S6 and S7.

The anionic composition is dominated by chloride and sulphate in S1, S3 and S4, except S1 which dominates in bicarbonate; other profiles are dominated by chloride or sulphate. Sulphate is higher than chloride in S4 and S6 due to the presence of high gypsum content, while the opposite is true for the other soils. Compared with these major anions, bicarbonate is found in negligible concentrations except for S1.

The presence of excessive amounts of exchangeable sodium reverses the process of aggregation and causes soil aggregates to disperse into their individual constituent consequently degrading soil structure by blocking soil pores which ultimately

Table 9.2 Average, maximum, minimum and mode of soil salinity (dS m^{-1}) in different land resources map units

Soil	Soil taxonomic class	CEC	Texture	OC	pH	ECe	ESP	Gypsum	TNV	Cations	Anions	Drainage	Suitability for plant
S1	Fluventic haplocambids	13.0	CL	0.57	8.1–8.2	0.76	1.58	1.0	43	Ca	$HCO_3 > Cl > SO_4$	Good	Suitable
S2	Fluventic haplocambids	14.8	CL	0.58	7.6–8	4.56	11.10	0.7	37	Mg	$Cl > SO_4 > HCO_3$	Moderate	YR
S3	Typic aquisalids	–	CL	0.26	8.–8.5	30.53	39.00	6.8	35	Na	$Cl > SO_4 > HCO_3$	Moderate	Pasture
S4	Typic Torrifluvents	–	SL	0.46	7.6–8	1.86	0.59	5.7	18	Mg	$SO_4 > Cl > HCO_3$	Good	Suitable
S5	Typic Torriorthents	9.8	SCL	0.36	7.8–8	1.90	3.46	0.5	45	Ca	$Cl > SO_4 > HCO_3$	Good	Suitable
S6	Typic aquisalids	–	L	0.56	7.5–8	137.40	88.78	12.6	22	Na	$SO_4 > Cl > HCO_3$	Moderate	Pasture
S7	Typic Aquicambids	25.6	C	1.10	7.9–8.5	3.10	11.82	–	42	Na	$Cl > SO_4 > HCO_3$	Poor	Suitable
S8	Typic aquisalids	10.0	SiL	1.40	7–7.9	53.20	41.79	7.6	23	Na	$Cl > SO_4 > HCO_3$	Poor	Pasture

Weighted mean according to soil horizon thickness *a*; *CEC* (meq per 100 g soil), *ESP* Exchangeable sodium percentage, *texture* soil surface texture, *CL* clay loam, *SL* sandy loam, *SCL* sandy clay loam, *L* loam, *C* clay, *SiL* silt loam, *OC* top soil organic carbon content, *ECe* electrical conductivity of soil saturation extract (dS m^{-1}), *gypsum* (%), *TNV* total neutralizable material in %, dominant cations and anions, *drainage* drainage classification, *suitability* suitability for crop cultivation, *YR* yield reduction of salt sensitive crop

Table 9.3 Physical and chemical characteristics of the soils S1–S8

Depth (cm)	Horizon	pH (H_2O)	TNV (%)	Gypsum (%)	Cations (meq l^{-1})	Org-C (%)	Sand	Silt	Clay	Texture class	SP%	ECe (dS m^{-1})	Ca + Mg (meq l^{-1})	Na^+	Cl^-	SO_4^{2-}	HCO_3^-	ESP
S1 – Qomshe, Pediment Plain, Thermic Carbonatic Fine Loamy Fluventic haplocambids																		
0–25	A	8.1	39.0	0.9	7.3	0.57	22.0	42	36.0	CL	37	0.71	5	2.3	4	–	3.2	0.68
25–50	Bw1	8.1	41.0	0.1	7.5	0.36	18.0	44	38.0	SiCL	38	0.65	5	2.5	4	–	3.2	0.80
50–90	Bw2	8.1	42.0	1.1	6.5	0.36	18.0	40	42.0	SiC	40	0.66	4	2.5	2	2	2.4	0.70
90–125	Bw3	8.1	41.0	1.3	6.5	0.36	18.0	38	44.0	C	44	0.63	4	2.5	3	1	24.0	0.70
125–160	C1	8.2	49.0	1.0	9.0	0.21	42.0	14	44.0	C	42	0.87	5	4.0	3	4	2.0	0.24
160–200	C2	8.1	43.0	1.4	11.0	0.15	24.0	44	32.0	CL	30	1.00	6	4.0	5	4	2.0	0.14
S2 – Esfahan, Alluvial Plain, Thermic Carbonatic Fine Fluventic haplocambids																		
0–25	A	8.0	39.5	0.5	40.0	0.58	24.6	39	36.4	CL	43	3.10	25	15.0	22	15	4.0	0.80
25–50	Bw	7.8	38.5	0.7	63.0	0.38	12.6	45	42.4	SiC	44	4.25	45	18.0	35	25	2.4	1.00
50–95	Bw2	7.7	37.0	0.7	78.0	0.35	11.6	47	41.4	SiC	43	5.10	48	30.0	45	32	2.4	1.20
95–145	Bw3	7.6	37.0	0.5	125.0	0.35	8.6	45	46.4	SiC	48	7.35	80	45.0	82	41	1.6	1.30
145–195	C1	8.0	35.0	0.9	31.0	0.19	10.6	45	44.0	SiC	46	2.35	24	70.0	17	11	2.4	1.20
195–200	C2k	8.0	32.0	0.6	30.5	0.26	6.6	41	52.4	SiC	59	2.94	24	95.0	19	8	2.8	1.50
S3 – Zarandid, Alluvial Plain, Thermic Mixed Fine Typic aquisalids																		
0–20	Az	8.3	31.0	15.5	975.0	0.26	31.0	41	28.0	CL	36	81.60	150	825.0	900	80.0	0.8	15.00
20–40	C1z	8.0	34.0	12.2	732.5	0.17	6.0	47	47.0	SiC	40	50.60	120	732.5	580	149.9	1.6	15.00
40–70	C2	8.1	36.0	2.1	341.0	0.08	6.0	33	61.0	C	52	19.40	66	275.0	170	168.8	1.2	13.00
70–100	C3	8.1	32.0	1.7	456.0	0.08	6.0	31	63.0	C	64	11.80	46	110.0	84	69.8	1.2	12.80
100–140	C4	8.1	37.0	2.8	315.0	0.05	8.0	49	43.0	SiC	56	21.30	90	225.0	206	106.0	2.0	9.00
140–170	C5	8.1	36.0	9.6	234.0	0.05	11.0	64	25.0	SiL	48	16.10	54	180.0	160	71.0	2.0	6.20
170–200		8.5	36.0	9.6	632.5	0.05	11.0	62	27.0	SiCL	44	39.70	170	462.5	360	168.6	2.4	8.00
S4 – Ghohab, Alluvial Plain, Thermic Mixed Fine Loamy over sandy Typic Torrifluvents																		
0–25	A	7.6	24.0	2.1	–	0.46	58.0	22	20.0	SCL	52	4.20	180	40.0	166	390.0	200	0.90
25–50	C1	8.0	27.0	9.3	–	0.15	53.0	23	24.0	SCL	25	2.60	0	–	–	–	–	–

50–130	IIC1	7.8	14.0	–	–	0.04	90.0	4	6.0	S	21	1.40	0	–	–	–	–	–
130–200	IIC2	8.0	18.5	–	–	0.05	84.0	10	6.0	LS	21	1.30	0	–	–	–	–	–
S5 – Vilashahr, Alluvial Colluvial Fan, Thermic Carbonatic Fine Loamy Typic Torriorthents																		
0–20	A	7.9	44.0	0.6	32	0.36	48	22	30	SCL	33	2.4	22	10	14	14	3.2	0.70
20–40	C1	7.8	42.0	0.7	32	0.27	48	22	30	SCL	36	2.4	22	10	16	14	1.6	0.70
40–70	C2	7.9	48.0	0.7	19	0.12	58	12	30	SCL	24	1.6	11	8	9	7	2.0	0.60
70–100	C3	8.0	49.0	0.4	16	0.06	64	16	20	SCL	31	1.3	9	7	8	6	2.0	0.32
100–150	C4	7.9	41.0	0.5	26	0.09	66	6	28	SCL	37	2.1	16	10	12	12	1.2	0.10
150–200	C5	7.8	45.0	0.4	25	0.09	78	2	20	S.CL	35	1.9	16	9	11	12	1.2	0.52
S6 – Parvaneh, Flood Plain, Thermic Mixed Fine Loamy Typic Aquisalids																		
0–20	C1z	7.7	15.0	22.4	5,761	0.56	42	37	21	L	39	344.0	56	5,200	4,400	13,596	0.4	12.00
20–40	C2z	7.8	22.3	16.2	4,094	0.70	30	46	24	L	39	305.2	94	4,000	3,000	1,088.8	1.2	14.00
40–70	C3zy	8.0	20.0	4.5	1,850	0.31	17	54	29	SiCL	48	134.8	200	1,850	1,140	708.8	1.2	9.00
70–100	C4zy	7.5	21.5	20.6	–	0.24	32	44	24	L	44	107.4	0	–	–	–	–	–
100–150	C5zy	7.5	25.0	6.2	–	0.20	22	55	23	SiL	48	70.0	0	–	–	–	–	–
150–200		7.8	22.5	13.8	–	0.15	36	44	20	L	48	74.7	0	–	–	–	–	–
S7 – Dargan, Alluvial Plain, Thermic Carbonatic Fine Typic Aquicambids																		
0–20	B1g	7.9	41.0	–	245.0	1.10	12	46	42	SiC	50	16.4	70	175	170	70.0	4.4	6.80
20–40	B2g	8.5	39.5	–	22.0	0.68	14	44	42	SiC	48	2.0	4	18.0	11	6.0	5.2	4.00
40–80	C1g	8.6	44.5	–	15.5	0.45	18	44	38	SiCL	56	2.4	3	12.5	6	4.4	4.0	3.60
80–120	C2g	8.5	38.0	–	11.8	0.19	18	50	32	SiCL	44	1.1	3	8.8	5	3.5	3.2	1.80
120–150	C3g	8.2	42.0	–	23.0	0.14	16	62	22	SiL	41	2.2	9	14.0	13	8.0	2.0	1.50
150–200		8.5	44.0	–	13.8	0.16	22	56	22	SiL	41	1.3	4	9.8	8	3.0	3.2	1.30
S8 – Gorgab, Flood Plain, Thermic Gypsic Fine Loamy Typic aquisalids																		
0–20	Az	7.0	12.0	231	3,668	1.40	–	–	–	–	48	250.0	868	2,800	4,960	40	2.4	3.60
20–45	C1z	7.4	23.0	134	1,540	0.32	42.6	27	30.4	CL	39	79.0	430	1,110	1,450	90	1.2	3.20
45–80	C2	7.7	25.5	47	772	0.19	17.6	40	42.4	SiC	52	23.2	212	500	710	60	2.4	5.00
80–105	C3	7.8	23.5	88	660	0.16	12.6	51	36.0	SiCL	52	31.0	160	340	530	128	0.8	5.20
105–145	C4	7.8	26.0	35	455	0.16	10.6	39	50.4	C	55	25.5	115	340	400	55	1.2	5.60
145–200	C5y	7.9	24.0	79	230	0.10	14.6	47	38.4	SiCL	58	19.1	90	230	230	36	1.2	5.60

restrict water movement and root growth (Hillel 2000). The ESP values are extremely variable in studied soils; the S3, S6 and S8 are very strongly sodic with ESP values 39, 89, and 42%, respectively, where S1, S4, S5 and S7 are non-sodic (Table 9.2).

9.3 Conclusions

The land resources in the Zayandeh-Rud basin are very fragile due to high soil salinity, low soil organic matter and excessive presence of harmful salt in the soil upper profile. Large land renovation and newly farm irrigation system instalments should consider the basic soil properties and water quality to get full advantage and return of invested money. The combine and comprehensive soil properties, water quality, irrigation system, crop nutrient recommendation and selection of resistance/tolerance plant should be considered to get the full advantage of available soil and water resources. Expansion of new agricultural area is not recommended due to the shortage of irrigation water. Conversion of old cultivated area to industrial and municipal area should be avoided due to high soil quality.

Given the importance of irrigated agriculture on the one hand and the shortage of water supply on the other hand, more ground-based soil and groundwater salinity monitoring schemes are needed as a prerequisite of sound irrigation practices in the irrigated region of the province especially in Zayandeh-Rud river basin as the most important crop production region in arid centre of Iran.

References

Abrol IP, Yadav JSP, Massoud FI (1988) Salt-affected soils and their management. FAO Soils Bull 39, Rome, p 131

Banaei MH, Momeni A, Baybordi M, Malakoti MJ (2005) Soils of Iran. Sana Publications, Tehran, Iran

Dewan ML, Famouri J (1964) The soils of Iran. FAO, Rome, p 319

FAO (2000) Global Network on Integrated Soil Management for sustainable Use of Salt-Affected Soils. Retrived from: http://www.fao.org/ag/ag1/ag11/spush/topic2.htm=iran

Ghassemi F, Jakeman AJ, Nix HA (1995) Salinization of land and water resources: human causes, extent, management and case studies. UNSW Press/CAB International, Sydney/Wallingford

Hillel D (2000) Salinity management for sustainable irrigation: integrating science, environment and economics. The World Bank, Washington, DC

ITC (2003) ILWIS 3. ITC, Enschede

Kalbasi M, Mousavi SF (1995) Seven-year study of fluctuations in N, P, EC and pH of the Zayanderud river. In: Proceedings of the regional conference on water resources management, Isfahan, Iran, 28–30 Aug 1995, p 151 (English abstract)

Ministry of Agriculture of Iran (1992) Research and development. Study of agricultural and revitalization and natural resources developments in Zayandeh Rud and Ardestan Basin, Iran

Mohammadi M (1994) The correlation study of soil of south central dry regions of Iran. First section. Soil and Water Research Institute, Karaj

Murray-Rust H, Salemi HR, Droogers P (2002) Water resources development and water utilization in the Zayandeh-Rud Basin, Iran

NIOC – National Iranian Oil Company (1975–1978) Geological Map of Iran at the scale of 1:1 000, 6 sheets. National Iranian Oil Company, Tehran

Pazira E (1999) Land reclamation research on soil physico-chemical improvement by salt leaching in southwest part of Iran. IERI, Karaj

Siadat H (1998) Iranian agriculture and salinity. In: Proceedings of the conference on new technologies to combat desertification, Tehran, 12–15 Oct 1998, pp 10–14

Soil Survey Staff (2003) Keys to soil taxonomy, 9th edn. USDA-NRCS, US Government Printing Office, Washington, DC

SWRI – Soil and Water Research Institute Iran (2000) Land Resources and Potential Map of Esfahan Province (1:250 000). SWRI, Karaj

Toomanian N, Jalalian A, Eghbal MK (2001) Genesis of gypsum enriched soils in north-west Esfahan, Iran. Geoderma 99:199–224

Chapter 10
Mapping the Risk of Soil Salinization Using Electromagnetic Induction and Non-parametric Geostatistics

Houria Dakak, Aicha Benmohammadi, Brahim Soudi, Ahmed Douaik, Mohamed Badraoui, and Abdelmjid Zouahri

Abstract The knowledge about the magnitude, the spatial extent, the distribution and the evolution of salinity over a period of time is essential for the better management of salt-affected soils. Soil salinity is determined, conventionally, by measuring the electrical conductivity of a saturated past extract (ECe). However, given the spatio-temporal variability of salinity, numerous samples are necessary, which makes the conventional procedure laborious and expensive. As an alternative, the apparent electrical conductivity of soil (ECa) can be measured in the field by the use of the electromagnetic induction (EMI) method. This method is fast and allows making extensive ECa determination in space and monitoring. In the present study, an area of 2,060 ha has been investigated in the irrigation district of Tadla, central Morocco. Twelve soil samples were collected for ECe measurement, while 92 ECa measurements were realized with EM38. The pairs of ECe-ECa values allowed establishing the calibration equation permitting to convert the ECa into ECe values and for other

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ECa values for which ECe was not accomplished. The geostatistics was used to develop maps for the risk of soil salinization. Initially, a threshold for the risk of soil salinization was determined, and indicators were built. Later, the spatial variability of these indicators was described and modelled using the variogram. Finally, the maps were generated based on a non-parametric method of geostatistical interpolation, that is, indicator kriging. The results showed that the study area presents various degrees of soil salinization risks. The south-eastern part and small areas in central west and east of the study area have a low risk of salinization. In contrast, the south-western, the north-western and the central parts have a high risk of salinization. All the remaining parts of the study area have a moderate risk of salinization. It is concluded that the combined use of ECe and ECa-EM38 values and geostatistics allowed establishing a reliable soil salinization risk map and help to develop rehabilitation plan for the salt-affected soils.

Keywords Central morocco • Indicator kriging • Indicator variogram • Soil salinity • Tadla plain

10.1 Introduction

Agriculture is an important economic sector in Morocco. Although it contributes only 20% to the gross domestic product (GDP) of the country, about 50% of the population is associated with agriculture sector. Most of Morocco is characterized by an arid and semiarid climate. Many efforts have been made to secure the production of food for an ever-increasing population including but not limited to building dams to irrigate plains and through agricultural intensification. The agriculture intensification in some cases degraded the lands and therefore compromised the sustainability of the whole production system.

Salt-affected soils in Morocco do occur in most parts. In places where marginal waters (saline, brackish) are used to offset water requirements of crops, mismanagement of resources caused the soils to become saline and retarded the crop yields. For the management and proper use of salt-affected soils, it is essential to understand the magnitude, the spatial extent and the temporal evolution of soil salinity. Soil salinity is highly variable in space and time due to different factors (parent material, groundwater, climate, anthropic activities, etc.), numerous samples are required to evaluate the degree of salinity of a given area and much more samples are necessary for monitoring it with time. This makes the conventional method of determining soil salinity by measuring the electrical conductivity of saturated paste extract-ECe (Rhoades et al. 1989; Sparks 1995) laborious and uneconomical. Many alternative ways have been tried in the past by measuring the soil apparent electrical conductivity (ECa) in the field using, for example, four-electrode probes (Halvorson et al. 1977; Nadler 1981), time domain reflectometry (TDR) (Dalton et al. 1984; Dalton and Van Genuchten 1986), or electromagnetic induction (EMI) sensors (Cameron et al. 1981; McKenzie et al. 1997; Dakak et al. 2011). Among these three techniques, the EMI is most widely used since it does not require any contact with soil (Rhoades and Corwin, 1981) thus allowing a more rapid and, consequently, an extensive sampling and monitoring of soil salinity. However, laboratory measurement of ECe is still required to calibrate ECa field measurements.

Since the beginning of the 1980s, geostatistical methods have been used in soil science for describing the spatial variability of soil properties and providing predictions at unsampled locations (Burgess and Webster 1980; Trangmar et al. 1985; Goovaerts 1999). Much have earlier been published around the world on soil salinity aspects (Hajrasuliha et al. 1980; Oliver and Webster 1990; Hosseini et al. 1994; Sylla et al. 1995; Bourgault et al. 1997; Odeh et al. 1998; Walter et al. 2001; Aradhanlioglu et al. 2003; Douaoui et al. 2006; Navarro-Pedreno et al. 2007; Shahid et al. 2010, 2011; Shahid and Rahman 2011). These works predicted the unknown values of soil salinity at unsampled locations based on parametric methods of geostatistical interpolation, that is, kriging. However, sometimes, one may be interested in quantifying a given risk, that is, the probability that, at an unsampled location, the unknown value is higher (or lower) than a given threshold. Geostatistics can help in answering this question by using non-parametric methods like disjunctive kriging or indicator kriging. These non-parametric methods were relatively less used than the parametric ones in the soil science literature (Webster and Oliver 1989; Smith et al. 1993; Goovaerts 2001; Van Meirvenne and Goovaerts 2001; Lark and Ferguson 2004; Amini et al. 2005) and much less for the specific case of soil salinity (Yates et al. 1986; Wood et al. 1990; Triantafilis et al. 2004).

Since disjunctive kriging and indicator kriging model the probability equally well and none is consistently superior to the other (Papritz and Dubois 1999) and since indicator kriging is less sophisticated and easier to use than disjunctive kriging, the former is used in this research work.

The objective of present study was to evaluate the spatial variability of soil salinity at the sub-watershed scale based on field and laboratory measurements. This variability was used in the frame of a non-parametric geostatistical interpolation method in order to assess the risk that the soil salinity, at unsampled locations, is higher than a given threshold.

10.2 Materials and Methods

10.2.1 Experimental Site

The irrigation district of Tadla in central Morocco, where our study area is located, covers 130,000 ha and is divided into two subdistricts separated by the Oum Rabia river (Fig. 10.1).

The soil salinity in this irrigation district varies between 0.35 and 23 dS m^{-1}. The topography is generally regular with a mean elevation of about 400 m. The climate is arid to semiarid Mediterranean with continental influence since the region is about 250 km from the Atlantic Ocean with cold and humid winter and warm

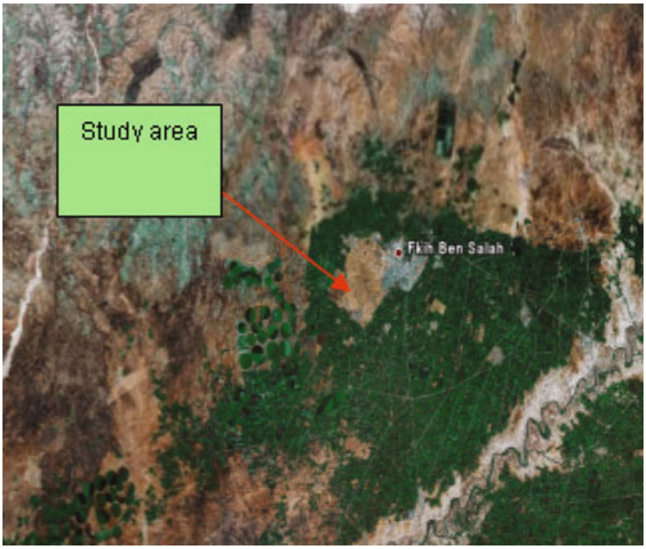

Fig. 10.1 The Tadla irrigation district showing the study area

and dry summer. Mean total rainfall amounts to 350 mm irregularly occurring along the year. Temperatures are also irregular and vary with seasons. Minimal temperatures occur during winter and range between 0 and 5°C whereas maximal temperatures occur during summer and reach 38–42°C. The mean annual evaporation is 1,800 mm and varies between 1,500 and 2,000 mm.

The predominant soil classes in the study area are the iso-humic which contains medium brown subtropical soils, saline and saline-sodic brown subtropical soils and medium chestnut soils. This soil class is characterized by moderate texture, deep to moderately deep and limestone presence from the surface. The water reserve is easily usable, on average 40–50 mm, and their texture is clayey and clayey-silt. The gradient of organic matter decreases with depth. The other class is the calci-magnesic, which includes brown limestones and 'rendziniform' soils. These soils are shallow, highly calcareous with a water reserve easily usable under 25 mm. The soil depths are 20–40 cm.

10.2.2 Data Sets

The experimental site is approximately 2,060 ha (Fig. 10.2). In this study, two data sets were used. The first one, called 'data to be calibrated', consists of the measurements of ECa in the field using the EM38 sensor of Geonics (McNeill 1986) at 92 locations on a pseudo-regular grid of 500×500 m. The second data set, called 'calibration data', corresponds to 12 locations, selected among the 92 locations above,

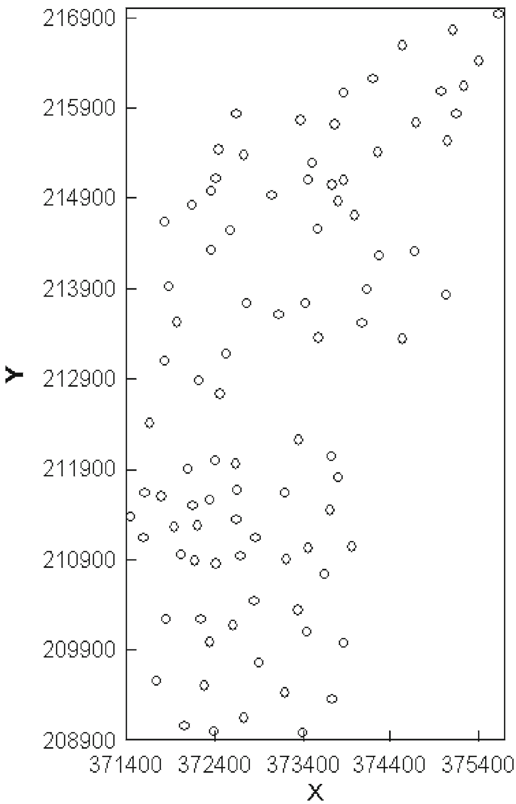

Fig. 10.2 Sampling scheme showing locations where ECa was measured

for which soil samples were collected and electrical conductivity from a saturated paste extract (ECe) was determined in the laboratory. Soil samples were taken at three depths to 90 cm by an increment of 30 cm. The mean ECe values at the three depths were considered in this study.

10.2.3 Methods

10.2.3.1 Calibration Equation

A simple linear regression model was used and applied to the 'calibration data' set in order to determine the calibration equation linking ECe to ECa:

$$\mathrm{ECe} = a + b \times \mathrm{ECa} \tag{10.1}$$

where a and b are the regression coefficients, that is, the constant and the slope, respectively. These coefficients were used to convert ECa values into ECe values for the 'data to be calibrated'.

10.2.3.2 Indicator Variogram and Kriging

The threshold value for evaluating the risk of salinization was set to 4 dS m^{-1} (Bowers and Wilcox 1965; Maas and Hoffman 1977). Based on this threshold, an indicator variable was created taking either 1 (ECe ≤ 4 dS m^{-1}) or 0 (ECe > 4 dS m^{-1}).

Geostatistics is based on the theory of regionalized variables (Matheron 1971). We describe here, very shortly, the concepts required for presenting the method used in this research work. Let $z(x)$ be the value of ECe at a given location x (in two dimensions). This value is considered as a realization of the random function $Z(x)$ (Goovaerts 1997). The indicator transform of $z(x)$ is $i_c(x)$ such that

$$i_c(x) = 1 \quad \text{if} \quad z(x) \le z_c, \quad \text{o} \quad \text{otherwise} \tag{10.2}$$

where z_c is the threshold value (in our case 4 dS m^{-1}).

$i_c(x)$ is considered as a realization of the random function $I_c(x)$:

$$I_c(x) = 1 \quad \text{if} \quad Z(x) \le z_c, \quad \text{o} \quad \text{otherwise} \tag{10.3}$$

It is known that

$$\text{Prob}\left[Z(x) \le z_c\right] = E\left[I_c(x)\right] = G\left[Z(x);\, z_c\right], \tag{10.4}$$

where Prob[ ], E[ ] and G[ ] denote, respectively, the probability, the mathematical expectation and the cumulative distribution function.

Since we are interested in determining the probability that ECe is higher than a given threshold, from Eq. (10.4), we can deduce Prob[$Z(x) > z_c$]:

$$\text{Prob}\left[Z(x) > z_c\right] = 1 - \text{Prob}\left[Z(x) \le z_c\right] = 1 - G\left[Z(x);\, z_c\right]. \tag{10.5}$$

The aim is to estimate $G[Z(x); z_c|(n)]$: the probability that $z(x) \le z_c$, conditional on a set (n) of observations of z at neighbouring sites, by kriging $I_c(x)$ from a set of indicator-transformed data.

The indicator variogram is estimated by the following equation:

$$\gamma_{I_c}(h) = \frac{1}{2N(h)} \sum_{\alpha=1}^{N(h)} \left[i_c(x_\alpha) - i_c(x_\alpha + h)\right]^2, \tag{10.6}$$

where $N(h)$ is the number of indicator pairs $i_c(x_\alpha)$ and $i_c(x_\alpha + h)$ separated by the distance h. The estimates are computed for a set of separation distances h, and the graph representing these estimates against h is called indicator variogram. A theoretical model is fitted to this experimental variogram. The spherical and exponential models are frequently used. The spherical model used in this study is defined below:

$$\gamma(h) = c_0 + c\left[\frac{3}{2}\frac{h}{r} - \frac{1}{2}\left(\frac{h}{r}\right)^3\right] \quad \text{for} \quad h > 0, \tag{10.7}$$

where c_0 is the nugget effect variance (due to random error and small-scale spatial variation), $c_0 + c$ is the sill variance (when the variogram reaches a plateau) and r is the spatial range (value of h at which the plateau is reached).

Once the indicator variogram is modelled, it is used to estimate $G[Z(x); z_c|(n)]$ at an unsampled location x_0:

$$I_c * (x_0) = \sum_{\alpha=1}^{n} \lambda_\alpha I_c(x_\alpha), \tag{10.8}$$

with λ_α being the weight attributed to the value $I_c(x_\alpha)$ at the location x_α; this weight is derived from the model of the indicator variogram (e.g. Eq. 10.7).

The simple linear regression was done using the SPSS statistical software (SPSS 2007), while the indicator variogram was described and modelled using the Variowin geostatistical software (Pannatier 1996) and the indicator kriging was done using the ArcGIS software (ESRI 2000).

10.3 Results and Discussion

10.3.1 Calibration Equation

The simple linear regression linking ECe to ECa, determined from the 'calibration data' set, has a constant of 0.58 and a slope of 4.22:

$$\text{ECe} = 0.58 + 4.22 \times \text{ECa}. \tag{10.9}$$

The Pearson correlation coefficient for the calibration equation was 0.88, showing that this relationship is strong and that ECe could be determined reliably from ECa. The regression coefficients were applied to the 'data to be calibrated' to estimate ECe from ECa for the whole data set. Some features of these estimated ECe values are presented in the next subsection.

10.3.2 Descriptive Statistics

The ECe summary statistics are reported in Table 10.1. The mean ECe value of the whole data set is 4.28 dS m^{-1} which is slightly above the threshold value for the risk of salinization. However, there is a large variability since the values range between 2.2 and 6.1 dS m^{-1} and their coefficient of variation is of 20%. The mean and median values are of the same magnitude indicating that ECe values follow roughly a normal distribution. This is confirmed by the skewness and kurtosis coefficients which are near 0 and 3, respectively.

Table 10.1 Summary statistics for ECe data

Statistics	Values
Mean	4.28
Median	4.30
Minimum	2.20
Maximum	6.10
Coefficient of variation	20%
Skewness	−0.35
Kurtosis	3.01

Table 10.2 Parameters of the model fitted to the ECe experimental indicator variogram

Parameters	Values
Model	Spherical
Range (m)	1,300
Nugget effect variance (dS m^{-1})^2	0.078
Partial sill variance (dS m^{-1})^2	0.140

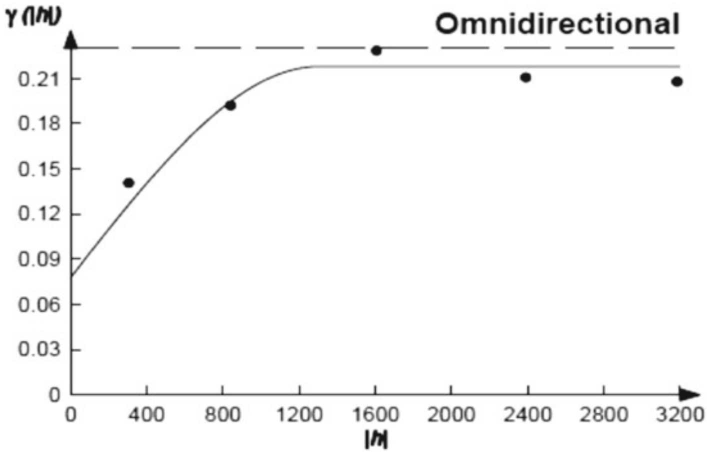

Fig. 10.3 The experimental and fitted ECe indicator variograms

10.3.3 Spatial Variability

The parameters of the model fitted to the experimental indicator variogram are reported in Table 10.2, and the fitted model is shown on Fig. 10.3.

The relative nugget effect, defined as the ratio of the nugget effect variance to the sill variance, is 36%, showing that more than one third of the total variation in transformed ECe values is random and not spatially structured. Since the ratio is in the interval 25–75%, the spatial variability of the transformed ECe variable can be considered to be moderate (Chang et al. 1998). The range is 1,300 m, meaning that two transformed ECe values separated by less than this distance could be considered to

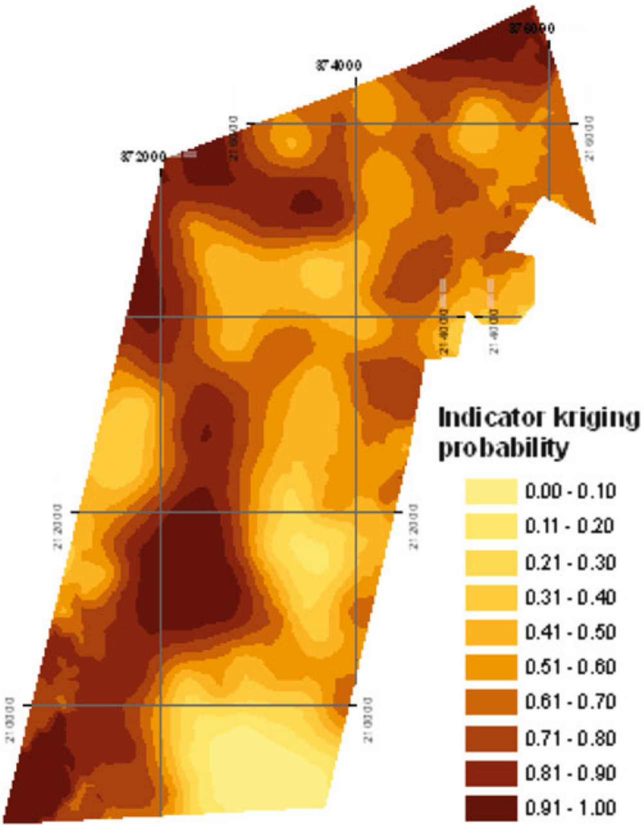

Fig. 10.4 Map of the risk of soil salinization (indicator kriging probability)

be spatially dependent on each other, while those further apart could be considered spatially independent and having no influence on each other.

10.3.4 Maps of the Risk of Soil Salinization

Figure 10.4 shows the map of the conditional probability derived from indicator kriging for the threshold value of 4 dS m^{-1}. The south-eastern part and small areas in central west and east of the study area have a low risk of salinization. In contrast, the south-western, the north-western and the central parts have a high risk of salinization. All the remaining parts have a moderate risk of salinization. A further investigation should be made to determine the relationship between the degree of risk of salinization and the spatial variability of soil properties that may have an influence on this soil degradation. Also, based on this map, we can see where the growing of a given crop could be risky and where it could be done without or with a small risk.

10.4 Conclusions

The risk of soil salinization of a sub-watershed at the Tadla plain in central Morocco was evaluated using laboratory and field measurements of electrical conductivity. Probabilities related to this risk were estimated using indicator kriging, a non-parametric method of geostatistical interpolation. This method allowed the delineation of different degrees of risk of soil salinization (low, moderate and high). Present work showed that the combined use of the electrical conductivity, electromagnetic induction and geostatistics allowed establishing a reliable soil salinization risk map. This information could serve as a basis for any rehabilitation effort of salt-affected soils, in the future, according to their actual risk of salinization and not by considering the average risk of the whole study area. To improve this delineation, more samples are required to distinguish subtle differences in risk. Furthermore, if someone is also interested in the estimation of the soil salinity values in addition to the risk, it would be recommended to use disjunctive kriging. Finally, since soil salinity is a dynamic soil property, it should be monitored with time. Methods used by Douaik et al. (2004) and Douaik (2005) could be useful sources for these studies.

References

Amini M, Afyuni M, Khademi H, Abbaspour KC, Schulin R (2005) Mapping risk of cadmium and lead contamination to human health in soils of central Iran. Sci Total Environ 347:64–73

Aradhanlioglu O, Oztas T, Evren S, Yilmaz H, Yildirim ZN (2003) Spatial variability of exchangeable sodium, electrical conductivity, soil pH and boron content in salt- and sodium-affected areas of the Igdir plain (Turkey). J Arid Environ 54:495–503

Bourgault G, Journel AG, Rhoades JD, Corwin DL, Lesch SM (1997) Geostatistical analysis of a soil salinity data set. Adv Agron 58:241–292

Bowers CA, Wilcox LV (1965) Soluble salts. In: Black CA (ed) Methods of soil analysis, Monograph 9. American Society of Agronomy, Madison, pp 933–951

Burgess TM, Webster R (1980) Optimal interpolation and isarithmic mapping of soil properties. I. The semivariogram and punctual kriging. J Soil Sci 31:315–331

Cameron DR, De Jong E, Read DWL, Oosterveld M (1981) Mapping salinity using resistivity and electromagnetic inductive techniques. Can J Soil Sci 61:67–78

Chang YH, Scrimshaw MD, Emmerson RHC, Lester JN (1998) Geostatistical analysis of sampling uncertainty at the Tollesbury Managed Retreat site in Blackwater Estuary, Essex, UK: kriging and cokriging approach to minimise sampling density. Sci Total Environ 221:43–57

Dakak H, Benmohammadi A, Soudi B, Douaik A, Badraoui M, Moussadek R (2011) Prospection de la salinité des sols par induction électromagnétique sur la plaine du Tadla (Maroc): tentative d'optimisation par analyse géostatistique. Sécheresse. doi:10.1684/sec.2011.0312

Dalton FN, Van Genuchten MT (1986) The time domain reflectometry for measuring soil water content and salinity. Geoderma 38:237–250

Dalton FN, Herkelrath WN, Rawlings DS, Rhoades JD (1984) Time domain reflectometry: simultaneous measurement of soil water and electrical conductivity with a single probe. Science 224:988–990

Douaik A (2005) Evaluation of the space-time variability of soil salinity by statistical, geostatistical, and Bayesian maximum entropy methods. PhD thesis, Ghent University, Ghent

Douaik A, Van Meirvenne M, Toth T, Serre ML (2004) Space-time mapping of soil salinity using probabilistic Bayesian maximum entropy. Stoch Environ Res Risk Assess 18:219–227

Douaoui A, Nicolas H, Walter C (2006) Detecting salinity hazards within a semiarid context by means of combining soil and remote sensing data. Geoderma 134:217–230

ESRI (2000) Using ArcMap. ESRI Inc., Redlands

Goovaerts P (1997) Geostatistics for natural resources evaluation. Oxford University Press, New York

Goovaerts P (1999) Geostatistics in soil science: state-of-the-art and perspectives. Geoderma 89:1–45

Goovaerts P (2001) Geostatistical modelling of uncertainty in soil science. Geoderma 103:3–26

Hajrasuliha S, Baniabbassi N, Metthey J, Nielsen DR (1980) Spatial variability of soil sampling for salinity studies in southwest Iran. Irrig Sci 1:197–208

Halvorson AD, Rhoades JD, Reule CA (1977) Soil salinity four-electrode conductivity relationships for soils of the northern Great Plains. Soil Sci Soc Am J 41:966–971

Hosseini E, Gallichand J, Marcotte D (1994) Theoretical and experimental performance of spatial interpolation methods for soil salinity analysis. Trans ASAE 37:1799–1807

Lark RM, Ferguson RB (2004) Mapping risk of soil nutrient deficiency or excess by disjunctive and indicator kriging. Geoderma 118:39–53

Maas EV, Hoffman GJ (1977) Crop salt tolerance-current assessment. J Irrig Drain Div ASCE 103:115–134

Matheron G (1971) The theory of regionalized variables and its applications. Cahiers du Centre de Morphologie Mathématique de Fontainebleau, Fascicule n°5, Ecole Nationale Supérieure des Mines, Paris

McKenzie RC, George RJ, Woods SA, Cannon ME, Bennett DL (1997) Use of the electromagnetic meter (EM38) as a tool in managing soil salinization. Hydrogeol J 5:37–50

McNeill JD (1986) Geonics EM38 ground conductivity meter. Tech. Note TN-21. Geonics Ltd., Mississauga

Nadler A (1981) Field application of the four-electrode technique for determining soil solution conductivity. Soil Sci Soc Am J 45:30–34

Navarro-Pedreno J, Jordan MM, Melendez-Pastor I, Gomez I, Juan P, Mateu J (2007) Estimation of soil salinity in semi-arid land using a geostatistical model. Land Deg Dev 18:339–353

Odeh IOA, Todd AJ, Triantafilis J, McBratney AB (1998) Status and trends of soil salinity at different scales: the case for the irrigated cotton growing region of eastern Australia. Nutr Cycl Agroecosys 50:99–107

Oliver MA, Webster R (1990) Kriging: a method of interpolation for geographic information systems. Int J Geogr Inf Syst 4:313–332

Pannatier Y (1996) VarioWin: software for spatial data analysis in 2D. Springer, New York

Papritz A, Dubois JP (1999) Mapping heavy metals in soil by (non) linear kriging: an empirical validation. In: Gomez-Hernandez J, Soares A, Froidevaux R (eds) GeoEnv II: geostatistics for environmental applications. Kluwer Academic, Dordrecht, pp 429–440

Rhoades JD, Corwin DL (1981) Determining soil electrical conductivity-depth relations using an inductive electromagnetic soil conductivity meter. Soil Sci Soc Am J 45:255–260

Rhoades JD, Manteghi NA, Shouse PJ, Alves WJ (1989) Soil electrical conductivity and soil salinity: new formulation and calibration. Soil Sci Soc Am J 53:433–439

Shahid SA, Khalil-ur-Rehman (2011) Soil salinity development, classification, assessment and management in irrigated agriculture. In: Handbook of plant and crop stress, 3ed edn (Mohammed Passarakli Editor The University of Arizona, Tucson, AZ 85721), Published by CRC Press, Boca Raton, pp 23–39

Shahid SA, Abdefattah MA, Omar SAS, Harahsheh H, Othman Y, Mahmoudi H (2010) Mapping and monitoring of soil salinization-remote sensing, GIS, modeling, electromagnetic induction and conventional methods – case studies. In: Ahmad M, Al-Rawahy SA (eds) Proceedings of the international conference on soils and groundwater salinization in arid countries, Sultan Qaboos University, Muscat Sultanate of Oman, January 2010, pp 59–97

Shahid SA, Taha FK, Ismail S, Dakheel A, Abdelfattah MA (2011) Chapter 3: Turning adversity into an advantage for food security through improving soil quality and providing production systems for marginal saline lands – ICBA perspectives and approach. In: Behnassi M, Shahid SA, DSilva J (eds) Sustainable agricultural development: recent approaches in resources management and environmentally-balanced production enhancement. Springer, New York, pp 43–67

Smith JL, Halvorson JJ, Papendick RI (1993) Using multiple-variable indicator kriging for evaluating soil quality. Soil Sci Soc Am J 57:743–749

Sparks DL (1995) The chemistry of saline and sodic soils: environmental soil chemistry. Academic, San Diego

SPSS (2007) SPSS base 16.0 user's guide. SPSS Inc., Chicago

Sylla M, Stein A, Van Breemen N, Fresco LO (1995) Spatial variability of soil salinity at different scales in the mangrove rice agro-ecosystems, West Africa. Agric Ecosys Environ 54:1–15

Trangmar BB, Yost RS, Uehara G (1985) Application of geostatistics to spatial studies of soil properties. Adv Agron 38:45–94

Triantafilis J, Odeh IOA, Warr B, Ahmed MF (2004) Mapping of soil salinity risk in the lower Namoi valley using non-linear kriging methods. Agric Water Manage 69:203–231

Van Meirvenne M, Goovaerts P (2001) Evaluating the probability of exceeding a site-specific soil cadmium contamination threshold. Geoderma 102:75–100

Walter C, McBratney AB, Douaoui A, Minasny B (2001) Spatial prediction of topsoil salinity in the Chelif valley, Algeria, using local ordinary kriging with local variograms versus whole-area variogram. Aust J Soil Res 39:259–272

Webster R, Oliver MA (1989) Optimal interpolation and isarithmic mapping of soil properties: VI. Disjunctive kriging and mapping the conditional probability. J Soil Sci 40:497–512

Wood G, Oliver MA, Webster R (1990) Estimating soil salinity by disjunctive kriging. Soil Use Manage 6:97–104

Yates SR, Warwick AW, Myers DE (1986) Disjunctive kriging. 2. Examples. Water Resour Res 22:623–630

Chapter 11
Spatiotemporal Variability and Mapping of Groundwater Salinity in Tadla: Geostatistical Approach

Mouanis Lahlou, Moulay Mohamed Ajerame, Patrick Bogaert, and Brahim Bousetta

Abstract Agricultural productivity may be constrained by many factors such as water scarcity, soil degradation, and use of marginal quality water. In Morocco, the main degradation processes occurring for irrigated areas are on-site impact (soil salinization and/or alkalinization) and off-site impacts (pollution of groundwater by salts and nitrates). Since 1995, the Moroccan Public Irrigation Agency has installed and maintained a network of soil and groundwater monitoring stations. For the present study, we selected the soil and water sampling sites on spatial representativeness in the perimeter, the main soil types, and the hydrogeological variants. Soil salinity, alkalinity, and sodicity as well as groundwater salinity, nitrates, and water table level were recorded to determine spatiotemporal variability and dynamics of groundwater salinity. A good understanding of its evolution in space and time will make possible to obtain reliable models for spatiotemporal prediction, estimation of the missing data, cartography, and over the long term for the delineation of risky zones. The spatiotemporal analysis of the groundwater salinity shows the presence of a strong spatial dependence and a weak temporal dependence. The spatiotemporal dependence of the residuals is very weak and primarily consists in random fluctuations. Consequently, a simple model was adopted, containing two components: a spatial component explaining more than 50% of the total variability of groundwater salinity and a temporal component that explains almost 77% of the remaining variability. Overall, this model explains more than 90% of total observed variability. Cartography of the average

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groundwater salinity was also established by kriging, by computing mean spatial variograms on the basis of per site data. The spatial variogram of the northern area was adjusted by the Gaussian model characterized by a sill of 3 dS^2/m^2 and a range of 12,526 m, while the southern area was adjusted by a Gaussian model with a sill of 0.2 dS^2/m^2 and a range of 9,674 m, with a nugget effect of 0.06 dS^2/m^2.

Keywords Geostatistical approach • Groundwater • Salinity • Spatiotemporal variability • Tadla

11.1 Introduction

Agricultural productivity may be constrained by many factors such as water scarcity, soil degradation, low soil fertility, use of marginal quality water for crop production, and climatic factors. In Moroccan irrigated agriculture conditions, on-site impacts are soil salinization and/or alkalinization, and off-site impacts are groundwater salinity and pollution by nitrates.

The Tadla irrigation perimeter in Morocco is covering 125,000 ha (Fig. 11.1). It is constituted by two large-scale irrigation areas (97,000 ha), along with 18,600 ha of private irrigation fed by tube wells and 9,100 ha of traditional small-scale areas at the bottom of the Atlas Mountains. Located 200 km southeast of Casablanca, it is fed by the Oum-er Rbia and Abid rivers. It produces 22% of the national sugar beet production, 11% of the olives and fruits, and substantial quantities of fodder, supporting 16% of the milk and 11% of the meat production. A conjunctive use environment characterizes irrigated agriculture in the Tadla plains.

Farmers are increasingly using groundwater resources in addition to available surface water resources. Recent research suggests that currently an annual volume of 500–600 million m^3 comes from groundwater, which is more than the surface supplies, and about 50% of the farmers have access to this resource.

The overuse of surface and groundwater in this area, coupled to intensive cultivation, induced (1) a reduction of groundwater resources and (2) a soil and groundwater quality degradation. Indeed, if secondary salinization and alkalization already affect important surfaces in the perimeter, the groundwater nitrate and salts pollution begin to be apparent. The ORMVAT, the Moroccan Public Irrigation Agency, has installed since 1995 a network of the soil and groundwater monitoring sites. The sampling sites for water and soil were selected on the basis of the spatial representativeness in the perimeter, the main soil types, and the main hydrogeological variants. The observed parameters for soils are salinity, alkalinity, and sodicity, while for groundwater these are salinity, nitrates, and water table level. Accurate information about the extent, magnitude, and spatial distribution of these parameters will help to create sustainable development of agricultural resources.

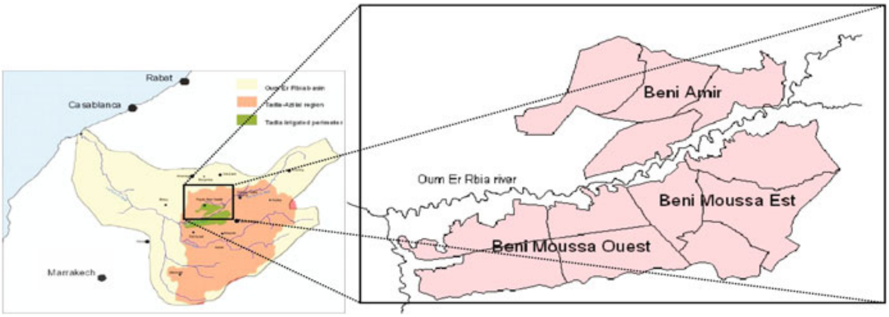

Fig. 11.1 Tadla irrigation perimeter localization and Tadla irrigation perimeter layout

11.2 Objectives

A good understanding of the spatiotemporal variability of the parameters and factors influencing the quality of soil and water and the development of models for these factors would clearly help to identify areas at risk as well as to optimize the existing monitoring networks. The main objective of this study is to perform a spatiotemporal variability analysis and modeling of the groundwater electrical conductivity (EC) from the data already made available from ORMVAT monitoring network and to compare the method of interpolation routinely used by the ORMVAT for producing maps (Inverse Distance Weighted—IDW) to more elaborate techniques such as geostatistical kriging methods.

11.3 Materials and Methods

11.3.1 Geostatistics

Geostatistics can be regarded as a collection of numerical techniques dealing with the characterization of spatial attributes, employing primarily random models in a manner similar to the way in which time series analysis characterizes temporal data (Olea 1999). Geostatistics offers a way of describing the spatial continuity of natural phenomena and provides adaptations of the classical regression techniques to take advantage of this spatial (and possibly temporal) continuity (Isaaks and Srivastava 1989).

11.3.1.1 The Semivariogram

Assuming that the first-order increments of the random field to be zero, i.e.,

$$E\left[Z(x+h, t+\tau) - Z(x, t)\right] = 0 \tag{11.1}$$

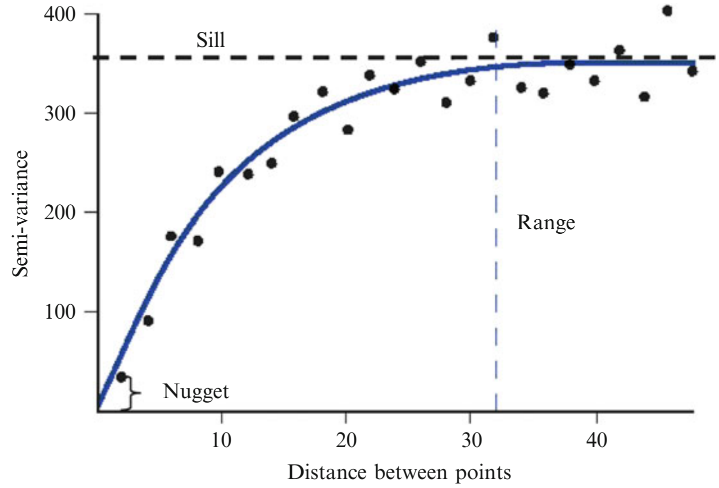

Fig. 11.2 Elements of semivariogram

and that their variance depends only on the distance and time increment between observations and not their position, Eq. 11.2 corresponds to an intrinsic stationarity hypothesis (Matheron 1973), with

$$E\left[Z\left(x+h,t+\tau\right)-Z\left(x,t\right)\right]^2=\mathrm{Var}\left[Z\left(x+h,t+\tau\right)-Z\left(x,t\right)\right]=2\gamma\left(h,\tau\right) \tag{11.2}$$

where the function $\gamma(h, \tau)$ is called the semivariogram. Stated simply, it measures the degree of dissimilarity between random variables separated by a given distance as a function of this distance. It is worth noting that under the hypothesis of second-order stationarity, the semivariogram and the classical autocovariance function $C(h, \tau)$ are directly related to each other, with

$$\gamma\left(h,\tau\right)=\sigma^2-C\left(h,\tau\right) \tag{11.3}$$

where σ^2 is the variance of the random field.

If the mean of the random field Z is constant, an unbiased estimator of spatiotemporal variogram is given by (Cressie 1993)

$$\begin{aligned}\gamma_{\downarrow}Z\left(h,\tau\right)&=1/2\left|N\left(h,\tau\right)\right|\Sigma_{\downarrow}\left(i,j,k,l\right)^{-}\left(N\left(h,\tau\right)\right)\\&\equiv\left[\left[\left(Z\left(x_{\downarrow}i,t,j\right)-Z\left(x_{\downarrow}i,\tau,j\right)\right)\right]^{-}2\right]\end{aligned} \tag{11.4}$$

Patterns of spatiotemporal correlation are visualized using a graphical representation called an empirical semivariogram (Fig. 11.2), which is a plot of the semivariance between sites as a function of their separation distance. It is common to fit well-known models, such as the exponential function, to the semivariogram in order to estimate three parameters, namely, the nugget effect, the sill, and the range. The nugget effect represents the variation in the data as the separation distance between sites get closes to zero. It can result from experimental error or could indicate that a substantial amount of variation is present at a scale finer than the minimum separation distance. The range is defined as the distance beyond which data can be considered as non-correlated, at least for practical purposes, whereas the sill corresponds to the variance of the random field.

11.3.1.2 Kriging

Kriging is a form of generalized linear regression arising from the formulation of an optimal estimation problem in a minimum mean square error sense (Matheron 1962; Burgess and Webster 1980a, b). Kriging is also called the best linear unbiased predictor, which means that it minimizes the variance of the prediction error under unbiasedness constraint. It is also an exact estimator in the sense that it restitutes the measured variable at a prediction location corresponding to a measurement location.

The first step in formulating a simple kriging involves calculation of the estimation error variance, which turns out to be a function of the estimator weights. Minimization of such estimation variance reduces to finding weights that minimize the mean square error, which is accomplished by equating to zero the first derivative of the error with respect to each of the unknown weights (Olea 1999). To obtain the optimal weights for spatial simple kriging, the observed values must be a realization of a second-order stationary random field $Z(x)$ with a known average. This indicates that its mean and covariance do not depend on time, but only on the distant between the variable. Stated in other words, $\forall t, h$:

$$E\left(Z(x)\right) = \mu \tag{11.5}$$

$$E\left[Z(x)\right] - \mu\big)\left(Z\left(x+h\right) - \mu\right)\big] = \mathrm{Cov}\left(Z(x), Z\left(x+h\right)\right) = \mathrm{Cov}(h) \tag{11.6}$$

An estimator Z_0^P is given by a linear combination of values x_i observed in areas:

$$Z_0^P = \mu + \sum_{i=1}^{k} \lambda_i \left(Z_i - \mu\right) \tag{11.7}$$

where λ_i are the so-called kriging weights.

Minimizing the kriging variance gives a system of n linear equations called the simple kriging equations system:

$$\sum_{i=1}^{n} \lambda_i C\left(x_i, x_\alpha\right) = C\left(x_\alpha, x_0\right) \forall \alpha \tag{11.8}$$

where $C(x_i, x_\alpha)$ is the covariance between two sample points (x_α, x_0), whereas $C(x_\alpha, x_0)$ is the covariance between a sampled point and the point to be estimated, as obtained from the adjusted covariance model. This can be written in matrix form as

$$K\lambda = k \tag{11.9}$$

If the covariance model is positive definite and there are no colocated sampling locations, then the corresponding covariance matrix is positive definite (and thus invertible), leading for the kriging weights to the solution

$$\lambda = K^{-1}k \tag{11.10}$$

Once the kriging weights are known, both the kriging estimate and the kriging variance can be computed, where the kriging variance is given by

$$\sigma_{\mathrm{KS}}^2 = C(0) - \sum_{i=0}^{n} \lambda_i C\left(x_i, x_\sigma\right) \tag{11.11}$$

11.3.2 Methodology

The ORMVAT has maintained an extensive database related to the monitoring of soils, surface water, and groundwater quality using a network of monitoring stations installed inside the two sub-perimeters. This database has been structured using the Database Management System MS Access to make it accessible and easy to use.

The dataset used here includes four parameters characterizing groundwater quality, namely, the electrical conductivity (EC), the water table level, pH, and nitrate (NO_3) concentrations. For soils quality, four parameters are used: the electrical conductivity (EC) of saturated paste extract, pH, organic matter content (OM), and exchangeable sodium (Na_e). The network is including 100 monitoring sites (Fig. 11.3), with 40 sites in the sub-perimeter of Beni Amir and 60 sites in the sub-perimeter of Beni Moussa, which are sampled at a frequency of six times a year, every 2 months (Bousetta 2007). The first campaign measure was conducted in October 1995.

Summary statistics for groundwater EC measurements in BA and BM sub-perimeters are shown in Table 11.1, and the corresponding histogram is shown in Fig. 11.4. It is clear that the two sub-perimeters present exhibit distinct characteristics.

Due to the direction of groundwater flowing from east to west, the groundwater loads more salt when moving toward the west, leading to the presence of a gradient of salinity following the same direction. Figures 11.5 and 11.6 highlight the presence of this trend. Typically, ordinary kriging assumes that the global mean (and variance) of the region can be considered as constant, a property known as first-order stationarity. Clearly, this is not the case here.

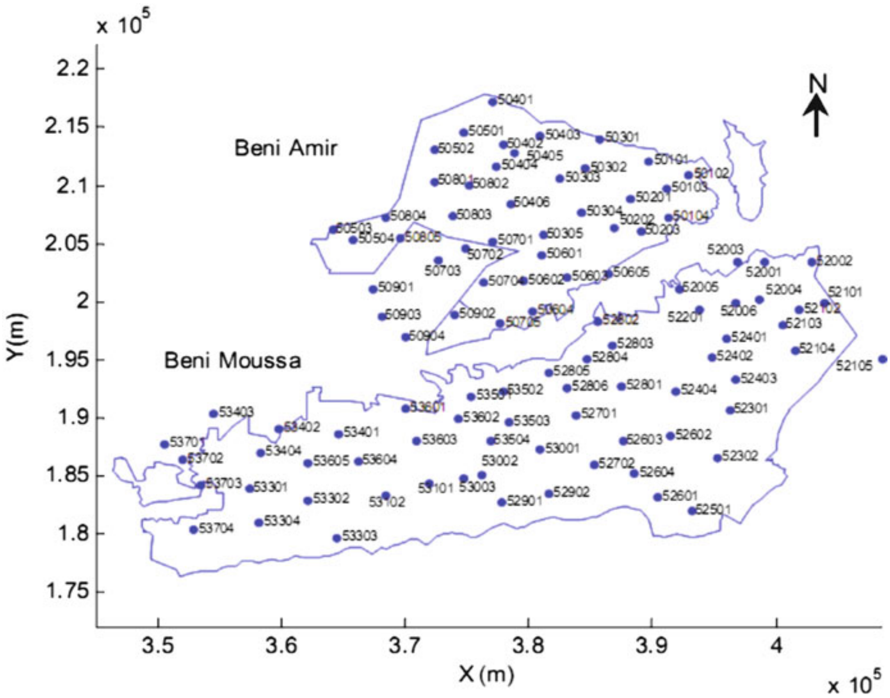

Fig. 11.3 Localization of the monitoring sites in the perimeter

Table 11.1 Summary statistics for groundwater EC measurements in BA and BM sub-perimeters

Groundwater EC	BA	BM
Mean	4.794	1.707
Standard error	0.043	0.023
Median	4.797	1.245
Mode	5.000	1.000
Standard deviation	1.961	1.305
Sample variance	3.846	1.702
Range	12.625	10.503
Minimum	0.500	0.297
Maximum	13.125	10.800
Count	2,063	3,158
Confidence level (95.0%)	0.085	0.046

Since the two sub-perimeters of Tadla, Beni Amir (BA), and Beni Moussa (BM) exhibit different hydrological and geological characteristics, the analysis and the modeling have to be made separately for the two sub-perimeters. The geostatistical calculations were done by MATLAB software with the BMElib library (Christakos 1990, 2000; Bogaert 2002).

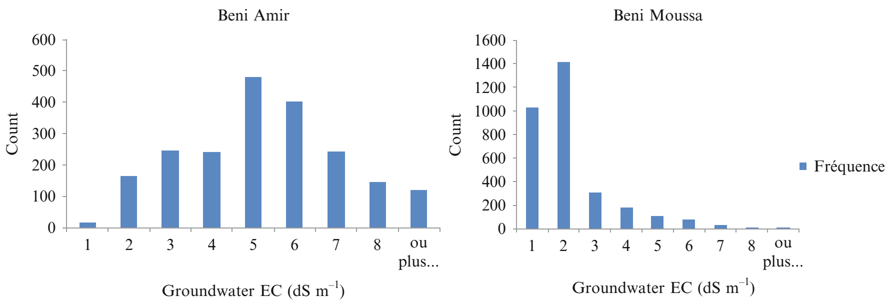

Fig. 11.4 Histograms for groundwater EC between 1995 and 2008 in the two sub-perimeters of BA and BM

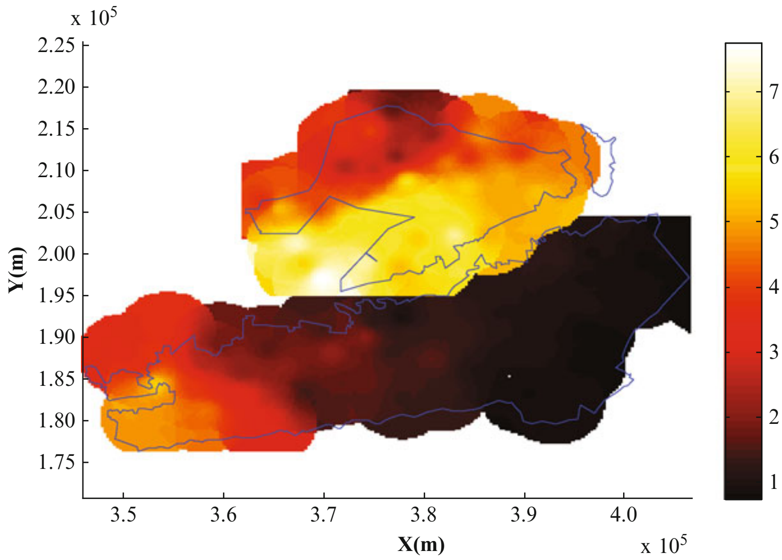

Fig. 11.5 Distribution in space of the average of groundwater EC

11.4 Results and Discussion

11.4.1 Exploratory Analysis

By examining the temporal variograms per site, we have seen that they are more or less different from one site to another but they are all flat, which means that the time dependence is very weak. The resulting models explain, respectively, 22 and 17% of total variability of BA and BM sub-perimeters.

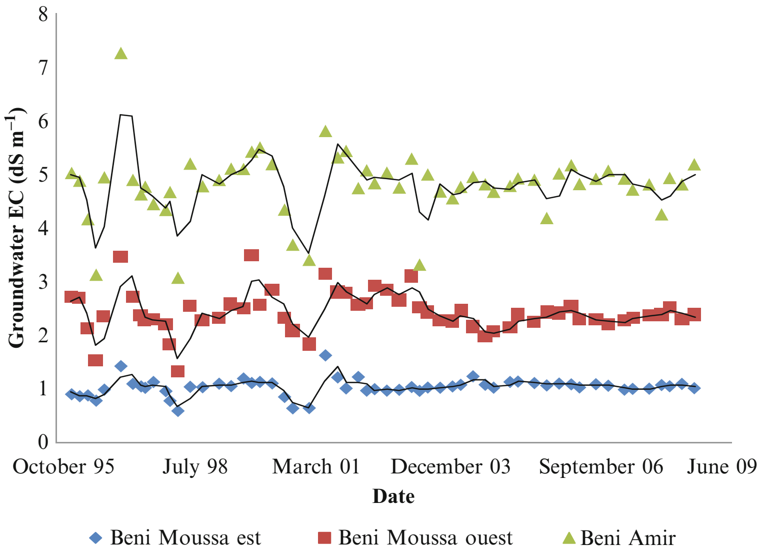

Fig. 11.6 Average groundwater EC by area over period of time

The temporal variogram based on mean spatial values by measurement date confirms the above remarks and has flattened aspect. In this case, the resulting models explain, respectively, 50 and 60% of total variability of BA and BM sub-perimeters. By examining the spatial variograms, it has been noted that the variance calculated in space is higher than that calculated in time. This means that there is a much greater variability in space (between sites) that along the axis of time (within one site) with a higher variance in the area of BA than in BM.

11.4.2 General Analysis

In order to establish the model that best represents the variability and structure of the spatiotemporal dependence of the groundwater EC, it is essential to determine the model that best represents this spatial mean. The selection was based on the proportion of variability explained. Tables 11.2 and 11.3 present the results obtained.

Where TSS is total of sum of squares of deviations from the mean value calculated per sub-perimeters, RSS_x is residual sum of squares of deviations from the mean value calculated per date, $RSS_{2,x}$ is residual sum of squares of deviations from the mean value estimated with plane regression per date, and $RSS_{3,x}$ is residual sum of squares of deviations from the mean value estimated with a global plane regression:

$$TSS = \sum_{i=1}^{n_i} \sum_{j=1}^{n_j} \left[Z(x_i, t_j) - \mu \right]^2 \qquad \mu = \frac{1}{n_i n_j} \sum_{i=1}^{n_i} \sum_{j=1}^{n_j} Z(x_i, t_j) \qquad (11.12)$$

Table 11.2 Variability explained by each model in space

	SS	df	SS/df	% of explained variance
BA	TSS	1876-1	3.8920	0.00
	RSS_x	1876-50	3.5478	08.85
	$RSS_{2,x}$	1876-3*50	1.9670	49.46
	$RSS_{3,x}$	1876-3	2.3699	39.11
BM	TSS	2724-1	1.7404	00.00
	RSS_x	2724-50	1.7038	02.22
	$RSS_{2,x}$	2724-3*50	0.8123	53.38
	$RSS_{3,x}$	2724-3	0.8779	49.61

Table 11.3 Variability explained by each model in time

	SS	df	SS/df	% of explained variance
BA	TSS	1876-1	3.8920	00.00
	RSS_t	1876-41	1.7000	56.32
	$RSS_{2,t}$	1876-2*41	1.5730	59.58
	$RSS_{3,t}$	1876-2	3.8930	00.02
BM	TSS	2724-1	1.7424	00.00
	RSS_t	2724-59	0.5274	69.73
	$RSS_{2,t}$	2724-2*59	0.5198	70.17
	$RSS_{3,t}$	2724-2	1.7425	00.03

$$\mathrm{RSS}_x = \sum_{i=1}^{n_i}\sum_{j=1}^{n_j}\left[Z(x_i,t_j) - \bar{Z}(t_j)\right]^2 \qquad \bar{Z}(t_j) = \frac{1}{n_i}\sum_{i=1}^{n_i} Z(x_i,t_j) \quad (11.13)$$

$$\mathrm{RSS}_{x,2} = \sum_{i=1}^{n_i}\sum_{j=1}^{n_j}\left[Z(x_i,t_j) - \mu(x_i,t_j)\right]^2 \qquad \mu(x_i,t_j) = \beta_{0,j} + \beta_{1,j}x_{1,i} + \beta_{2,j}x_{2,i} \quad (11.14)$$

$$\mathrm{RSS}_{x,3} = \sum_{i=1}^{n_i}\sum_{j=1}^{n_j}\left[Z(x_i,t_j) - \mu(x_i)\right]^2 \qquad \mu(x_i) = \beta_0 + \beta_1 x_{1,i} + \beta_2 x_{2,i} \quad (11.15)$$

Where TSS is total of sum of squares of deviations from the mean value calculated per sub-perimeters, RSS_t is residual sum of squares of deviations from the mean value calculated per site, $RSS_{2,t}$ is residual sum of squares of deviations from the mean value estimated with regression per site, and $RSS_{3,t}$ is residual sum of squares of deviations from the mean value estimated with a global regression:

$$\mathrm{RSS}_t = \sum_{i=1}^{n_i}\sum_{j=1}^{n_j}\left[Z(x_i,t_j) - \bar{Z}(x_j)\right]^2 \qquad \bar{Z}(x_i) = \frac{1}{n_j}\sum_{j=1}^{n_j} Z(x_i,t_j) \quad (11.16)$$

$$\mathrm{RSS}_{t,2} = \sum_{i=1}^{n_i}\sum_{j=1}^{n_j}\left[Z\left(x_i,t_j\right)-\mu\left(x_i,t_j\right)\right]^2 \qquad \mu\left(x_i,t_j\right)=\beta_{0,i}+\beta_{1,i}t_j \tag{11.17}$$

$$\mathrm{RSS}_{t,3} = \sum_{i=1}^{n_i}\sum_{j=1}^{n_j}\left[Z\left(x_i,t_j\right)-\mu\left(x_i\right)\right]^2 \qquad \mu\left(x_i\right)=\beta_0+\beta_1 t_j \tag{11.18}$$

Tables 11.1 and 11.2 show that the total variability of the groundwater EC can be explained up to 56% in the BA and 70% in the BM by using only the average per site and 60% in the BA and 70% in the BM when using a regression per site. Although, Fisher *F*-tests indicate for the two perimeters that a regression per site yields significantly better models in terms of explained variance, it does not however considerably improve the variability explained by the model (see Table 11.2) compared to the number of additional parameters to be accounted for. As a compromise, we retain the model using only the average value per site.

Once this model is chosen, we tried to improve the part of explained variability by studying the spatial and temporal dependence of the residues. This required that we get rid, first, the effect of mean and then analyze the structure of the temporal and spatial dependence of residuals by considering separately space and time. Spatial variograms were estimated by the measurement of date, then a mean of these estimated variograms was calculated and modeled (Fig. 11.7), with the following models for each sub-perimeter:

$$\mathrm{BA}: \gamma\left(\|h\|\right)=\mathrm{Nugget}\left(\|h\|;0.29\right)+\mathrm{Exp}\left(\|h\|;1;5216\right) \tag{11.19}$$

$$\mathrm{BM}: \gamma\left(\|h\|\right)=\mathrm{Nugget}\left(\|h\|;0.11\right)+\mathrm{Sph}\left(\|h\|;0.2;5087\right) \tag{11.20}$$

In the area of BA, the spatial variogram was adjusted by an exponential model of a sill of 1 dS^2/m^2 and a nugget effect of 0.29 dS^2/m^2, while in the subarea of BM, it was adjusted by a spherical model of a sill of around 0.2 dS^2/m^2 and a nugget effect of 0.11 dS^2/m^2.

We note that these variograms are almost flat, which means a low spatial dependence of the residuals or conversely the presence of a large nugget effect in both sub-perimeters, representing 23% of the total variance in the sub-perimeter of BA and 35% in the sub-perimeter of BM. Spatial interpolation will thus be made difficult, due to the limited amount of spatial dependence.

On the other side, the temporal semivariograms based on the same residuals (Fig. 11.8) show that there is a weak to null temporal dependence.

It can thus be concluded that these residuals are mainly noise and erratic fluctuations that cannot be predicted. However, by looking at Fig. 11.9, it is also clear that these residuals change over time in the same way from site to site. For all sites, we could thus estimate an average residual by date using the Eq. 11.21 and then reconduct a spatial analysis upon these residuals:

$$Z\left(x_{i,t}\right)=\mu\left(x_i\right)+\varepsilon_t \tag{11.21}$$

where μ is the mean of the site and ε_t is the residual at time *t*.

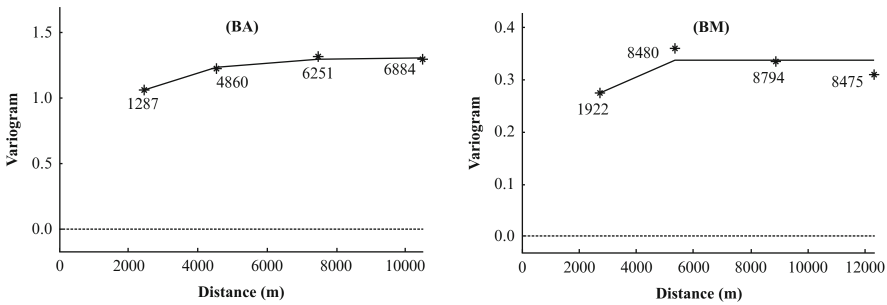

Fig. 11.7 Electrical conductivity mean variograms

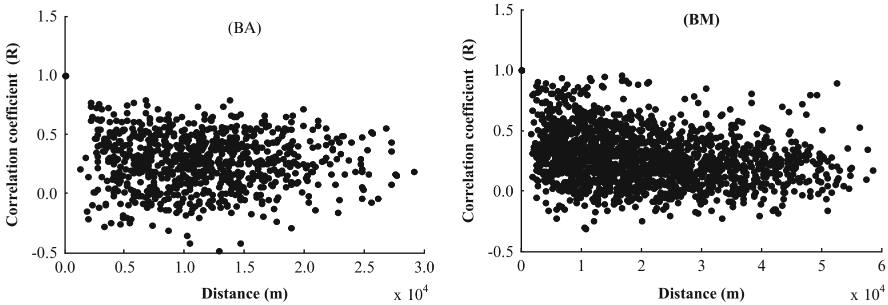

Fig. 11.8 Correlation between the residuals for EC as a function of the distance

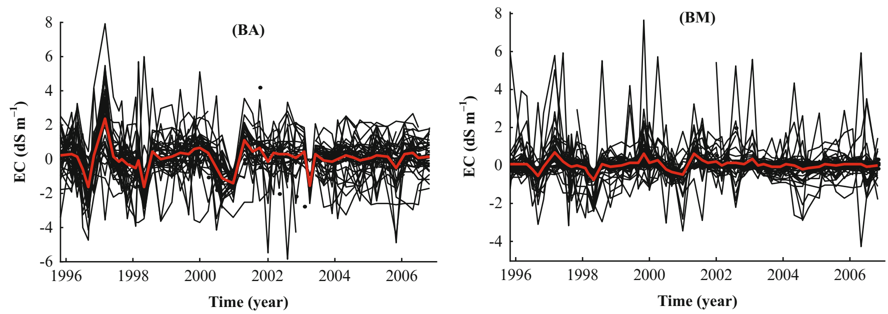

Fig. 11.9 Residuals of the groundwater electrical conductivity and their means

The estimated variograms were calculated and modeled (Fig. 11.10), with the following models for each sub-perimeter:

- The spatial variogram of BA sub-perimeter was adjusted by a Gaussian model with a sill of 3 dS^2/m^2 and a range of 12,526 m.

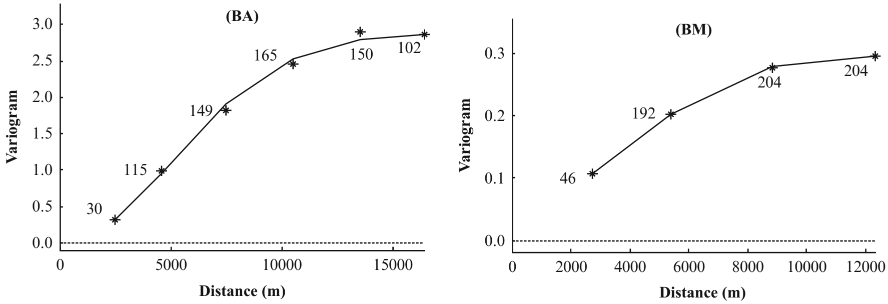

Fig. 11.10 Groundwater electrical conductivity variograms adjusted based on-site mean values

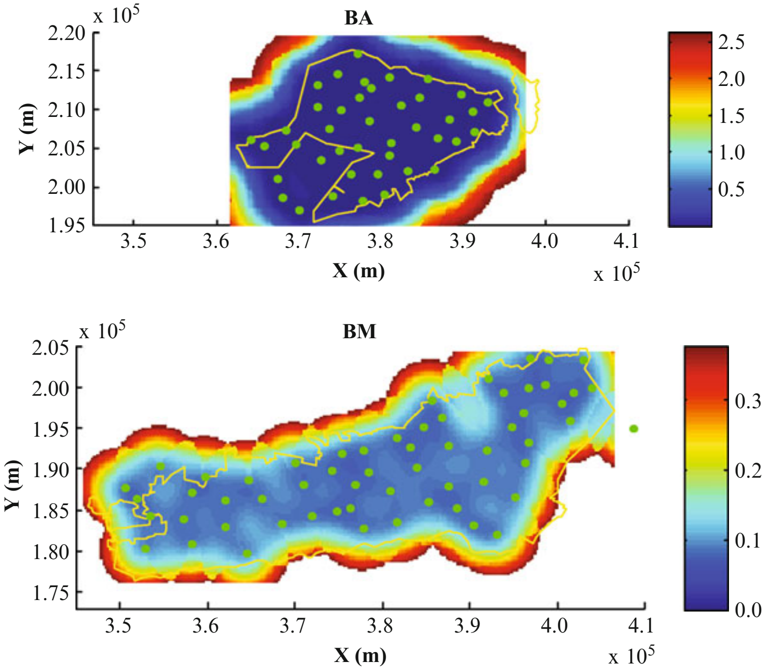

Fig. 11.11 Kriging variance in BA and BM

- While the BM sub-perimeter was adjusted by a Gaussian model with a sill of 0.2 dS^2/m^2 and a range of 9,674 m, with a nugget effect of 0.06 dS^2/m^2.

In this case, the part of explained variability is about 89% in the BA and 96% in the BM. Figure 11.11 represents the corresponding kriging variance, respectively.

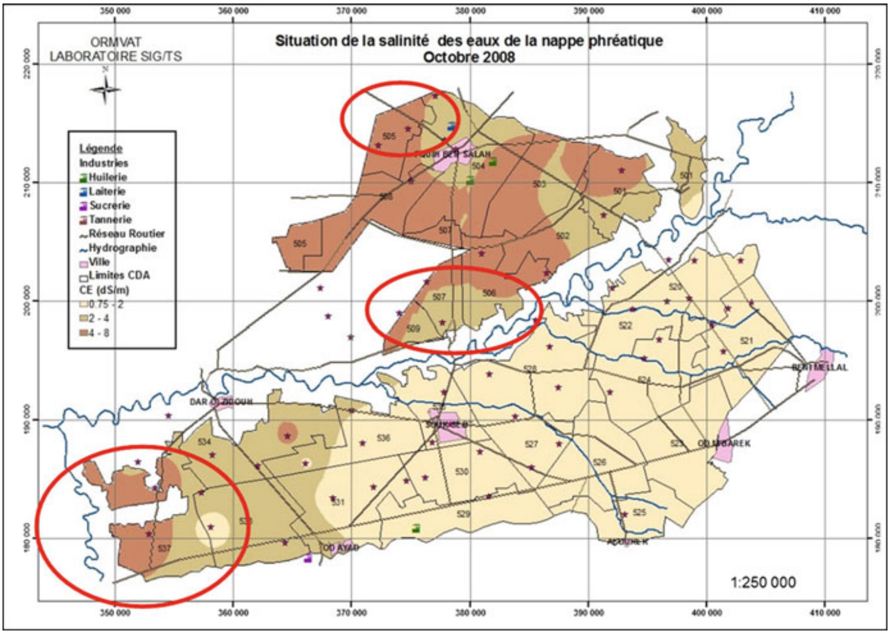

Fig. 11.12 Mean groundwater salinity as interpolated by IDW method (ORMVAT 2008)

11.4.3 Mapping

For mapping, kriging was used for interpolations. In the case of BM sub-perimeter and due to the east–west linear gradient of the EC (Fig. 11.5), ordinary kriging was used, whereas in BA sub-perimeter of the EC, simple kriging by assuming a constant mean is used.

Figure 11.12 shows the mean groundwater salinity map as produced by ORMVAT based on the IDW interpolation method, while Fig. 11.13 shows the same map at the same date but using the kriging method. Clearly, some discrepancies in the interpolation results can be seen from these maps, and misinterpretation can be damaging for some farmers.

11.4.4 Model Validation

The validation of the spatiotemporal model presented above was based on the study of the distribution of differences between the observed values and calculated by the model. Thus, under the sub-perimeter of BA, the mean of differences is equal to 0.01 dS/m and a variance of 1.52 dS^2/m^2, while under the sub-perimeter of BM, the mean of differences is equal to 0.003 dS/m and a variance of 0.10 dS^2/m^2.

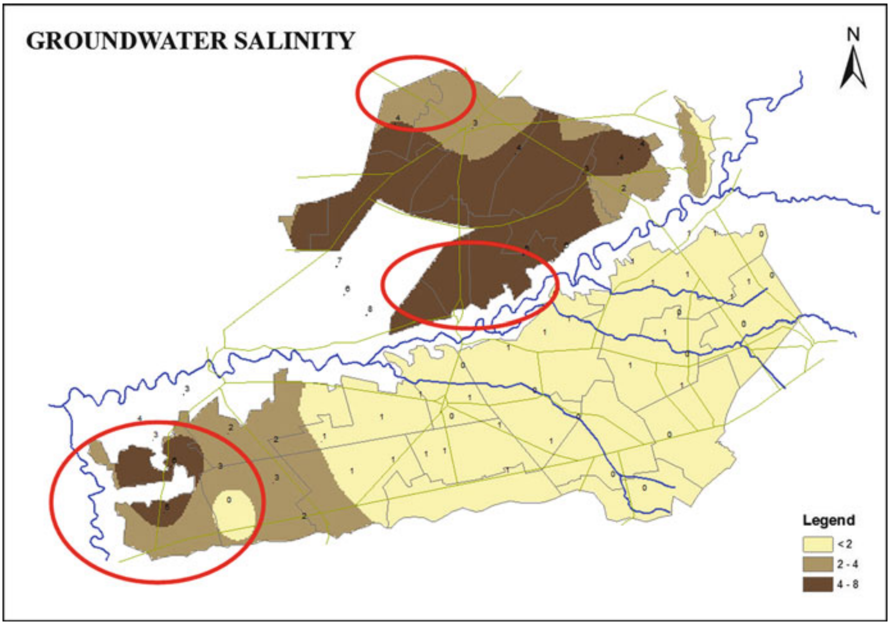

Fig. 11.13 Mean groundwater salinity as interpolated by kriging method

11.5 Conclusion

Spatial analysis allowed us to detect a significant spatial dependence of groundwater salinity values which explains more than 56% of the total variability. On the other side, the temporal analysis has shown that there is no temporal dependence of the residuals over time, so that they can therefore be regarded as pure noise. However, the temporal residuals exhibit the same temporal pattern for all spatial sites. This allowed us to estimate a mean residue by measurement date. The resulting final model is quite simple, as it incorporates a spatial component (average salinity site) and a temporal component (mean residue per measurement date) which can explain up to 90% of the total observed variability of the data. The gradient of variation of the mean salinity observed in the area in BM can be explained by the direction of flow of groundwater, which is east–west. The water load more salt in moving toward the west, which also correspond to the hydrogeological boundary perimeter.

References

Bogaert P (2002) Spatial prediction of categorical variables: the Bayesian maximum entropy approach. Stoch Environ Res Risk Assess 16:425–448

Bousetta B (2007) Variabilité spatio-temporelle de certaines caractéristiques de la nappe phréatique du Tadla : Apport de la géostatistique et du traitement informatique. Mémoire du 3ème cycle. IAV Hassan II
Burgess TM, Webster R (1980a) Optimal interpolation and isarithmic mapping of soil properties. I: the semi-variogram and punctual kriging. J Soil Sci 31:333–341
Burgess TM, Webster R (1980b) Optimal interpolation and isarithmic mapping of soil properties. II: block kriging. J Soil Sci 31:315–331
Christakos G (1990) A Bayesian/maximum-entropy view to the spatial estimation problem. Math Geol 22:763–776
Christakos G (2000) Modern spatiotemporal geostatistics. Oxford University Press, New York, p 304
Cressie N (1993) Statistics for spatial data. Wiley, New York, p 900
Isaaks EH, Srivastava RM (1989) An introduction to applied geostatistics. Oxford University Press, New York, p 561
Matheron G (1962) Traité de Géostatistique Appliquée, vol 14, Tom I: Mémoire du Bureau de Recherches Géologiques et Minières. Edition Technique, Paris, p 333
Matheron G (1973) The intrinsic random functions and their applications. Adv Appl Probab 5:439–468
Olea RA (1999) Geostatistics for engineers and earth scientists. Kluwer Academic, Boston, p 303
ORMVAT (2008) Office Régional de Mise en Valeur Agricole du Tadla, Morocco. Annual report

Chapter 12
Spatial Analysis Using a Proportional Effect Semivariogram Model

Adel M. Elprince

Abstract The assumption of zero trend seems unlikely for many soil properties that change systematically across the landscape. Removal of a trend may result in a bias in estimating the semivariogram and in many studies has not resulted in apparent improvements in kriging estimates. This study was conducted with the objective to use a proportional effect semivirogram model approach for handling a region with a pronounced trend aside from trend removal. To demonstrate this approach, soil samples (0–30-cm depth) were collected along four transects and analyzed for the electrical conductivity (EC) of the soil/water (1:5) extracts. The 50-m long transects centered on the points (x_j) were from four subregions with maximum contrast in salinity means [$m(x_j)$]. Fractile diagrams and goodness-of-fit analysis at the 0.05 significance level indicated that the normal distribution function fitted the EC values of the four transects. Except for transect T(x1), a lognormal distribution function might also be accepted. A proportional effect stationary semivariogram model: $\gamma_e(h, x_j)/\Phi\left[m(x_j)\right] = \gamma_s(h)$ was fitted to the local experimental semivariograms $\gamma_e(h, x_j)$ by the steepest-descent optimization method. The predicted local dispersion variances were reasonable when compared with the experimental variances thereby supporting validity of the proposed model. Statistical analysis of cross validation (kriging) results confirmed the adequacy of the stationary semivariogram model and the validity of the estimated parameters. The assumption of quasi-stationary instead of stationary along the transect improved predictions of true kriging variance. The proportional effect quasi-stationary semivariogram models may offer a possible approach for krig handling a regionalized variable having a pronounced trend without the need for trend removal.

Keywords Geostatistics • Proportional effect • Spatial analysis • Model validation • Soil salinity

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12.1 Introduction

During the last decade, considerable research has reported the application of geostatistics for studying the spatial variability of soil properties (Russo and Bresler 1981; Van Kuilenburg et al. 1982; Warrick et al. 1986; Webster and Oliver 1990; Ünlü et al. 1990; Gorway Crawford and Herget 1997; Mueller et al. 2003; Ersahin 2003; Wu et al. 2003, 2008; Elprince et al. 2004; Regalad and Ritter 2006; Herbst et al. 2009; Elprince 2009). Geostatistics treats a soil property as a regionalized variable; an actual function defined by a spatial probability law. To infer the first two moments of the spatial law, the stationary of order 2 and intrinsic hypotheses have allowed replacement of ensemble averages by space averages. Both hypotheses imply an assumption of zero trend (Journel and Huijbregts 1978). In practice, this assumption is seldom satisfied for the study region, and often there is a pronounced trend.

Because soils frequently change systematically across the landscape, the assumption of zero trend seems unlikely for many soil properties (Yost et al. 1982; Hamlett et al. 1986). If the trend is removed (the deterministic component is subtracted from the data), the residuals (the stochastic component) might be stationary or intrinsic. In that case, semivariograms could be constructed using the residuals and kriging performed (Davidoff et al. 1986).

Detrending, however, has received limited applications because removal of a trend drastically alters the shape of the semivariograms and, hence, alters any conclusions that would be drawn from them (Davidoff et al. 1986). Moreover, trend removal by numerical methods may result in a bias in estimating the variogram, (Warrick et al. 1986) and in many studies, detrending has not resulted in apparent improvements in kriging estimates (Yost et al. 1982; Laslett and McBratney 1990; Bregt et al. 1991; Elprince et al. 2004).

There are methods reported in the literature that do not require detrending and are applicable to the most general cases for which field data exhibit large-scale variability (trend). These methods, basically overcome the difficulty stemming from the interdependency between the small-scale variability (semivariogram) and the large-scale variability (mean, i.e., trend function), include the generalized covariance method (Journel and Huijbregts 1978), the iterative generalized least squares (residual kriging) method (Ripley 1981; Neuman and Jacobson 1984), restricted maximum likelihood method (Kitanidis and Lane 1985), and the rescaled semivariogram (Pannatier 1996).

There is another method for handling a region with a pronounced trend aside from trend removal. The region may be partitioned into subregions, each with zero trend, and a proportional effect model fitted to the subregion semivariograms. Proportional effect was developed by the founders of geostatistics (Journel and Huijbregts 1978). These authors presented a proportional effect case study on regionalization of uranium grades along vertical transects of a sedimentary uranium deposit in Niger (Journel and Huijbregts 1978). This example and many other published examples (Pd, porosity, permeability, and *Nephrops norvegieus* (L.) biomass) of proportional effect (also called heteroscedasticity) show a quadratic relationship between the variance and the mean (a linear relationship between the standard deviation and the mean) (Oz and Deutsch 2002; Maynune et al. 1998). Proportional effect is the increase in variability in high-valued areas.

Modern geostatistics is more concerned with direct simulation methods (DSM) that allow modeling heterogeneity than with straight kriging that allow optimal estimation. The DSM must consider the proportional effect to provide reasonable measures of local variability (Oz and Deutsch 2002). According to Deutsch (1996), cross validation and checking the local distribution of uncertainty will quickly reveal problems and help determine the optimal approach. Similarly, Johnston et al. (2001) stated that one should check his models with cross validation, and especially validation, when he uses trend models.

In a case study by Elprince et al. (2004), a soil salinity map (1:45,000 scale) has been produced for Al-Hassa date-growing oasis (20,000 ha) in Saudi Arabia. Detrending using universal kriging, using linear and quadratic trend surfaces, resulted in some unrealistic interpolated salinity values and variances and underestimated the areas of salt-affected soil by about 15%. Ordinary kriging seemed the "best" kriging approach when using 12 neighboring points and an exponential variogram model allowing optimal estimation. Although soil salinity data indicated a proportional effect, no attempt has been made to include it in the estimation. This proportional effect seemed to account for the causes of variation in soil salinity as of the oasis chemical model (Elprince 1985). More accurate soil salinity map can probably be produced upon the incorporation of the proportional effect in the estimation.

The aim of this study was to develop an optimal approach for incorporating the proportional effect in the estimation. The specific objectives were (1) to identify the spatial structure of soil salinity using the underlying probability density functions and semivariograms in four subregion transects with different salinity means, (2) to fit a proportional effect model to the subregion semivariograms, and (3) to evaluate the validity and reliability of the proportional effect semivariogram model by the method of cross validation.

12.2 Materials and Methods

12.2.1 Soil Sampling and Analysis

The soil samples used in this study were collected from Al-Hassa oasis. The oasis is located in the eastern province of Saudi Arabia, 60 km inland of the Gulf coast between 25° 37′ 12″ and 25° 20′ 24″ N and 49° 32′ 24″ and 49° 46′ 48″ E (Fig. 12.1). Details on the climate, soil, and water resources of the oasis can be seen elsewhere (Elprince 2009). Detailed description of the soil sampling location provided areas with different salinity means (Elprince et al. 2004). Soil samples were taken along four transects in areas with maximum contrast in salinity means, namely, KFU

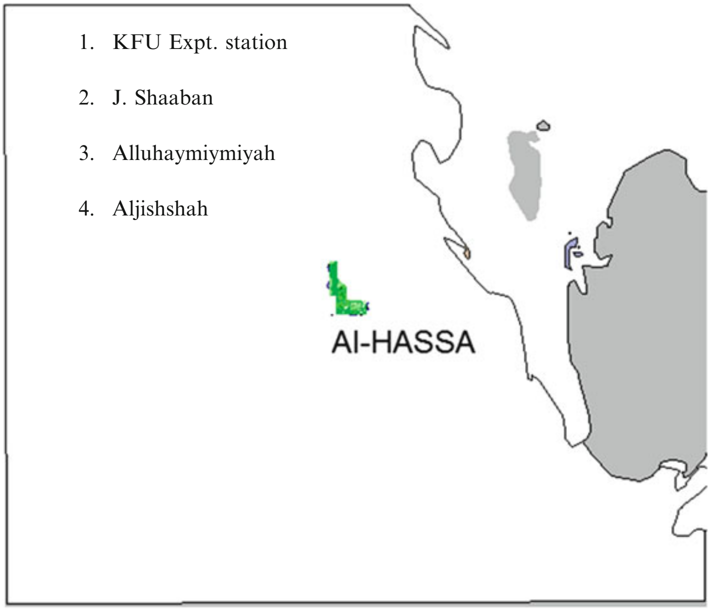


Fig. 12.1 The soil samples were collected from Al-Hassa date-growing oasis, 60 km from the Gulf. Soil samples were taken along four transects in areas with maximum contrast in salinity means, namely, KFU experimental station, Jabal Shaaban, Alluhaymiyah, and Aljishah for transects 1–4, respectively. Each transect length was 50 m with samples (0–30-cm depth) taken 1m apart

experimental station, Jabal Shaaban, Alluhaymiyah, and Aljishah for transects 1–4, respectively. Each transect length was 50 m with samples (0–30-cm depth) taken 1 m apart. Samples were air-dried and sieved to pass the <2-mm size, and their 25°C equilibrium 1:5 (soil/water) extracts were analyzed for electrical conductivity (EC) using a conductivity meter (Model CO150, Hach Europe, Namur, Belgium) (Page et al. 1982).

12.2.2 Intrinsic and Stationary Methods

For an entire field made of n points at locations x_j, we may have the following realizations for a soil property:

$$z_i(x_j),\ j = 1, 2, \ldots, n \quad \text{and} \quad i = 1, 2, \ldots, k(x_j), \tag{12.1}$$

where $k(x_j)$ is the number of realizations at location x_j. The $z_i(x_j)$ values are a particular realization of a random function $Z(x)$ characterized by a spatial probability law. In application, fulfillment of the spatial probability law is never required, but rather satisfaction of the first two moments is sufficient. The first-order moment is the expectation:

$$E\{Z(x)\} = m(x), \tag{12.2}$$

where $m(x)$ is the mean and the second-order moment may be the variogram:

$$2\gamma(x_1 - x_2) = \mathrm{var}\{Z(x_1) - Z(x_2)\}. \tag{12.3}$$

where γ represents the semivariogram. Both moments are dependent on location. To compute these moments, many realizations at the two points x_1 and x_2 are required. In practice, unlike theory, we encounter only one realizations, i.e., $k(x_j) = 1$.

The following practical solution is therefore proposed as an approach to this problem. Since, in applications the variogram is only used for limited distances, one may partition the region to subregions or zones, each zone centered around a point x_j and of length L. Then we make the reasonable assumption that each zone (x_j) has a finite mean independent of location (x) within the zone, i.e., each zone has a zero trend:

$$E\{Z(x, x_j)\} = E\{Z(x+h, x_j)\}, \tag{12.4}$$

where h represents the separation distance between pairs of random variables. That is, the random variable is repeating itself within the zone. This homogeneity therefore provides the equivalent of many realizations of the same random variable. Thus,

$$E\{Z(x, x_j)\} = m(x_j),\ x \in x_j, \tag{12.5}$$

where $x \in x_j$ means x belongs to the zone (e.g., transect as in the present study) centered at location x_j. The second assumption is that for each pair of random variables $\{Z(x, x_j), Z(x+h, x_j)\}$ within this zone, the semivariance exists, is independent of location (x), and dependent on the separation distance h:

$$\begin{aligned} 2\gamma(h, x_j) &= \mathrm{var}\{Z(x+h, x_j) - Z(x, x_j)\} \\ &= E\left\{\left[Z(x+h, x_j) - Z(x, x_j)\right]^2\right\}, x \in x_j \end{aligned} \tag{12.6}$$

The intrinsic hypothesis assumptions are used to derive Eqs. (12.5) and (12.6). Subsequently, the model may be referred to as an intrinsic model. If the semivariogram is with a finite range, the variance and covariance exist. Under these circumstances, the model may be referred to as a stationary of order 2 model or simply a stationary model (Journel and Huijbregts 1978).

12.2.3 Experimental Semivariograms

The experimental semivariogram for each transect centered at location x_j was computed using the formula:

$$\gamma_e(h, x_j) = \left[2N(h, x_j)\right]^{-1} \sum_{i=1}^{N(h,x_i)} \left[z(x_i, x_j) - z(x_i + h, x_j)\right]^2, \quad (12.7)$$

where $N(h, x_j)$ is the number of pairs of sample points a distance h apart (Journel and Huijbregts 1978).

12.2.4 Semivariogram Model Validation

Kriging (cross validation) was used to judge the adequacy of the quasi-stationary model to represent the spatial structure of the data. In this case, one measured point at a time was excluded from the model analysis, and a kriged estimate was made. This estimate is then compared with the actual measurement (Wackernagel 1995).

The value of the regionalized variable at a point x_o is predicted by a linear combination of the values of n_r surrounding data points (where r represents some specified radius of influence):

$$z^*(x_o) = \sum_{i=1}^{n_r} \lambda_i z(x_i), \quad (12.8)$$

where $z^*(x_o)$ is the predicted value, λ_i is the weight of the ith neighboring value, and $z(x_i)$ is an observed value at location x_i. Kriging is optimal in the sense that it is the best linear unbiased estimator of $z(x_o)$, i.e., $E\left[z^*(x_o) - z(x_o)\right] = 0$ and $\text{var}\left[z^*(x_o) - z(x_o)\right]$ is minimum. Values of λ_i are obtained by solving the set of $(1 + n_r)$ linear equations:

$$\sum_{j=1}^{n_r} \lambda_j \gamma_{ij} + \beta = \gamma_{io} \quad \text{and} \quad \sum_{j=1}^{n_r} \lambda_j = 1, \quad i = 1, 2, \ldots, n_r, \quad (12.9)$$

where γ_{ij} is $\gamma(x_i - x_j)$ and β is the Lagrangian multiplier. To solve the kriging system, namely, Eq. 12.9, the Gaussian elimination method with partial pivoting to reduce round-off error was used (Bajpai et al. 1977; Al-Khafaji and Tooley 1986).

Kriging variance σ_k^2 is an independent estimate of the error in the kriged value $z^*(x)$, and it is calculated using the equation (Van Kuilenburg et al. 1982):

$$\sigma_k^2 = \beta + \sum_{i=1}^{n_r} \lambda_i \gamma_{io}. \quad (12.10)$$

The validity of the semivariogram model is then tested based on the statistical analysis of the mean normalized error (ME) and the mean square normalized error (MNE). The following conditions must be satisfied for the model to be valid:

$$\mathrm{ME} = \frac{1}{n}\sum_{i=1}^{n} \mathrm{NE}(x_i) = 0, \tag{12.11}$$

$$\mathrm{MNE} = \left\{\frac{1}{n}\sum_{i=1}^{n} \left[\mathrm{NE}(x_i)\right]^2\right\}^{0.5} = 1, \tag{12.12}$$

where $\mathrm{NE}(x_i) = \left[z(x_i) - z^*(x_i)\right]/\sigma_k(x_i)$. Furthermore, the mean square of error prediction MSEP can be very useful. For example, the deviation of MSEP from the average kriging variance $\langle \sigma^2_k \rangle$ may arise for several reasons, one of which is the misspecification of the model (Bregt et al. 1991):

$$\mathrm{MSEP} = \frac{1}{n}\sum_{i=1}^{n} \left[z(x_i) - z^*(x_i)\right]^2, \tag{12.13}$$

12.3 Results and Discussion

12.3.1 Descriptive Statistics

Fractile diagrams have been constructed to test the hypothesis that the sample (under observation) is drawn from a population with normal distribution or lognormal distribution. The basis for making the fractile diagram has been described elsewhere (Biggar and Nielsen 1976; Elprince et al. 2004). This analysis indicates that the normal distribution function fits the EC values of the four transects at the 0.05 significance level. Except for transect $T(x_1)$, a lognormal distribution function may also be accepted.

The soil salinity means $m_T(x_j)$ are 2.4, 5.8, 26, and 49 dS m^{-1} and the standard deviations $s_e(x_j)$ are 0.9, 1.8, 13, and 17 dS m^{-1} for transects 1–4, respectively. The resulted linear relationship, $s_e(x_j) = (0.38 \pm 0.04)\, m_T(x_j)$ with $R^2 = 0.94$, illustrates the proportional effect very well. It is indicating as local average increases, so, too, does the local variability which is the most common case for earth science data (Issaks and Srivastara 1989; Oz and Deutsch 2002). In the past, this has been linked in a vague way to the lognormal distribution (Cressie 1985).

12.3.2 Fitting a Proportional Effect Semivariogram Model to Data

Observing the experimental semivariograms $\gamma_e(h, x_j)$ revealed that the sill increased with the mean $m(x_j)$ of the experimental data for each local neighborhood. Such a direct proportional effect indicates that the scales of the experimental semivariograms can be made to coincide by dividing each by a function of the corresponding $m(x_j)$. This assumes that a stationary (or intrinsic) model $\gamma_s(h)$ independent of the neighborhood location x_j exists such that

$$\frac{\gamma_e(h, x_j)}{\Phi\left[m\left(x_j\right)\right]} = \gamma_s(h) \tag{12.14}$$

The two stationary (or intrinsic) models $\gamma_e(h, x_k)$ and $\gamma_e(h, x_j)$ for the two different transects $T(x_k)$ and $T(x_j)$, respectively, are said to differ from each other by a proportional effect (Journel and Huijbregts 1978).

To identify a functional form for $\Phi[m(x_j)]$, it is often useful to draw the normalized experimental semivariograms $\gamma'_e(h, x_j)$, i.e., $\left[\gamma_e(h, x_j) / m^2(x_j)\right]$, which suggests the following form for $\Phi[m(x_j)]$:

$$\frac{\Phi\left[m(x_j)\right]}{m^2(x_j)} = a + f\left[m(x_j)\right], \tag{12.15a}$$

where $f[m(x_j)]$ is the normal density function:

$$f\left[m(x_j)\right] = \left(b\sqrt{2\pi}\right)^{-1} \exp - 0.5\left[\frac{m(x_j - c)}{b}\right]^2. \tag{12.15b}$$

The normal density function in Eq. (12.15a) should be multiplied by a constant equal to one with units in $(\text{dS m}^{-1})^{-1}$ for a dimensionless $\Phi[m(x_j)]$ as of Eq. (12.14).

The steepest-descent method (Hamming 1989) has been used to find optimum values for the constants a, b, and c in Eq. (12.15a, b) for fitting the proportional effect model (Eq. (12.14)) to the experimental local semivariograms. A first suitable guess for values of a, b, and c are made and $\gamma_e(h, x_j)/\Phi[m(x_j)]$ are computed for the four transects. The first approximation mean $\gamma_s(h)$ is then calculated as

$$\gamma_a(h) = \frac{1}{n_T} \sum_{i=1}^{n_L} \left\{ \frac{\gamma_e(h_i, x_j)}{\Phi\left[m(x_j)\right]} \right\}, \tag{12.16}$$

where n_T is the number of transects, i.e., 4. Substitution of Eq. (12.16) in the right-hand side of Eq. (12.14) yields a first approximation for the proportional effect intrinsic (PEI) normalized semivariogram $\gamma_{ei}'(h, x_j)$. The objective function (O_f) is then computed:

$$O_f = \sum_{j=1}^{n_T} \sum_{i=1}^{n_L} \left[\gamma_{ei}'\left(h_i, x_j\right) - \gamma_e'\left(h_i, x_j\right)\right]^2, \tag{12.17}$$

where n_L is the maximum number of lags, i.e., 50. Then values of a, b, and c are changed in steps. The steps lie in the direction of the negative gradient until three points are found for which the middle one has the least of the three values of the objective function (O_f). Quadratic interpolation yields the minimum O_f and the optimum values of a, b, and c along the line being searched. The ith iteration continue until the stop criterion is met, namely, $|O_f(i+1) - O_f(i)|$ becomes less than a preset error. The optimum values of a, b, and c are found equal to 0.05 (dS m^{-1})$^{-2}$, 9.7 dS m^{-1}, and 30.5 dS m^{-1}, respectively.

The resulting discrete values of $\gamma_s(h)$ are fitted to a spherical model:

$$\gamma_s(h) = c_o + (c_1 - c_o)\left[\frac{3h}{2r} - \frac{h^3}{2r^3}\right], \quad \text{for } h \le r, \tag{12.18a}$$

$$\gamma_s(h) = c_1, \quad \text{for } h > r, \tag{12.18b}$$

The nugget (c_o), sill (c_1), and range (r) are found equal to 1.51 (dS m^{-1})^2, 2.90 (dS m^{-1})^2, and 23.2 m, respectively. The fitting has been performed using the steepest-descent optimization method (Hamming 1989). The objective function is a weighted sum of residual squares which lends more credibility to points with large numbers of pairs, $N(h)$. This implies that samples within 23.2 m of one another are correlated, but about 52% of the total variation in the sample values seems to be due to purely random behavior – perhaps a reflection of the type of salinization.

Substituting the discrete values of $\gamma_s(h)$ and Eq. (12.15a, b) in Eq. 12.14 yields the PEI-normalized semivariograms $\gamma_{es}'(h, x_j)$ (Figs. 12.2, 12.3, 12.4, and 12.5). Substitution of Eqs. (12.15a, b) and (12.18a, b) into Eq. (12.14) yields the proportional effect stationary (PES) normalized semivariogram:

$$\gamma_{es}'(h, x_j) = \left\{0.5 + 0.04\exp - 0.5\left[\frac{m(x_j) - 30.5}{9.71}\right]\right\} \cdot \left\{1.51 + 1.39(0.065h - 4.10^{-5}h^3)\right\},$$
$$h \le 23.3\text{m} \tag{12.19a}$$

$$\gamma_{es}'(h, x_j) = 0.14 + 0.12\exp - 0.5\left[\frac{(m(x_j) - 30.5)}{9.71}\right]^2, \quad h > 23.3\text{m} \tag{12.19b}$$

The resulting semivariograms $\gamma_{es}'(h, x_j)$ computed using Eq. (12.19a, b), (the smooth curves in Figs. 12.2, 12.3, 12.4, and 12.5), are approximately the same as the experimental $[\gamma_e'(h, x_j)]$ and the PEI-normalized semivariograms $[\gamma_{ei}'(h, x_j)]$. Physically, Eq. 12.19 indicates that the range (a measure of the autocorrelation distance) appears to be independent of location while the dispersion variance is local.

12.3.3 Predicted Standard Deviations vs. Means Relationship

Because the local dispersion variances $\text{var}_p(x_j)$ are linear in γ and the present support is small with respect to the experimental range one gets (Journel and Huijbregts 1978):

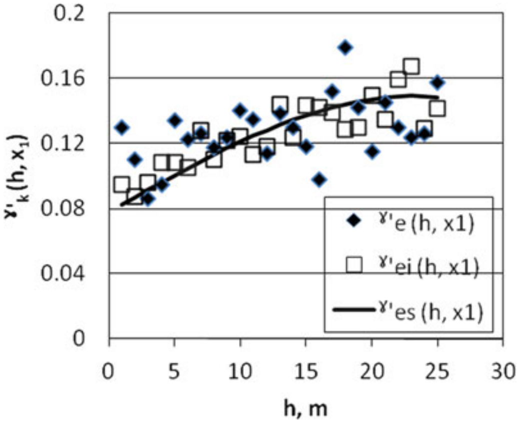


Fig. 12.2 The normalized proportional effect intrinsic (*PEI*) and proportional effect stationary (PES) semivariogram models fitted to the normalized experimental semivariograms $\gamma'_e(h, x_1)$ of the soil salinity data for transect 1, KFU experimental station

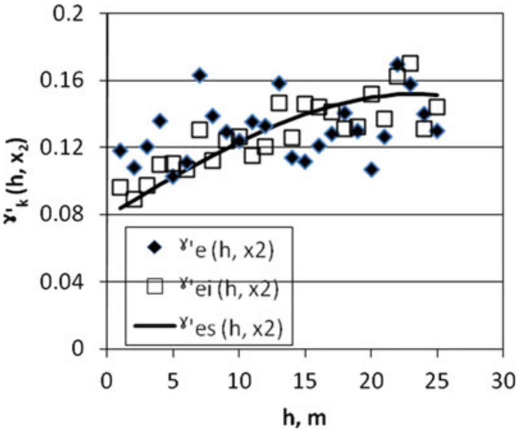


Fig. 12.3 The normalized proportional effect intrinsic (*PEI*) and proportional effect stationary (*PES*) semivariogram models fitted to the normalized experimental semivariograms $\gamma'_e(h, x_2)$ of the soil salinity data for transect 2, Jabal Shaaban

$$\mathrm{var}_p(x_j) = \Phi\left[m(x_j)\right] \cdot c_1, \tag{12.20}$$

Thus, local dispersion variances $\mathrm{var}_p(x_j)$ can be predicted using Eq. (12.20) for any location x_j having a mean equal to $m(x_j)$. The required $\Phi[m(x_j)]$ is given by Eq. (12.15a), and c_1 is the sill of the stationary semivariogram. The predicted values of $\mathrm{var}_p(x_j)$ are equal to 0.86, 5.11, 171, and 372 $(\mathrm{dS\ m^{-1}})^2$ for transects 1–4, respectively. These values are reasonably close to the corresponding estimated dispersion variances, namely, 0.81, 3.24, 169, and 289, respectively. This agreement lends support to the proposed PES model.

The $\mathrm{var}_p(x_j)$ data values are used to predict the linear relationship between predicted standard deviations and means, $s_p(x_j) = (0.42 \pm 0.04) \cdot m_T(x_j)$ with $R^2 = 0.97$ which is reasonably close to the previously derived experimental relationship, $s_e(x_j) = (0.38 \pm 0.04) \cdot m_T(x_j)$ with $R^2 = 0.94$. Again, this agreement lends support to the proposed PES model.

Fig. 12.4 The normalized proportional effect intrinsic (*PEI*) and proportional effect stationary (*PES*) semivariogram models fitted to the normalized experimental semivariograms $\gamma'_e(h, x_3)$ of the soil salinity data for transect 3, Alluhaymiyah

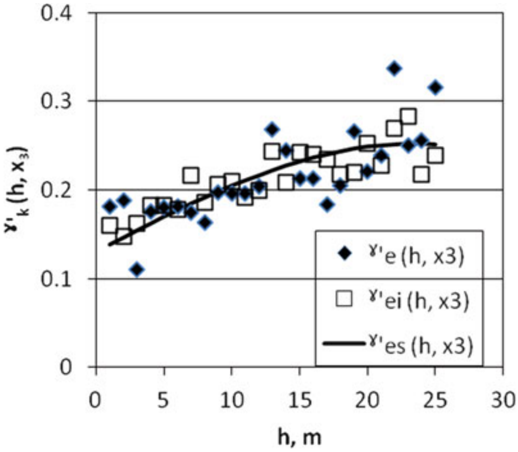
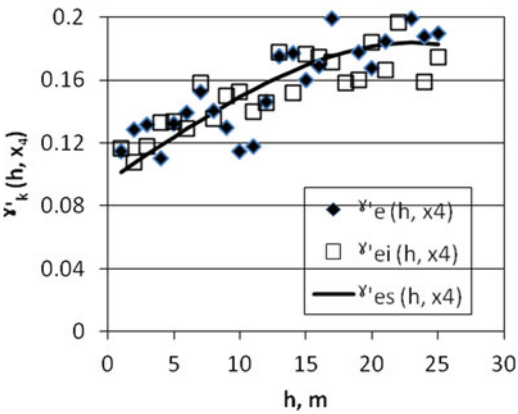


Fig. 12.5 The normalized proportional effect intrinsic (PEI) and proportional effect stationary (PES) semivariogram models fitted to the normalized experimental semivariograms $\gamma'_e(h, x_4)$ of the soil salinity data for transect 4, Aljishah



12.3.4 Cross Validation

Results of cross validation of the PES model are presented in Table 12.1. As Table 12.1 indicates, the average kriging variance $<\sigma_k^2>$ underestimates the MSEP of three transects and overestimates the MSEP of transect $L(x_3)$. Laslett et al. (1987) predicting soil pH (H_2O and $CaCl_2$) calculated the percentage underestimation (*U*) of the estimated kriging variances at 64 test sites. The values for *U* ranged from 22 to 77%. Bregt et al. (1991) calculated U at 75 test sites predicting soil moisture deficits. The value of U was 70%. In the present study, the value of U ranges from 36 to 45% for transects $L(x_1)$, $L(x_2)$, and $L(x_4)$. On the other hand, $<\sigma_k^2>$ overestimates the MSEP of transect $L(x_3)$ by 25%. Thus, the deviation of the true kriging variance seems reasonably acceptable and not caused by misspecification of the model. Also included in Table 12.1 are values of ME and MNE and the associated *t* values for all transects. The *t*-test has been used to test the significance of the

Table 12.1 Results of the cross validation of a proportional effect stationary semivariogram model for the soil $EC_{1:5}$ (based on the transect mean, m_T)

						t[a]	
Transect	MSEP $(dS\ m^{-1})^2$	$<\sigma_k^2>$ $(dS\ m^{-1})^2$	U (%)	ME	MNE	ME	MNE
$T(x_1)$	0.42	0.23	45	−0.004	1.33	−0.02	2
$T(x_2)$	2.9	1.85	36	−0.01	1.25	−0.05	1.75
$T(x_3)$	124	155	−25	−0.011	0.89	−0.09	−0.77
$T(x_4)$	476	289	39	0.007	1.28	0.04	1.67

U is percentage underestimation of the estimated average kriging variance $<\sigma_k^2>$. *ME* is mean normalized error. *MNE* is mean square normalized error. *MSEP* is mean square of error prediction

[a] $t=(x-\mu_o)/(s/\sqrt{n})$; $df=n-1$; $H_o: \mu-\mu_o$ (unknown); $H_A: \mu\neq\mu_o$; region of rejection: $t>t_{\alpha/2}$ and $t<-t_{\alpha/2}$; at 0.05 significance level and $df=47$ the t value is 2.01 (McCuen and Snyder 1986)

deviation from ME = 0 and MNE = 1 (Ünlü et al. 1990; McCuen and Snyder 1986). The test results indicate that the deviations are not significant at the 0.05 significance level.

12.3.5 A Proportional Effect Quasi-Stationary (PEQS) Semivariogram Model

As previously stated, the semivariogram, in practice, is only used for limited distances. Subsequently, we may release the zero trend assumption applied to the four transects. That is, instead of substituting the transect mean (m_T), we may substitute the mean of the nearest neighboring points (m_r) for the term $m(x_j)$ in Eq. (12.19) where

$$m_r = \frac{1}{n}\sum_{i=1}^{n_r} z(x_i, x_j), \tag{12.21}$$

Results of cross validation using Eq. (12.21) are presented in Table 12.2. As seen from Table 12.2, when using in estimation the eight nearest neighboring points, the t-test indicates the validity of the PEQS model and estimated parameters except for transect $T(x_1)$. However, upon using the 16 nearest neighboring points, the failing case is corrected.

As seen from Tables 12.1 and 12.2, there are no changes in the values of MSEP associated with replacing m_r by m_T. The reason is that in estimating $z^*(x)$ most of the weights are given to the two most nearest neighboring points with high insensitivity to estimated parameters. While this is the case for the values of $z^*(x)$, values of $<\sigma_k^2>$ seem more sensitive to estimated parameters. The percentage underestimation and overestimation of the estimated kriging variance decreases upon using

Table 12.2 Results of the cross validation of a proportional effect quasi-stationary semivariogram model for the soil $EC_{1:5}$ (based on the nearest neighboring points, m_r)

							t[a]	
Transect	n_r	MSEP (dS m^{-1})^2	$<\sigma_k^2>$ (dS m^{-1})^2	U (%)	ME	MNE	ME	MNE
T(x_1)	16	0.42	0.24	43	0.019	1.29	0.10	2.00
	8	0.42	0.24	43	0.023	1.32*	0.12	2.12
T(x_2)	8	2.90	1.88	35	0.025	1.28	0.13	1.80
T(x_3)	8	124	139	−12	0.025	1.19	0.14	0.70
T(x_4)	8	476	328	31	0.031	1.14	0.19	1.22

U is percentage underestimation of the estimated average kriging variance $<\sigma_k^2>$. *ME* is mean normalized error. *MNE* is mean square normalized error. *MSEP* is mean square of error prediction

[a]$t=(x-\mu_o)/(s/\sqrt{n})$; d$f=n-1$; H_o : $\mu-\mu_o$ (unknown); H_A: $\mu\neq\mu_o$; region of rejection: $t>t_{\alpha/2}$ and $t<-t_{\alpha/2}$; at 0.05 significance level and d$f=47$ the t value is 2.01 (McCuen and Snyder 1986)

*Significance at 0.05 level

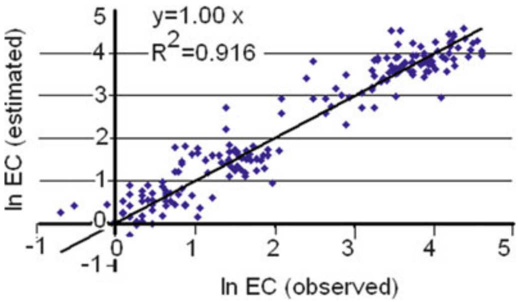


Fig. 12.6 Cross validation test results: Natural logarithm of kriged vs. observed values of the soil salinity data for four subregion transects. The kriging was done using a proportional effect quasi-stationary (*PEQS*) semivariogram model

m_r instead of m_T. Thus, the assumption of quasi-stationary instead of stationary along the transect improved predicting the true kriging variance.

Figure 12.6 shows the values of the natural logarithm of the kriged vs. observed values of the soil salinity property for 192 test sites from the four transects (4×48 = 192), the slope, and the coefficient of determinant (R^2) of which equal to 1.00 and 0.92, respectively. Thus, there is no reason to doubt the adequacy and validity of the PEQS semivariogram model and estimated parameters.

12.3.6 Conclusion

It is concluded that this study offers a practical solution for krig handling a soil property with a pronounced trend without the need for trend removal. This is successfully achieved by partitioning the region into subregions with zero trends and fitting a proportional effect quasi-stationary semivariogram model to the subregion semivariograms. The successful prediction of the linear relationship between the standard deviations and the means as well as cross validation indicates that the 1D procedure developed in this study is the optimal approach and can be extended to 2D cases.

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References

Al-Khafaji AW, Tooley JR (1986) Numerical methods in engineering and applications. Prentice-Hall, Upper Saddle River

Bajpai AC, Calus IM, Fainley JA (1977) Numerical methods for engineers and scientists. Weily, London

Biggar JW, Nielsen DR (1976) Spatial variability of the leaching characteristics of a field soil. Water Resour Res 12:78–84

Bregt AK, McBratney AB, Wopereis MCS (1991) Construction of isolinear maps of soil attributes with empirical confidence limits. Soil Sci Soc Am J 55:14–19

Cressie N (1985) When are relative variograms useful in geostatistics? J Int Assoc Math Geol 17:693–702

Davidoff B, Lewis JW, Selim HM (1986) A method to verify the presence of a trend in studying spatial variability of soil temperature. Soil Sci Soc Am J 50:1122–1127

Deutsch CV (1996) Direct assessment of local accuracy and precision. In: Baafi EY, Schofield NA (eds) Geostatistics Wollongong. Kluwer Academic Publisher, New York

Elprince AM (1985) Model for the soil solution composition of an oasis. Soil Sci Soc Am J 41:39–41

Elprince AM (2009) Prediction of soil fertilization maps using logistic modeling and a geographical information system. Soil Sci Soc Am J 73:2032–2042

Elprince AM, Alsaeedi AH, Abdullah A (2004) Mapping soil salinity using global positioning system and geographic information systems: spatial estimation and map projection. In: Taha FK, Ismail S, Jaradat A (eds) Proceedings International Symposium on prospects of saline agriculture in the Arabian Peninsula. Amherst Scientific Publisher, pp 53–74

Ersahin S (2003) Comparing ordinary kriging and cokriging to estimate infiltration rate. Soil Sci Soc Am J 67:1848–1855

Gorway Crawford CAG, Herget GW (1997) Incorporating spatial trends and anisotropy in geostatistical mapping of soil properties. Soil Sci Soc Am J 61:298–309

Hamlett JM, Horton R, Cressie NAC (1986) Resistant and exploratory techniques for use in semivariogram analyses. Soil Sci Soc Am J 50:868–875

Hamming RW (1989) Introduction to applied numerical analysis. Hemisphere Publishing Corporation, New York

Herbst M, Prolingheuer N, Grap A, Huisman JA, Weihermuller L, Vanderborght J (2009) Characterization and understanding of bare soil respiration spatial variability at plot scale. Vadoes Zone J 8:672–771

Issaks E, Srivastara RM (1989) Applied geostatistics. Oxford University Press, New York

Johnston K, Verhoef JM, Krivoruchko K, Lucas N (2001) Using ArcGIS geostatistical analyst. ISRI, Redlands

Journel AG, Huijbregts C (1978) Minning geostatistics. Academic, London

Kitanidis PK, Lane RW (1985) Maximum likelihood parameter estimation of hydrologic spatial processes by the Gaiss-Newton method. J Hydrol 78:53–71

Laslett GM, McBratney AB (1990) Further comparison of spatial methods for predicting soil pH. Soil Sci Soc Am J 54:1553–1557

Laslett GM, McBrateney AB, Pahl PJ, Hutchinson ME (1987) Comparison of several prediction methods for soil pH. J Soil Sci 38:325–341

Maynune FX, Sarda F, Conan GY (1998) Assessment of the spatial structure and biomass evaluation of *Nephrops norvegieus* (L.) population in the northwest Mediterranean by geostatistics. ICES J Mar Sci 55:102–120

McCuen RH, Snyder WM (1986) Hydrologic modeling statistical methods and applications. Prentice-Hall, Upper Saddle River

Muller TG, Hatsock NJ, Stombaugh YS, Shearer SA, Cornelius PL, Barnhisel RI (2003) Soil electrical conductivity map variability in limestone soils overlain loess. Agron J 95:496–507

Neuman SP, Jacobson EA (1984) Analysis of nonintrinsic spatial variability by residual kriging with application to regional groundwater levels. J Int Assoc Math Geol 16:499–521

Oz and Deutsch (2002) www.uofaneb.ua/berta.ca/ccg//pdfs/2002; verified 6 Mar 2010

Page AL, Miller RH, Keeney DR (eds) (1982) Methods of soil analysis. Part 2. Chemical and microbiological properties, 2nd edn. ASA and SSSA, Madison

Pannatier I (1996) VARIOWIN: software for spatial data analysis in 2D. Springer, New York

Regalad XM, Ritter A (2006) Geostatistics tools for characterizing the spatial variability of soil water forest watershed. Soil Sci Soc Am J 70:1071–1181

Ripley BD (1981) Spatial statistics. Wiley, New York

Russo D, Bresler E (1981) Soil hydraulic properties as stochastic processes: I. An analysis of field spatial variability. Soil Sci Soc Am J 45:682–687

Ünlü K, Nielsen DR, Biggar JW, Morkoc F (1990) Statistical parameters characterizing the spatial variability of selected soil hydraulic properties. Soil Sci Soc Am J 54:1537–1546

Van Kuilenburg J, De Gruijter JJ, Marsman BA, Bouma J (1982) Accuracy of spatial interpolation between point data on soil moisture supply capacity, compared with estimates from mapping units. Geoderma 27:311–325

Wackernagel H (1995) Multivariate geostatistics. Springer, New York

Warrick AW, Myers DE, Nielsen DR (1986) Geostatistical methods applied to soil science. In: Klute A et al (eds) Methods of soil analysis. Part 1, physical and mineralogical methods, 2nd edn. American Society of Agronomy, Madison, pp 53–90

Webster R, Oliver MA (1990) Statistical methods in soil and land resources survey. Oxford University Press, New York

Wu J, Norvell WA, Hopkins DG, Smith DB, Ulmer MG, Welch RM (2003) Improved prediction and mapping of soil copper by kriging with auxiliary data for cation-exchange capacity. Soil Sci Soc Am J 67:919–927

Wu C, Wu J, Luo Y, Zhang L, DeGloria SD (2008) Spatial estimation of soil total nitrogen using cokriging with predicted soil organic matter content. Soil Sci Soc Am J 73:1676–1681

Yost RS, Uehara G, Fox RL (1982) Geostatistical analysis of soil chemical properties of large land areas. II. Kriging. Soil Sci Soc Am J 46:1033–1037

Chapter 13
Spatial Monitoring of Soil Salinity and Prospective Conservation Study for Sinnuris District Soils, Fayoum, Egypt

Mahmoud M. Shendi, Mahmoud A. Abdelfattah, and Ahmed Harbi

Abstract Mapping, updating, and managing soil salinity are considered difficult tasks due to the large spatial and temporal variability of salinity phenomena. In the present study, GIS and field studies are integrated on an area of 22,019 ha to monitor soil salinity development during 2002–2009 in Sinnuris District soils, Fayoum, Egypt. Results have shown decrease in areas of soil salinity from 42.57 to 29.5% within the studied period, mainly due to subsurface drainage networks system and soil reclamation activities. The saline soils in the study area are classified as Typic Aquisalids, Typic Haplosalids, and Typic Salitorrerts. Based on the updated soil studies, groundwater, and Digital Elevation Models (DEM), a strategic management plan supplemented with GIS spatial maps (semi-detailed GIS maps of soil characteristics) is suggested to improve salinity conditions to overcome the future challenges of water scarcity in the area. Future prospective GIS models were produced to simulate drainage condition at groundwater level and to improve salinity conditions in the study area. The study is of vital importance for decision makers for the management of natural resources in Fayoum Governorate.

Keywords GIS • Sinnuris soils • Soil conservation • Soil salinity • Spatial simulation

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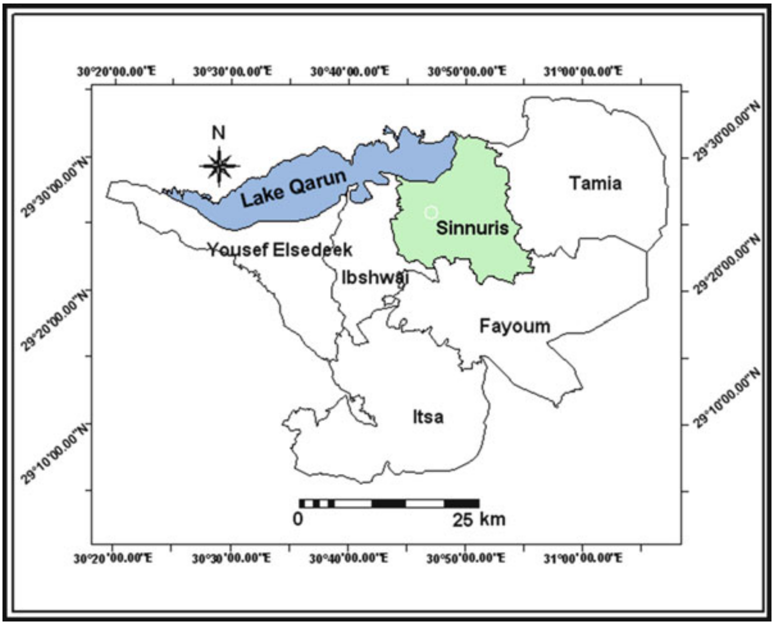


Fig. 13.1 Location map of the study area

13.1 Introduction

El-Fayoum Governorate is a natural depression in the Eocene limestone plateau located at about 90-km southwest of Cairo. Its floor is covered mainly by Fluvio-lacustrine deposits belonging to Pleistocene/Holocene periods. The depression is joined to Nile River by Bahr Yousef canal which leaves the Nile near Dayrute town, Assuit Governorate. At the depression bottom, Lake Qarun covers an area of about 210 km^2 of salty water of average 33.9–37.6 g L^{-1} (FWMP 1999). The lake receives majority of drainage water in the depression, and its water level is maintained to not exceed –43.5 m mean sea level (MSL). The storing capacity of the lake and its salinity are considered main limiting factors for agriculture development in Fayoum Governorate. Because of its international importance being feeding and resting place for migratory birds, Lake Qarun has been declared a natural protectorate in 1989. Sinnuris District is located in the eastern-north part of Fayoum depression and covers an area about 55,726 ha that fall within latitude 29°20′ and 29°30′ N and longitude 30°43′ and 30°56′ E (Fig. 13.1).

The study area is generally characterized by a hot and dry climate with scanty rainfall between December and April with annual average of 8 mm $year^{-1}$, whereas average evaporation ranges from 3.5 to 10 mm day^{-1}. The minimum temperature is usually recorded in January and the maximum in July with an average temperature of 22°C. Adjacent to southern and eastern shores of Lake Qarun, i.e., the depression

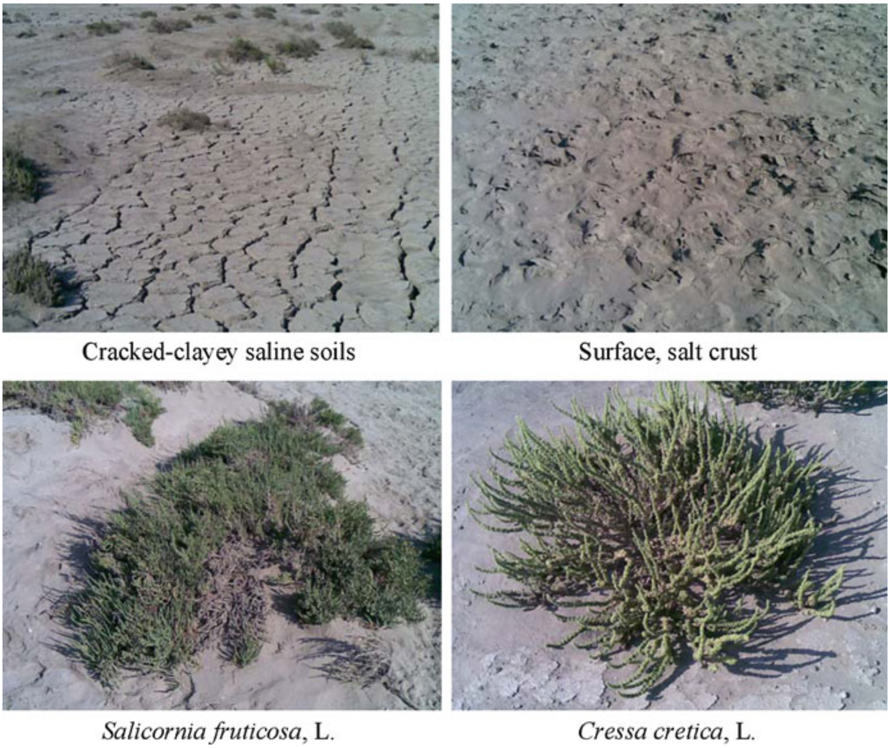


Fig. 13.2 Saline soils and halophytic plants in the south of Lake Qarun (**a**) Cracked-clayey saline soils; (**b**) Surface, salt crust; (**c**) *Salicornia fruticosa*, L.; (**d**) *Cressa cretica*, L.

bottom, saline soils with low permeability and clayey texture are commonly developed (Fig. 13.2).

The present study was conducted with the objectives to monitor soil salinity in Sinnuris District within the period (2002–2009); to define strategic priorities for agricultural drainage improvement in areas suffering from salinity problems; and to prepare guidelines for prospective development, improvement, and conservation plans to manage soil salinity in the study area.

13.2 Materials and Methods

Present study is completed in four stages: (1) conducting a semi-detailed soil survey in the year 2002 and GIS data preparation; (2) conducting a semi-detailed soil/water table survey in year 2009 and GIS data preparation; (3) laboratory analysis of soil samples and coding of soil database attributes; and (4) GIS monitoring analysis and prospective improvement and conservation planning.

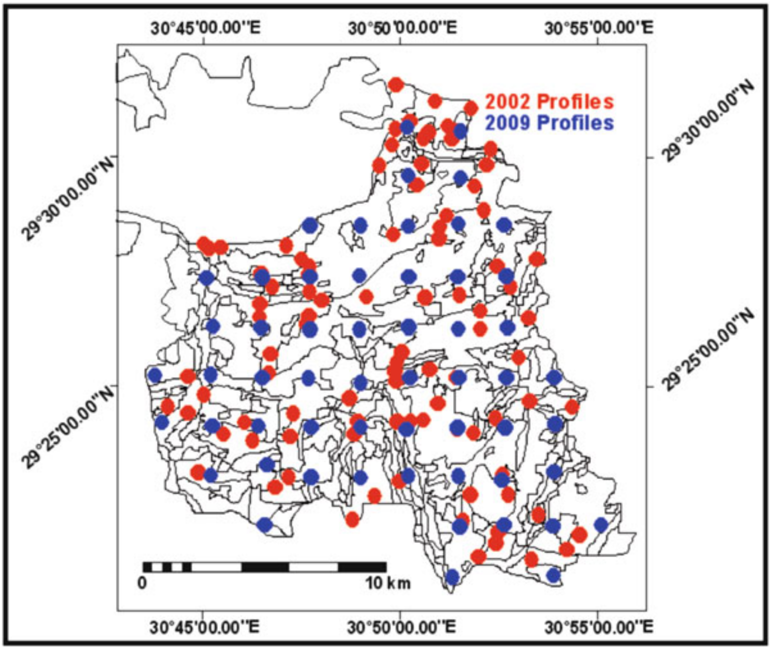


Fig. 13.3 Site location map of integrated soil profiles for years 2002 (*red dots*) and 2009 (*blue dots*)

13.2.1 Semi-detailed Soil Survey in the Year 2002 and GIS Data Preparation

A semi-detailed soil survey was conducted in 2002 in Sinnuris District. The survey was accomplished by interpreting aerial photographs acquired in 1956 and enhanced Landsat TM Satellite image taken in 2001. The geopedolological approach (Zinck 1989) was used for the interpretation of aerial photographs. To increase the purity of soil map units, the interpretation map was crossed with the soil slope and then crossed with the detailed soil texture classes from soil survey of Sinnuris District (Soil, Water and Environment Research Institute 1998) using ILWIS 3.3 GIS capabilities. To complete the study, 117 soil profiles were integrated to represent different soil map units (Abdelfattah 2002). Soil samples from representative soil profiles were analyzed for routine physical and chemical analysis and stored as attribute data for different map units. The location of integrated soil profiles is shown in Fig. 13.3. The final geopedological soil map and its main attribute data are given in Fig. 13.4 and Tables 13.1 and 13.2.

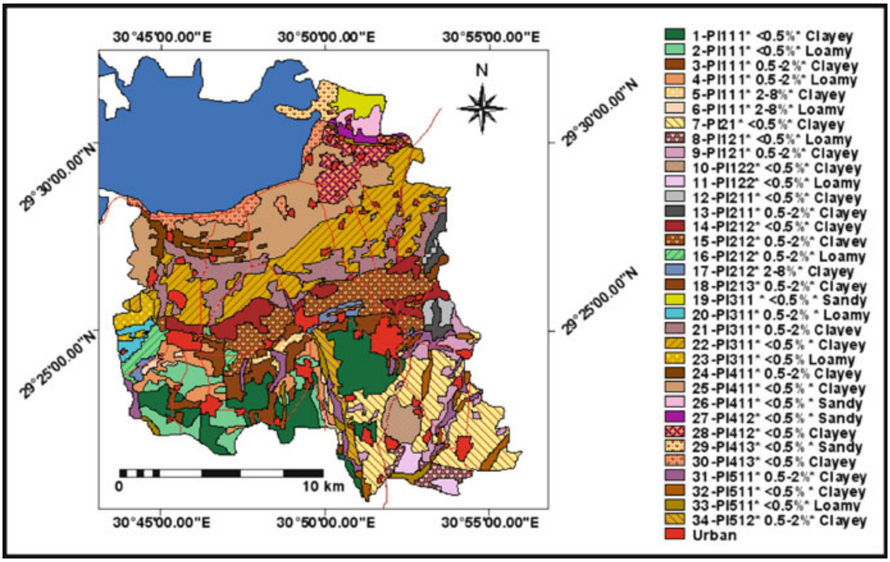


Fig. 13.4 Geopedological soil map of the study area

13.2.2 *Semi-detailed Soil and Water Table Surveys in the Year 2009 and GIS Data Preparation*

Fifty-six soil profiles were investigated for salinity status in the year 2009. The investigated sites were also explored for the presence of water table. At each investigated site, soil and water samples (where water table was recorded) were collected for the analyses in the laboratory. The investigation points were planned on a grid system with lag distance of 2 km. The regular spacing of data collection was planned to facilitate average interpolation, geostatistics, and future monitoring. The exact locations were registered with GPS (Global Positioning System) and imported to ILWIS GIS as point map.

13.2.3 *Analysis of Soil Samples*

Soil samples were processed for air-drying, ground gently, and sieved through a 2-mm sieve to obtain fine earth fraction (<2 mm). The undisturbed soil samples collected for bulk density measurement were used without above processing. Soil samples were analyzed for the following physical and chemical characteristics:

Physical Analyses—Particle size distribution using the pipette method (Piper 1950). Soil bulk density was determined on undisturbed soil cores (Black 1965),

Table 13.1 Legend of the geopedological soil map

Landscape	Relief	Lithology	Landform	Mapping unit	Symbol	Soil classification	Area (ha)
Plain Pl	Higher terraces (Pl 1)	Nile alluvial deposits (Pl 11)	Nearly level terrace tread (Pl 111)	Slope <0.5% and clayey	Pl 1111	Typic Haplotorrerts	1,870.38
				Slope <0.5% and loamy	Pl 1112	Typic Torrifluvents	873.18
				Slope 0.5–2% and clayey	Pl 1113	Vertic Torrifluvents	1,002.06
				Slope 0.5–2% and loamy	Pl 1114	Typic Torrifluvents	650.61
				Slope 2–8% and clayey	Pl 1115	Typic Haplotorrerts	166.86
				Slope 2–8% and loamy	Pl 1116	Typic Torrifluvents	129.42
		Fluvio-lacustrine deposits (Pl 12)	Gently sloping terrace tread (Pl 121)	Slope <0.5% and clayey	Pl 1211	Typic Haplotorrerts	2,115.90
				Slope <0.5% and Loamy	Pl 1212	Typic Haplotorrerts	236.43
				Slope 0.5–2% and clayey	Pl 1213	Typic Torrifluvents	500.40
			Basin (Pl 122)	Slope <0.5% and clayey	Pl 1221	Typic Torrifluvents	324.27
				Slope <0.5% and loamy	Pl 1222	Typic Torrifluvents	205.92
	Moderately high terraces (Pl 2)	Alluvial deposits (Pl 21)	Nearly level terrace tread (Pl 211)	Slope <0.5% and Clayey	Pl 2111	Typic Haplotorrerts	170.37
				Slope 0.5–2% and clayey	Pl 2112	Typic Haplotorrerts	237.51

			Sloping terrace tread (Pl 212)	Slope <0.5% and clayey	Pl 2121	Typic Haplotorrerts	757.17
				Slope 0.5–2% and clayey	Pl 2122	Vertic Torrifluvents	1,539.99
				Slope 0.5–2% and loamy	Pl 2123	Chromic Haplotorrerts	1,539.99
				Slope 2–8% and clayey	Pl 2124	Vertic Torrifluvents	177.30
			Basin (Pl 213)	Slope 0.5–2% and clayey	Pl 2131	Typic Haplotorrerts	53.37
Plain Pl	Moderately low terraces (Pl 3)	Fluvio-lacustrine deposits (Pl 31)	Gently sloping terrace tread (Pl 311)	Slope <0.5% and sandy	Pl 3111	Typic Haplocambids	236.70
				Slope 0.5–2% and loamy	Pl 3112	Typic Haplotorrerts	161.37
				Slope 0.5–2% and clayey	Pl 3113	Typic Haplotorrerts	1,538.55
				Slope <0.5% and clayey	Pl 3114	Vertic Torrifluvents	2,868.84
				Slope <0.5% and loamy	Pl 3115	Xeric Haplargids	224.91
	Low terraces (Pl 4)	Fluvio-lacustrine (Pl 41)	Nearly level to gently sloping terrace tread (Pl 411)	Slope 0.5–2% and clayey	Pl 4111	Calcic Aquisalids	378.45
				Slope <0.5% and clayey	Pl 4112	Typic Haplotorrerts	2,205.63
				Slope <0.5% and sandy	Pl 4113	Xeric Torripsamments	193.32

(continued)

Table 13.1 (continued)

			Basin covered with sand sheet (Pl 412)	Slope <0.5% and sandy	Pl 4121	Typic Torripsamments	11.10
				Slope <0.5% and clayey	Pl 4122	Typic Haplosalids	626.22
			Marshes (Pl 413)	Slope <0.5% and sandy	Pl 4131	Typic Aquisalids	257.76
				Slope <0.5% and clayey	Pl 4132	Typic Haplosalids	524.43
	Incisions (Pl 5)	Alluvial deposits (Pl 51)	Vales (Pl 511)	Slope 0.5–2% and clayey	Pl 5111	Typic Torrifluvents	560.07
				Slope <0.5% and clayey	Pl 5112	Typic Torrifluvents	352.53
				Slope <0.5% and loamy	Pl 5113	Vertic Torrifluvents	222.75
			Overflow-mantle (Pl 512)	Slope 0.5–2% and clayey	Pl 5121	Vertic Torrifluvents	266.13

Table 13.2 Land map units characteristics

No.	LMUs symbol	Available water (FC-WP)[a]	CEC cmolc kg^{-1}	$CaCO_3$ eq. (%)	Drainage conditions[b]	EC dS m^{-1}			ESP			Soil depth (cm)	Soil texture[c]	Soil pH	Organic matter (%)
						0–30 cm	30–90 cm	90–125 cm	0–30 cm	30–90 cm	90–125 cm				
1	Pl111 1	34.11	42.33	4.59	W	1.52	1.32	1.39	13.85	14.77	14.92	150	C	7.98	1.46
2	Pl111 2	20.71	29.74	1.64	W	2.77	1.50	1.17	13.96	14.06	13.6	150	SCL	7.47	1.44
3	Pl111 3	24.69	21.79	1.52	W	1.43	1.85	1.85	10.38	9.71	9.71	80	SCL	7.77	0.80
4	Pl111 4	18.82	35.12	2.62	W	1.29	1.17	1.24	6.44	6.31	6.58	150	SCL	8.10	–
5	Pl111 5	18.00	29.60	2.58	MW	1.17	5.05	5.61	13.72	13.72	13.72	150	CL	8.31	1.05
6	Pl111 6	19.50	29.48	2.89	W	0.76	0.74	0.73	11.02	11.02	11.02	150	SCL	8.00	1.36
7	Pl121 1	17.69	40.59	4.02	W	4.02	4.89	4.55	13.74	14.34	14.29	150	C	7.81	1.04
8	Pl121 2	20.00	25.85	5.69	W	1.12	1.62	1.73	19.34	19.34	19.34	150	SCL	8.20	1.31
9	Pl121 3	9.02	12.00	1.76	W	1.16	0.88	0.85	2.92	3.33	3.85	150	SCL	8.19	–
10	Pl122 1	20.12	16.45	5.47	W	1.75	1.70	1.70	6.62	6.17	6.17	100	SCL	7.44	0.82
11	Pl122 2	20.50	29.02	4.65	MW	1.76	3.30	3.16	17.12	17.12	17.12	150	SL	8.40	0.95
12	Pl211 1	19.50	38.32	5.39	W	1.66	2.27	2.29	12.53	12.53	12.53	150	C	8.06	1.23
13	Pl211 2	20.00	38.97	10.62	MW	1.69	3.08	3.34	29.47	29.47	29.47	150	C	8.38	1.25
14	Pl212 1	22.90	40.31	10.34	MW	11.67	8.16	7.20	14.58	14.58	14.63	110	C	7.70	1.12
15	Pl212 2	24.13	32.79	4.46	W	1.72	1.50	1.49	11.6	12.68	13.16	110	C	7.75	1.3
16	Pl212 3	16.75	33.31	3.26	W	1.17	1.23	1.26	7.66	9.25	9.68	150	C	7.73	1.17
17	Pl212 4	18.50	33.59	3.07	W	1.04	1.52	1.43	11.02	11.02	11.02	120	CL	8.06	1.42
18	Pl213 1	19.00	37.85	9.57	MW	1.61	2.23	2.85	14.93	14.93	14.93	150	C	8.39	1.41
19	Pl311 1	18.50	6.42	1.40	EW	3.50	4.39	6.07	11.99	13.15	15.28	205	S	7.80	0.03
20	Pl311 2	18.50	33.71	6.15	MW	1.45	1.31	1.25	28.39	28.39	28.39	120	SCL	8.46	1.25
21	Pl311 3	19.50	38.13	6.00	MW	6.68	3.23	3.44	12.18	17.16	16.18	130	C	7.92	1.53
22	Pl311 4	20.65	26.34	10.84	W	9.09	8.16	8.50	14.19	16.19	16.46	100	C	7.71	1.02
23	Pl311 5	18.50	35.25	4.95	MW	1.74	4.13	4.29	14.14	14.06	13.95	110	CL	7.99	1.32
24	Pl411 1	23.95	25.78	11.20	P	22.93	19.08	19.8	31.80	31.26	31.26	80	C	8.55	0.91

(continued)

Table 13.2 (continued)

No.	LMUs symbol	Available water (FC-WP)[a]	CEC cmolc kg^{-1}	$CaCO_3$ eq. (%)	Drainage conditions[b]	EC dS m^{-1} 0–30 cm	EC dS m^{-1} 30–90 cm	EC dS m^{-1} 90–125 cm	ESP 0–30 cm	ESP 30–90 cm	ESP 90–125 cm	Soil depth (cm)	Soil texture[c]	Soil pH	Organic matter (%)
25	Pl411 2	21.00	50.66	5.28	MW	2.18	2.28	2.19	23.54	38.70	37.89	170	C	8.00	1.17
26	Pl411 3	17.00	13.07	5.09	W	4.98	7.58	8.03	31.83	54.51	51.83	125	LS	8.26	2.48
27	Pl412 1	17.00	16.75	4.68	SWE	4.93	8.73	9.64	19.39	19.39	19.39	120	LS	8.00	0.66
28	Pl412 2	21.00	33.03	7.63	P	80.98	29.03	22.17	13.57	13.47	12.58	120	C	7.73	0.84
29	Pl413 1	20.00	22.13	7.60	P	145.93	31.33	31.33	21.01	26.25	26.25	50	L	7.59	1.27
30	Pl413 2	16.80	47.46	9.80	P	37.48	40.91	40.77	33.88	32.62	32.05	115	C	7.90	1.1
31	Pl511 1	28.10	26.99	1.53	SWE	1.25	1.35	1.26	6.28	9.69	10.24	135	SCL	7.63	0.95
32	Pl511 2	19.00	32.21	3.97	W	0.81	0.86	0.85	9.47	9.47	9.47	140	SCL	8.08	0.74
33	Pl511 3	26.34	26.05	1.53	W	1.38	1.31	1.38	8.29	8.07	7.96	110	SC	7.50	1.49
34	Pl512 1	20.37	26.99	3.34	W	2.00	1.40	1.40	9.10	8.15	7.95	110	CL	7.74	1.15

[a] *FC* moisture content at field capacity, *WP* moisture content at wilting point

[b] W well, *MW* moderately well, *IM* imperfectly, *EW* excessively well, *SWE* somewhat excessively, *P* poorly, *SWP* somewhat poorly

[c] *C* clay, *CL* clay loam, *SCL* sandy clay loam, *SL* sandy loam, *L* loam, *SC* sandy clay, *LS* loamy sand (Soil Survey Division Staff 1993)

where as hydraulic conductivity coefficient was determined on undisturbed soil cores, using Darcy law (Richards 1954).

Chemical Analyses—Calcium carbonate equivalents using the Collin's calcimeter method. Organic matter was determined by Walkely and Black method (Jackson 1967). Soil-saturated paste was prepared and pH was measured (Richards 1954); from this saturated soil paste, soil extract was collected under vacuum and analyzed using standard methods as described by Jackson (1967).

Soil saturation extract was analyzed for electrical conductivity (ECe) and expressed as dS m^{-1}, and soluble anions (CO_3^{2-}, HCO_3^-, Cl^-) and cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) were measured using standard titration procedures, except Na and K which were measured by flame photometer. Due to the unavailability of the rapid method for sulfate measurements, soluble SO_4^{2-} were determined by difference, by subtracting soluble anions (CO_3^{2-}, HCO_3^-, Cl^-) from the total soluble cations, expressed in milliequivalents per liter.

Extractable cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+) were determined in 1N ammonium acetate extract (pH 7). Exchangeable cations were then calculated by difference (extractable-soluble) expressed in meq/100 g soil. The cation exchange capacity (CEC) of soil samples was determined by saturating the soil exchange complex with Na by using 1N buffered (pH 8.2) sodium acetate solution. The excess salts were then washed with 95% ethanol, and Na was extracted with 1N ammonium acetate (pH 7) solution and replaced Na measured using flame photometer and expressed as CEC on cmolc kg^{-1} soil basis (Richards 1954).

13.2.4 Analysis of Water Samples

The location of each investigation site was registered using GPS; then the groundwater table depth was recorded and water samples collected for analysis. The groundwater samples were filtered through Wattman filter papers No. 42, stored in clean dry plastic bottles in a refrigerator, and analyzed for following parameters.

Water pH was measured using standard pH meter after calibration with buffer solutions (pH 4, 7), and electrical conductivity of water samples (ECw) was measured using an EC meter (US Salinity Lab Staff 1954).

The analytical results were coded to ILWIS GIS as attributes data for all tested points.

Moving average interpolation method was used to generate the groundwater depth and groundwater salinity.

13.2.5 GIS Monitoring Analysis and Prospective Conservation Planning

The interpolation capabilities of ILWIS GIS were used to establish a geographic information system for the soils and groundwater in the study area. Crossing capability between maps of different dates was also used to monitor the studied characteristics.

13.3 Results and Discussion

13.3.1 Soils of Sinnuris District

The geopedological map and its legend are shown in Fig. 13.4 and Table 13.1. It is clear from the legend that each map unit name contains information about landform, slope percentage, and textural class. Three main soil orders (Soil Survey Staff 2006) were recorded in the study area; Vertisols, Entisols and Aridisols, (Table 13.1 and Fig. 13.5). The recoded areas of Soil Great Groups were 9,786.9 ha (Haplotorrerts), 9,680 ha (Torrifluvents), 303.9 ha (Torripsamments), 636.3 ha (Aquisalids), 1,149.9 ha (Haplosalids), 224.7 ha (Haploargids), and 236.8 ha (Haplocampids). The physical and chemical soil characteristics are shown in Table 13.2.

13.3.2 Monitoring of Soil Salinity

13.3.2.1 Soil Salinity in the Year 2002

According to the soil survey held in the year 2002 (Fig. 13.6), the areas of saline soils with salinity values (>4 dS m^{-1}) reached to 9,371.5 ha, whereas soils of high-salinity values (>16 dS m^{-1}) reached to 1,785.98 ha. These areas are located mainly

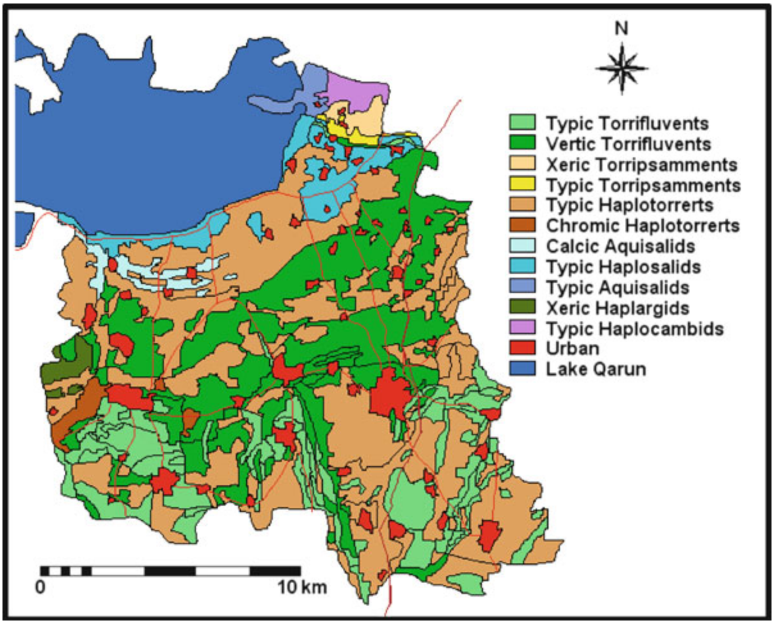
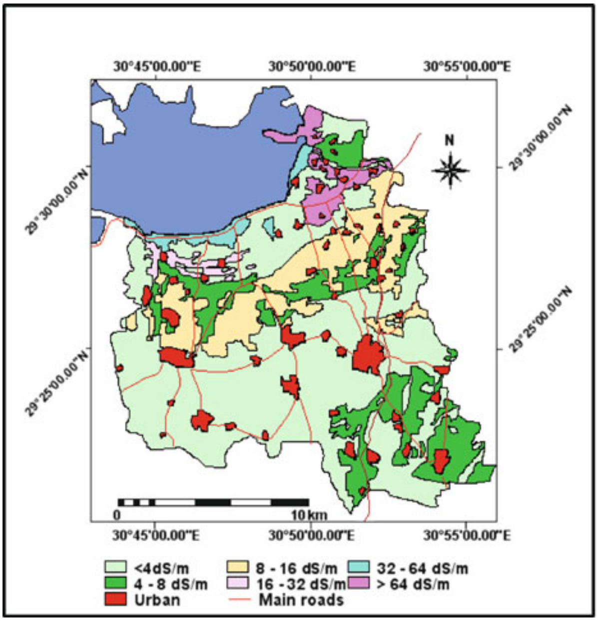


Fig. 13.5 Soil classification map



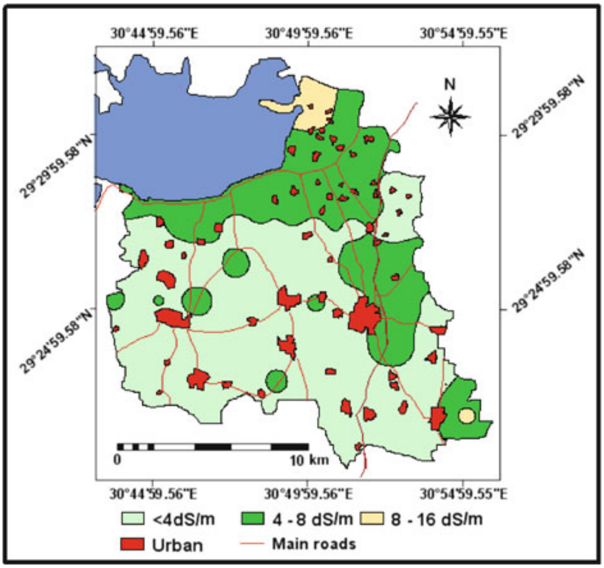
Salinity dS m^{-1}	Area (hectares)
<4	12647.63
4-8	3960.36
8-16	3625.17
16-32	378.07
32- 64	522.47
>64	885.44

Fig. 13.6 Soil salinity map of the year 2002

adjacent to Lake Qarun where poor drainage conditions, shallow saline groundwater, and clayey soils with low permeability occurred. In the east-north of the study area, soils are also very saline despite that the soils exhibit lighter textural classes due to sand encroachment from the sand sheets and dunes occurred in the north of the area. In the areas, beside the downstream connection of El-Bats main drain with Lake Qarun, the high soil salinity values are due mainly to the capillary rise of shallow saline groundwater and subsequent evaporation. Based on the results from the present study, it is suggested that lowering the groundwater depth, subsoiling (physical soil improvement), and gypsum application (amelioration of soil sodicity) may improve salinity and drainage conditions in the area.

13.3.2.2 Soil Salinity in the Year 2009

As indicated in Fig. 13.7, a pronounced improvement in soil salinity condition is achieved. The total saline area with salinity values (>4 dS m^{-1}) is reduced from 9,371.5 ha in the year 2002 to 7,972.1 ha in the year 2009, i.e., (about 15% decrease in salinity area). No high salinity values (>16 dS m^{-1}) were recorded. The highest salinity values were recorded in the area beside the downstream connection of El_Bats main drain with Lake Qarun. A small area of 521.6 ha, about 0.5 km. east of Matartares Town, in the southeast part of the study area showed a deterioration in salinity conditions, which may indicate the needs for drainage improvement in the area.



Salinity dS m^{-1}	Area (hectares)
<4	14046.56
4-8	7372.12
8-16	600.0

Fig. 13.7 Soil salinity map of the year 2009

13.3.2.3 Salinity Monitoring Between the Years 2002 and 2009

Using crossing capability of ILWIS GIS, the raster salinity maps were crossed together to monitor the salinity development in the area (Fig. 13.8). The area where salinity conditions were improved reached to 7,475.26 ha. The main improvement area was a belt of about 2-km width north of Sanhour Town in the form of terraces, south of Lake Qarun, with length of about 3.5 km. The improvement is attributed mainly to the applied subsurface drainage networks system and soil reclamation activities. An area of about 4,141.79 ha showed a trend of degradation by increasing salinity values. The main degraded area is located adjacent to Lake Qarun with an area of 1,974.37 ha. Another degraded area appeared east of Sinnuris Town with an area of about 1,308 ha. A small area of 521.6 ha, about 0.5 km east of Matartares Town, showed also a deterioration trend in salinity conditions. The resulted map is considered of a vital importance to the decision makers as this can be based for planning priorities for soils, drainage improvement, and conservation plans.

An attempt was made also to investigate the possible contribution of Lake Qarun elevation and its salinity on the soil salinity and groundwater level in Sinnuris District. It is known that the storing capacity of Lake Qarun and its salinity plays a prime strategic role on the development of Fayoum Governorate in general. Many studies referred to the siltation occurred on the lake bottom and its effects on shallowing the bottom of the lake and reducing storing capacity (Dardir and Wali 2009). In Table 13.3, FWMP (1999) provided important data to link between the lake level, its volume and its area. The data of FWMP (1999) was used beside the digital

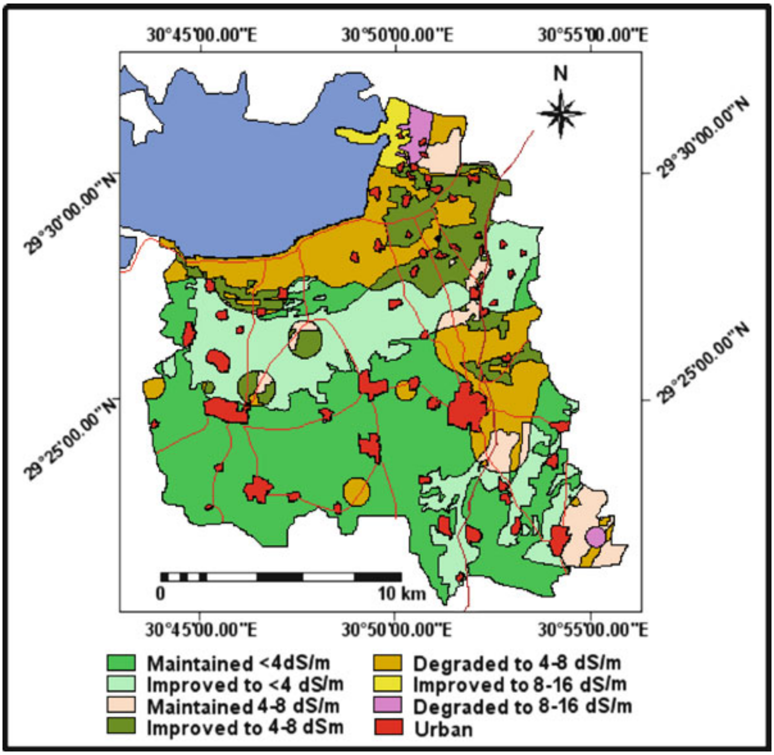


Fig. 13.8 Salinity monitoring between 2002 and 2009 period

Table 13.3 Relationship between lake level, water volume, and lake area (After FWMP 1999)

Lake level (MSL)	Water volume million m^3	Lake area km^2
$Z=-42$ m	1,251.7	219.5
$Z=-43$ m	1,027.1	216.0
$Z=-44$ m	809.9	208.4
$Z=-45$ m	605.5	194.9
$Z=-46$ m	420.0	173.0
$Z=-47$ m	266.0	130.4
$Z=-48$ m	158.1	88.7
$Z=-49$ m	86.1	56.6
$Z=-50$ m	39.0	38.3
$Z=-51$ m	10.8	18.1
$Z=-52$ m	1.0	3.6
$Z=-53$ m	0.04	0.03
$Z=-54$ m	0.0	0.0

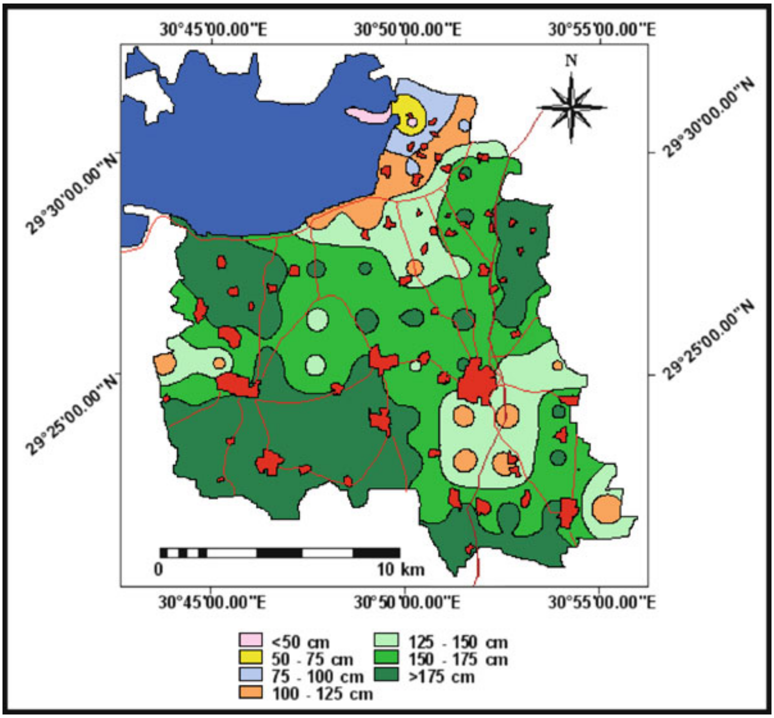


Fig. 13.9 Groundwater depth map 2009

elevation model resulted in the present study after integrating the limited available spot heights of lake bottom included in the topographic map scale 1:100,000 (EGSA 1956). A simulation model was used to simulate the effect of digging the lake bottom of 30 cm for the improvement of drainage condition in Sinnuris District soils. The simulation model indicated that we need to remove 64.5×10^6 m^3 to lower down 30-cm lake water. The simulation results can only be applied to improve an area of about 105.83 ha south of the lake. It is expected that the simulation results could be enhanced after the availability of semi-detailed recent survey data for the lake bottom levels.

13.4 Groundwater Studies

The depth of groundwater table is presented in Fig. 13.9. The resulted groundwater depth map indicated clearly that soils located in the eastern parts of Lake Qarun are generally the most suffered areas from the shallow groundwater. The groundwater depth map showed an area of 707.29 ha, east of Lake Qarun, possess water level shallower than 1 m. which clearly match with the results for soil salinity of that

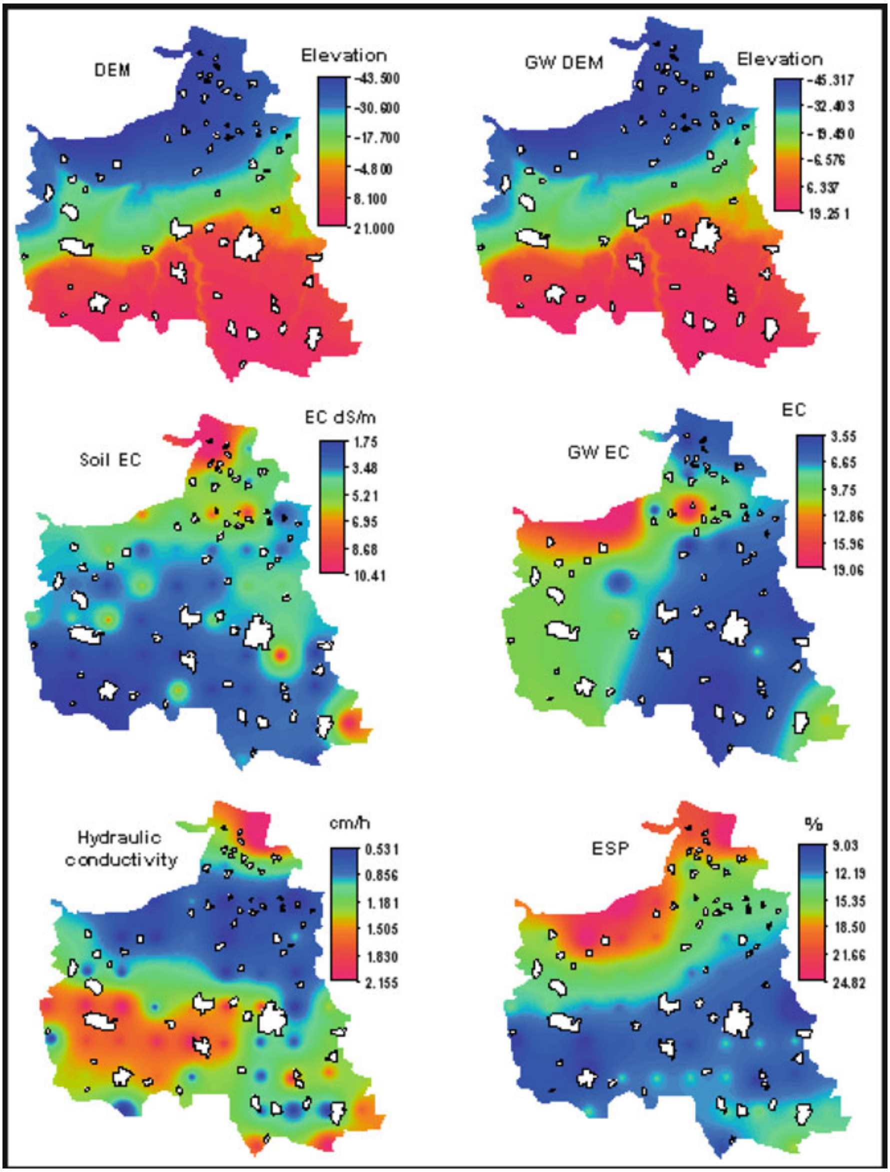


Fig. 13.10 Relationship between soil salinity and DEM, GW-DEM, GW salinity, hydraulic conductivity, and ESP values

area. As indicated in Figs. 13.9 and 13.10; the groundwater depth varied from 31 to 200 cm below soil surface with an average of 117 cm below soil surface. The comparison of the digital elevation model (DEM) of soil surface with the DEM of the groundwater depth (GW) indicated that the groundwater elevation is running in a clear harmony with the soil elevation values (Fig. 13.9). The comparison between the spatial variability of soil salinity values with soil elevation, depth of groundwater, salinity of groundwater, soil hydraulic conductivity, and ESP (exchangeable sodium percentage) values indicated a very complex relationship that needs to be explored with more detailed studies to clarify the contribution rule of each item (Fig. 13.10).

13.5 Conclusions and Recommendations

Monitoring of soil salinity from years 2002 to 2009 showed improvement trend in soil salinity in Sinnuris soils. The study provided a suitable geographic database that can be used for planning priorities for soils improvement and conservation plans. Based on the results from the present study, it is recommended to continue soil salinity monitoring, groundwater level depth, groundwater salinity, and Qarun lake salinity to make the suitable intervention needed to prevent deterioration of soil and water resources. It is also recommended to (1) apply the suggested simulation model dealing with Lake Qarun storing capacity after updating the lake bottom levels and to study the economic aspects and the cost/benefits of the applied scenario; (2) study simulation models on the effects of using mixed irrigation/drainage water to overcome the future challenges of water scarcity and to study the effects on soil salinity, groundwater depth, and water/salts balance in Lake Qarun; and (3) monitor salts balance and salts extract from Lake Qarun to prevent environmental deterioration as much as possible.

References

Abdelfattah MA (2002) A GIS evaluation of soil and water management for sustainable agriculture in El Fayoum Governorate, Egypt. Ph.D. thesis, Fayoum University, Fayoum

Black CA (1965) Methods of soil analysis, part I. American Society of Agronomy, Inc., Madison

Dardir AA, Wali AM (2009) Extraction of salts from lake Qarun, Egypt: environmental and economic impacts. Global NEST J 11(1):106–113

EGSA (1956) Topographic maps scaled 1:100,000. Egyptian General Surveying Authorities, Cairo, Egypt

FWMP (1999) Technical note no. 55. Fayoum Water Management Project II, ARCADIS Euroconsult, Darwish Consulting Engineers, Cairo, Egypt

Jackson ML (1967) Soil chemical analysis. Prentice Hall/Ladia Private, Ltd., New Delhi

Piper CS (1950) Soil and plant analysis. International Science Publisher, Inc., New York

Richards LA (ed) (1954) Diagnosis and improvement of saline and alkaline soils, Handbook no. 60. United States Department of Agriculture, Washington, DC

US Salinity Lab Staff (1954) Diagnosis and improvement of saline and alkali soils, US Department of Agriculture (USDA), Handbook no. 60. US Salinity Lab Staff, Riverside

Soil Survey Division Staff (1993) Soil survey manual, USDA, Handbook no. 18. Government Printing Office, Washington, DC

Soil Survey Staff (2006) Keys to soil taxonomy, 10th edn. United States Department of Agriculture, Natural Resources Conservation Center, Washington, DC

Soil, Water and Environment Research Institute (1998) Detailed soil survey for Sinnuris District. Soil, Water and Environment Research Institute, Fayoum, Egypt

Zinck JA (1989) Physiography and soils. Soil Survey Course, ITC Lecture Note, K6 (SOL 41): 1988/1989, Enschede, The Netherlands

Chapter 14
Geographical Distribution of Soil Salinity, Alkalinity, and Calcicity Within Fayoum and Tamia Districts, Fayoum Governorate, Egypt

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Abstract Geographical distribution of soil salinity, alkalinity, calcicity, soil texture, and organic matter (grid system-log distance of 2 km) has been evaluated and mapped in the study area (about 770 km^2) using GIS-ILWIS format. It is found that in the soils of Tamia District, ECe ranged between 1.22 and 22.4 dS m^{-1} and 1.03 and 97.1 dS m^{-1} in Fayoum District soils within the top layer. Results show 91.5% of Tamia soils and 56.5% of Fayoum District soils present ECe>4 dS m^{-1}, indicating that salt-affected soils are distributed throughout the study area. About 94.5% of Tamia soils and 30% of Fayoum soils are calcareous (>10% $CaCO_3$ eq), due to the nature of parent material from which these soils are evolved. Soil pH of more than 8.00 was found in about 3.25% of Tamia soils and 73% of Fayoum District soils, whereas the soils with pH>8.5 are 3.96% in Tamia and 9.53% in Fayoum District. The organic matter contents seldom exceeded 1% in Tamia soils and did not exceed 1.5% for Fayoum soils. Soil texture in both districts is found as clay, sandy clay, sandy clay loam, sandy loam, and sandy. The maps generated through GIS are useful for decision makers for land use planning, conservation, and uses, as well as interest to researchers and soil science students to use the information for further investigations.

Keywords Alkalinity • Calcicity • Geographical distribution • GIS • Soil salinity

14.1 Introduction

Nearly 10% of the total land surface is covered with different types of salt-affected soils, and no continent of our globe is free from salt-affected soils. Salt-affected soils are estimated to occupy about 954 million ha (Massoud 1974) of the globe.

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Extensive areas (about 10 million ha annually) of irrigated lands have been and are increasingly becoming degraded by salinization and alkalization mainly in hot arid and semiarid regions (Ghassemi et al. 1995), although they are also found in polar regions (Buringh 1997). Available data suggest that the present rate of such degradation has surpassed the rate of expansion in irrigation (Seckler 1996).

Fayoum Governorate, Egypt, is a large depression located about 90 km southwest of Cairo, between latitudes 29° 10′ and 29° 30′ N and longitudes 30° 20′ and 31° 10′ E; it occupies a portion of Eocene limestone plateau at the northern part of the western desert (Fig. 14.1). Fayoum depression differs from all other depressions of Egypt because the main source of potable and irrigation water is from Nile canal (Bahr Yussef canal) which enters Fayoum from the eastern edge at Al Lahoon (+26 m above sea level) and extends through the governorate with a northward slope ending at the coast of Lake Qaroun (42 m below sea level). The total area of Fayoum Governorate is 6,068.7 km^2 including two artificial lakes at Wadi El Rayan, in addition to the natural Lake Qaroun. The annual average rainfall is 8 mm, with some years of no rainfall at all, while in some cases as much as 44 mm rain falls in 1 day. The minimum average temperature in summer is 22°C, while the maximum is 38°C or higher (up to 50°C). In the coldest months (December and January) the minimum average temperature reaches 4°C. Evaporation ranges between 3.5 and 10 mm day^{-1}, and the average annual evaporation reaches 6.7 mm day^{-1}. Relative humidity records indicate monthly variations between 42.6 and 67.4, and the average annual humidity is 55% (Euroconsult 1992). Dryness prevails all over the year throughout Fayoum Governorate and the climate of this area is arid (Walter 1950; Erian 1982).

According to several researches (Hanna and Labib 1977; Shendi 1984), the Fayoum depression formation is belonging to three groups of sediments of distinctly different origins: river Nile, lacustrine and desertic sediments forming four terraces. The most features of Fayoum depression soils are the presence of calcic, gypsic, salic, and gleyic horizons (Al-Sharif 1987, 1994; Abdel Aal 1990). Studies of Hammad et al. (1983) showed that the Fayoum soils belong to three soil orders: Vertisols, Entisols, and Aridisols.

The governorate includes six administrative districts, namely, Fayoum, Tamia, Etsa, Senoures, Ebshway, and Yousef Al Seddik (Fig. 14.1). The study area (about 770 km^2) included the lands of Fayoum (about 425.2 km^2) and Tamia (about 344.4 km^2) Districts. The main problems constraining the sustainable agriculture in both districts are the salinization, alkalization, calcicity, low organic matter, closed drainage system, and high water table. The total extent and distribution of these problems within the two districts are not yet known. It is, therefore, essential to generate important soil information for better management and uses of these soils. Among others, root zone soil salinity plays important role in limiting crop production. To achieve the set targets for this study, the extent and geographical distribution of soil salinity, alkalinity, calcicity, organic matter and soil texture was determined throughout the area of Fayoum and Tamia Districts within the plant root zone using the geographic information systems “GIS” and Integrated Land and Water Information Systems “ILWIS” software.

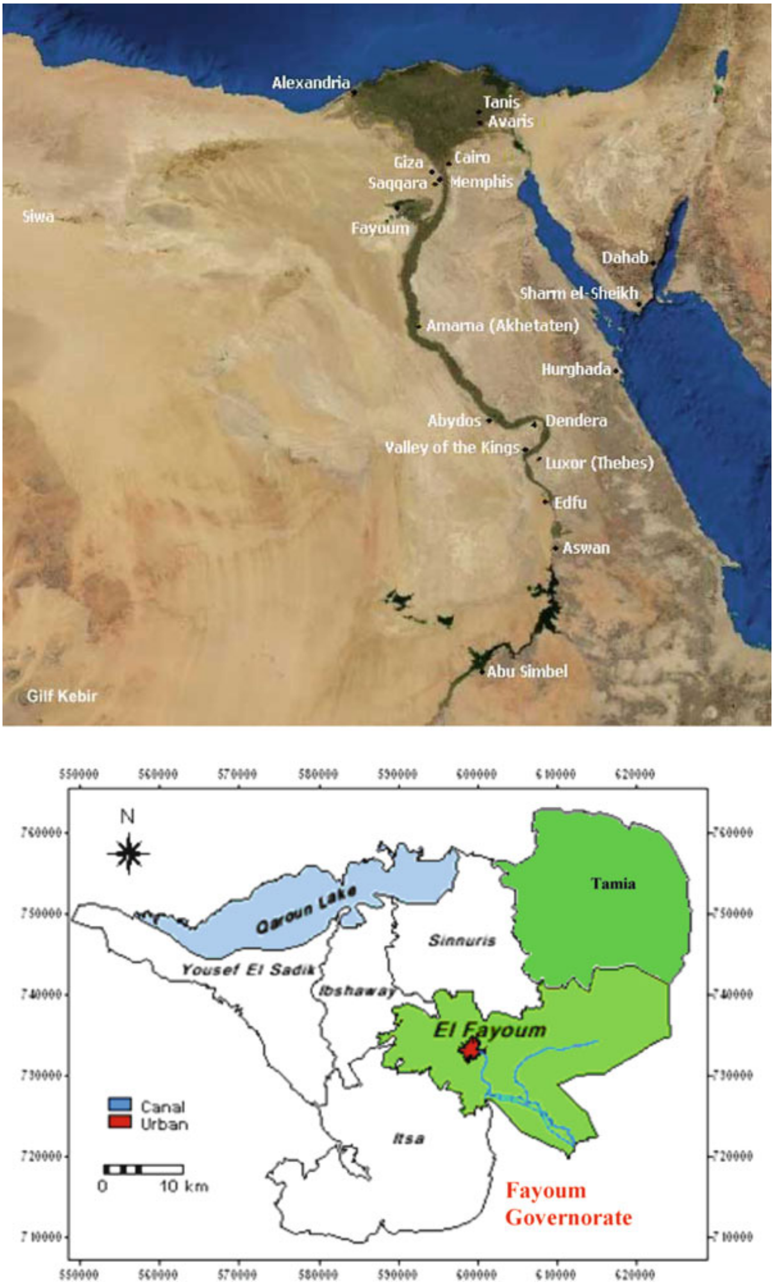


Fig. 14.1 The political map of Egypt and the map showing location of the study area

The present study is part of a more comprehensive research program being conducted by the principal author of this chapter, on soil pollution with heavy metals covering all six districts of Fayoum Governorate.

14.2 Materials and Methods

Surface and subsurface soil samples were collected during the years 2008 and 2009 from 81 and 83 sites representing Fayoum and Tamia Districts soils, respectively. Samples were collected using a grid system at a distance of 2 km. Locations of the investigated sites (Fig. 14.2) were recorded by global positioning system “Garmin GPS.” Two samples were collected from each site (0–30 and 30–60 cm).

Soil samples were processed for air-drying, gently ground to pass a 2-mm sieve and stored in plastic bottles. Soil samples were analyzed for the following characteristics: particle-size distribution, by the hydrometer method (ASTM No. 152 H Temp.) using sodium hexametaphosphate-sodium carbonate as dispersing agents (Bouyoucos 1962); calcium carbonate content were measured using Scheiber’s calcimeter as described by Houba et al. (1995) and pH in saturated soil paste using a pH meter. The electrical conductivity of soil saturation extract (ECe) was measured using a conductivity bridge as described by US Salinity Lab staff (1954). Organic matter content was determined using Walkley and Black method (Jackson 1979).

The results of soil salinity (ECe), $CaCO_3$% equivalents, soil pH, organic matter, and clay contents were categorized into different ranges. Their distribution throughout the study area (Fayoum and Tamia Districts) within the top 60 cm was mapped using the interpolation capabilities of “ILWIS” and geographic information systems “GIS.”

14.3 Results and Discussion

14.3.1 Soil Salinity Distribution in Both Districts

The ECe data are presented in Tables 14.1 and 14.2, whereas salinity (ECe) mapping is shown in Fig. 14.3, revealing Fayoum and Tamia Districts soils are suffering from soil salinization (ECe > 4 dS m^{-1}). An area of 56.5% in Fayoum District and 91.5% in Tamia District are salinized. Looking at the area with ECe > 8 dS m^{-1} in both districts, it is found that such a salinity level exists in 20% of Fayoum and 33% of Tamia District soils. Maximum ECe at 30-cm soil layer was recorded as 97.1 and 22.4 dS m^{-1} for Fayoum and Tamia Districts, respectively.

The causes of soil salinization in both districts could be due to the interactions of various factors: limited available supply of irrigation water, shallow groundwater table, water salinity, poor drainage, soil parent material, topography, poor land management, and arid climate (high temperature, high evaporation rate, low humidity, and wind action). Data indicated that the mean values of salinity (ECe) were generally

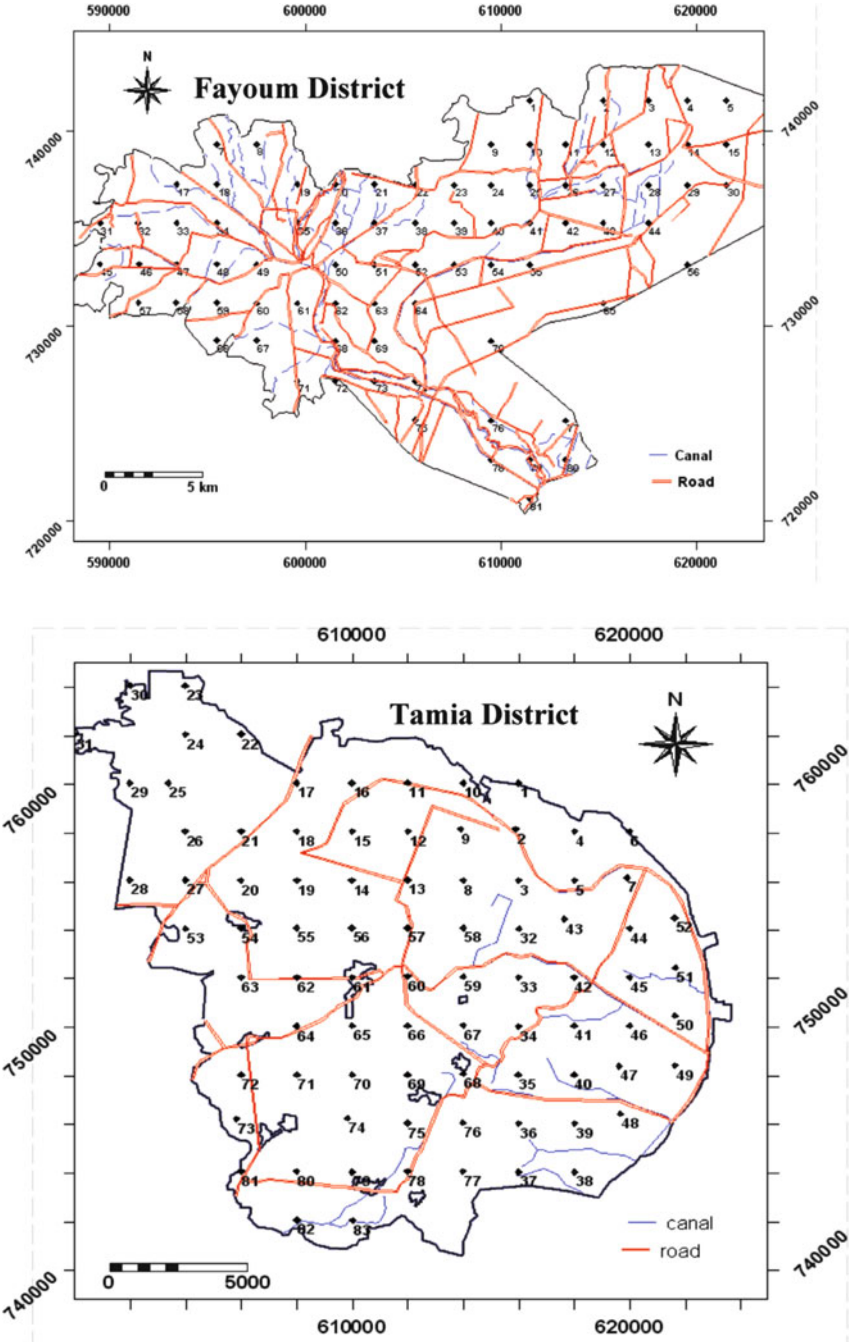


Fig. 14.2 Locations of investigation sites where soil samples were collected

Table 14.1 Distribution of soil salinization, soil pH, $CaCO_3$ equivalents, organic matter, and clay contents in Fayoum and Tamia Districts soils (0–30 cm)

Distribution				
Level	Fayoum		Tamia	
ECe (dS m^{-1})	Area (ha)	% of district area	Area (ha)	% of district area
<4	18,505	43.52	2,907	8.44
4–8	15,779	37.11	20,183	58.60
8–12	4,902	11.53	11,170	32.43
12–32	2,245	5.28	183	0.53
>32	1,088	2.56	–	–
Soil pH				
7–7.5	336	0.79	1,922	5.58
7.5–8	11,065	26.02	31,401	91.17
8–8.5	27,065	63.65	1,113	3.23
>8.5	4,053	9.53	7	0.02
$CaCO_3$ equivalents (%)				
5	1,020	2.40	1,260.61	3.66
5–10	28,675	67.44	8,297.32	24.09
10–20	12,301	28.93	18,668.11	54.20
20–30	523	1.23	2,903.54	8.43
30–40	–	–	1,239.95	3.60
>40	–	–	2,073.47	6.02
Organic matter (%)				
<0.25	1,237	2.91	227	0.66
0.25–0.5	2,096	4.93	10,289	29.87
0.5–0.75	2,670	6.28	17,969	52.17
0.75–1	13,483	31.71	5,924	17.20
1–1.5	23,033	54.17	34	0.10
Clay (%)				
1–10	21	0.05	14	0.04
15–30	8,053	18.94	18,427	53.40
30–45	7,941	18.68	14,067	40.84
45–60	23,858	56.06	1,918	5.57
>60	2,666	6.27	17	0.05
Total area	42,519	100	34,443	100

greater in Tamia than Fayoum soils. The mean ECe of the top 30 cm were generally greater than those of the subsoils of Tamia; however, the opposite was observed within Fayoum District soils (Fig. 14.4). The use of drainage water from agriculture fields through mixing with fresh Nile and irrigation of wide areas in Tamia District as well as influence of dominant Gypsiferous Shales parent material (Hammad et al. 1983) may have contributed salinity in Tamia District soils, compared to Fayoum District soils, which are developed mostly on fluvial parent material (Abo El-Einane 1977) and all the soils are irrigated with fresh Nile water.

Table 14.2 Distribution of soil salinization, soil pH, $CaCO_3$ equivalents, organic matter, and clay contents in Fayoum and Tamia Districts soils (30–60 cm)

Distribution				
Level	Fayoum		Tamia	
ECe (dS m^{-1})	Area (ha)	% of district area	Area (ha)	% of district area
<4	24,283	57.11	3,351	9.73
4–8	11,123	26.16	20,442	59.35
8–12	2,947	6.93	–	–
12–32	2,411	5.67	10,515	30.53
>32	1,756	4.13	134	0.39
Soil pH				
7–7.5	–	–	5,780	16.78
7.5–8	3,376	7.94	27,554	80.00
8–8.5	34,853	81.97	1,106	3.21
>8.5	4,290	10.09	3	0.01
$CaCO_3$ equivalents (%)				
<5	879	2.07	826.63	2.40
5–10	29,870	70.25	9,130.83	26.51
10–20	11,762	27.66	18,671.55	54.22
20–30	8	0.02	2,076.92	6.03
30–40	–	–	4,290.23	7.23
>40	–	–	1,246.84	3.62
Organic matter (%)				
<0.25	708	1.67	141	0.41
0.25–0.5	1,252	2.94	10,901	31.65
0.5–0.75	5,118	12.04	18,737	54.40
0.75–1	15,267	35.90	4,657	13.52
1–1.5	20,174	47.45	7	0.02
Clay (%)				
1–10	1	0.01	48	0.14
15–30	669	1.57	18,396	53.41
30–45	23,569	55.43	15,579	45.23
45–60	18,248	42.92	403	1.17
>60	32	0.07	17	0.05
Total area	42,519	100	34,443	100

In a previous study (Abd El Motaleb 2002), remarkable increase in soil salinity levels of Senoures and Tamia soils irrigated with mixed water (drainage water mixed with Nile water) was recorded, compared with those soils irrigated with Nile fresh water. Present study revealed the occurrence of very highly saline and highly alkaline soils near the coast of the recent Lake Qaroun, where the water table exists at depths mostly less than 80 cm; this shallow water table occur due to seepage from the lake saline water (43,000 ppm) to the surrounding low relief lands (Al Sharif 1994; Abdel Aal 1990). We believe that Fayoum and Tamia District soils were not directly affected by the very high salinity of recent Lake Qaroun since they occur at higher

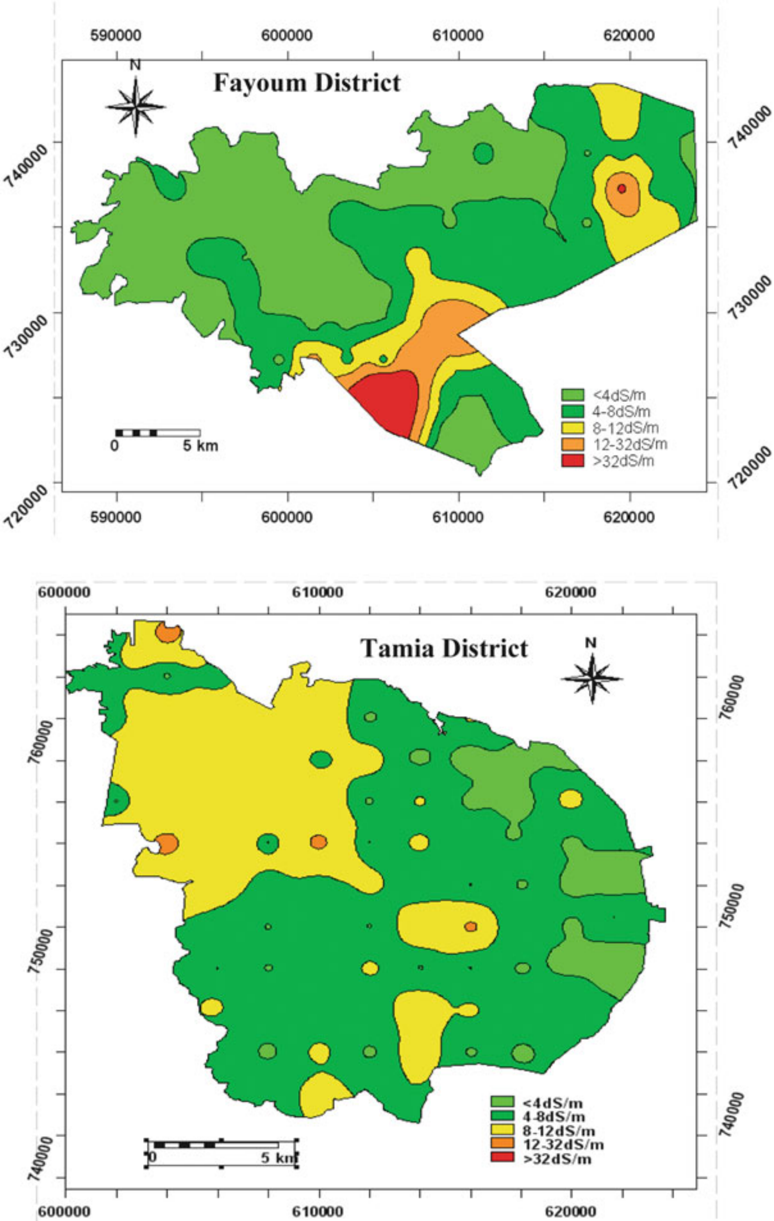


Fig. 14.3 Map showing ECe in the upper 30-cm soil

level and far from the lake; however, the presence of high local water table in some sites may be one cause of their high salinity. Contrary to the general trend observed in Tamia District soils as shown in Fig. 14.4, it is observed that subsoil salinity is higher than at the top soil, in some sites, such as sites number 25, 26, 29, 30, and 34,

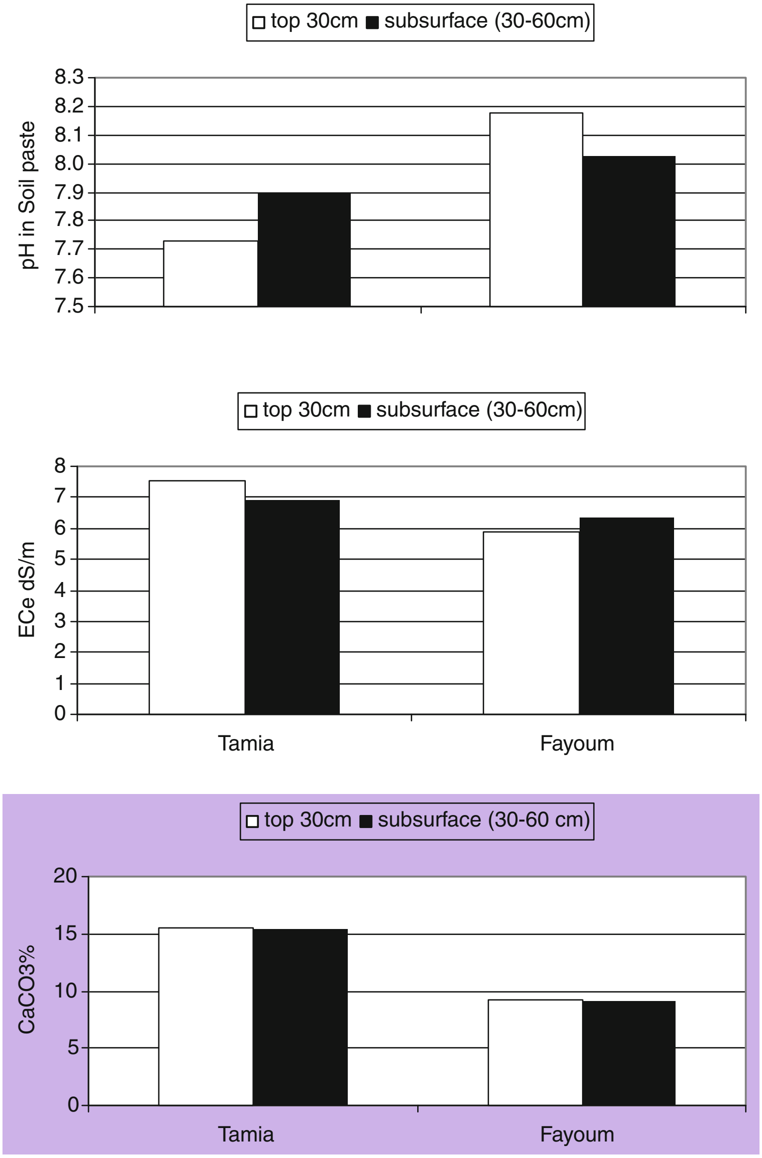


Fig. 14.4 Mean values of soil pH, ECe, and $CaCO_3$ equivalents in the soils of Fayoum and Tamia Districts

located in the lowest part in the northwest edge of Tamia District (37 m below sea level). This emphasizes the influence of topography, high water table, and parent material on salinization in the study area.

Effective control of soil salinization in the study area is impractical due to limited availability of Nile water and the limited extension of using mixed water (agriculture drainage with Nile water) to irrigate wide areas. However, salt-affected areas in two districts could be managed through improving such as by appropriate land uses, suitable agricultural practices and management, efficient drainage and irrigation systems, selection of salt-tolerant plant species based on salinity problem, and fertility management.

14.3.1.1 Soil Reaction (pH) in Tamia and Fayoum District Soils

The pH levels of saturated soil paste and their distribution throughout the study area within the top 30 cm of soil profile are presented in Tables 14.1 and 14.2 and Fig. 14.5. It is clear that less than 1% of Fayoum District soils have pH values ranging from 7 to 7.5 in comparison with about 5.58% of Tamia soils. The majority (91.17%) of Tamia soils has pH values ranging from 7.5 to 8 as compared with only 26.02% of Fayoum soils. Soils of pH 8.0–8.5 occupied 63.65% of Fayoum and only 3.23% of Tamia Districts soils. About 9.53% of Fayoum and only 0.02% of Tamia District soils were of pH > 8.5. Based on the mean values of soil pH, it could be generally indicated that Fayoum soils were more alkaline than Tamia District soils (Fig. 14.4). The mean pH values within subsoils (30–60 cm) slightly exceeded those in the top 30 cm of Tamia; however, the opposite was observed within Fayoum District soils. These results may be due to the influence of the greater contents of neutral salts in decreasing soil pH within surface and subsurface layers in addition to the influence of $CaCO_3$ content in both Districts (Fig. 14.4). In general, the pH values in the soils of both the districts are above the optimum pH levels (6.7–7.1) where most of the nutrients are available to plants. Therefore, careful nutrient management will be required for optimum plant growth, such as to reduce P unavailability and to practice band placing to avoid P fixation in soil. Other management practices include using amendments to lower pH in the soils, such as through using biofertilizers, farmyard manure, and organic materials, that will also ultimately improve soil physical health and fertility status of soils.

14.3.1.2 Calcium Carbonate Equivalents in the Soils of Tamia and Fayoum Districts

Tables 14.1 and 14.2 and Figs. 14.4 and 14.6 present data on $CaCO_3$ equivalents in the soils of both districts. Majority of the soils in both districts contain > 5% $CaCO_3$ equivalents and therefore classified as slightly calcareous. The soils with > 10% $CaCO_3$ equivalents (0–30 cm) are 94.5 and 30% in Tamia and Fayoum District, respectively. Maximum $CaCO_3$ (0–30 cm) was recorded as 30% in Fayoum and 1.43% soils in Tamia. Only 0.16% of the study area presented >40% $CaCO_3$ with a maximum of 67% $CaCO_3$.

The levels of $CaCO_3$ equivalents were generally greater in the subsurface layers of Tamia soils than Fayoum soils. Data presented in Fig. 14.4 show slight differences between the mean $CaCO_3$ contents of top and subsurface layers of both Tamia and

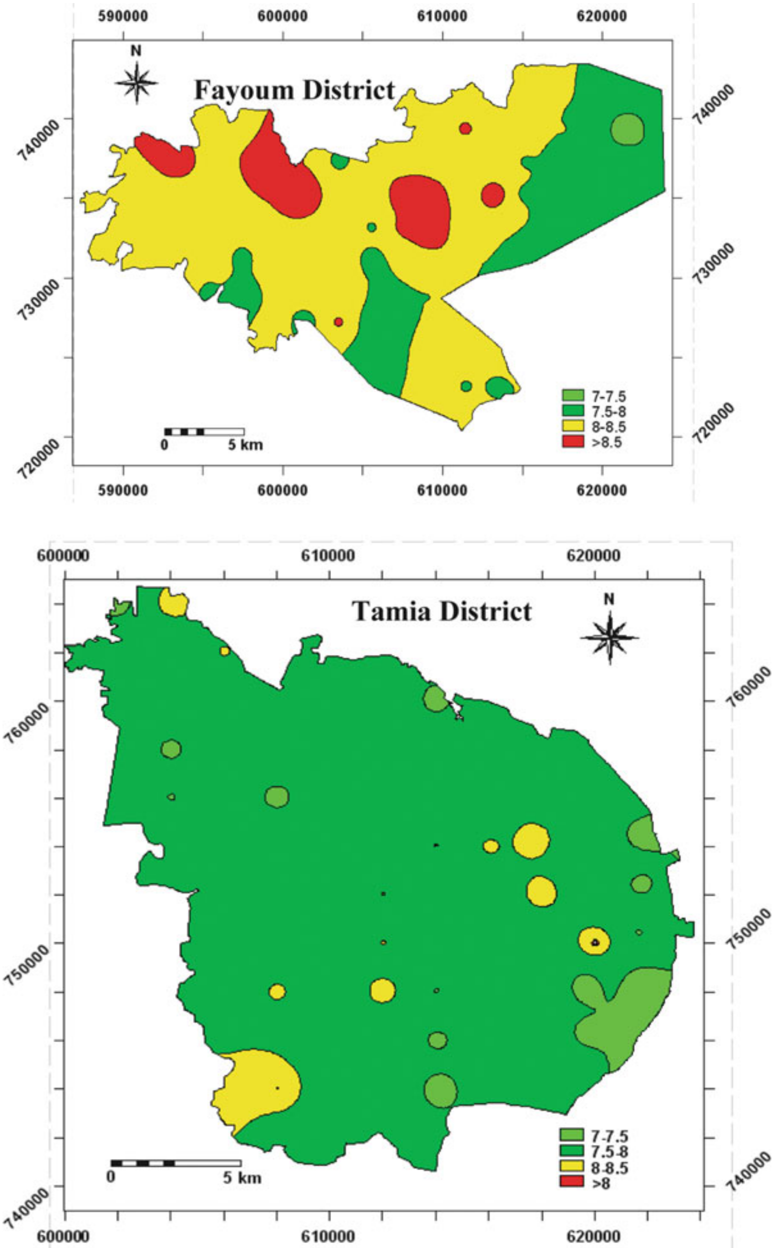


Fig. 14.5 Map showing soil pH in the upper 30-cm soil

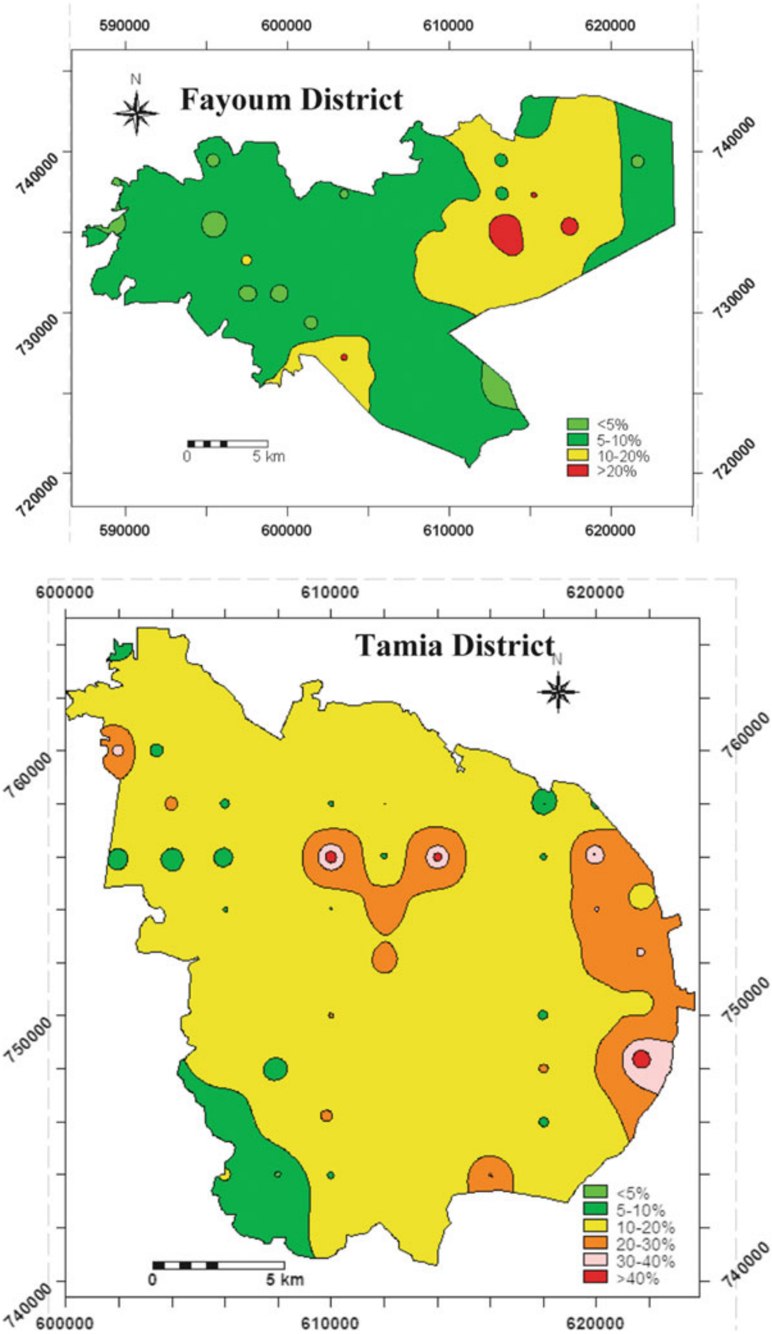


Fig. 14.6 Map showing $CaCO_3$ equivalents in the upper 30-cm soil

Fayoum soils. The $CaCO_3$ richness in Tamia soils relative to Fayoum soils could be due to the calcareous parent material in this area. In a previous study (Khalil 1970), the richness of $CaCO_3$ in the soils of Fayoum Governorate has been stated due to erosion process and weathering of the Eocene limestones surrounding depression; such weathering products of these calcareous rocks are rich in $CaCO_3$ and contribute to the formation of soils adjacent to rocks. Morphological description of soils revealed calcium carbonate accumulation (calcification) in the form of secondary carbonate "segregations and concretions" in the soils of Fayoum depression (Hanna and Labib 1977). The high calcicity of soils within the study area particularly in Tamia District may cause some physical and nutritional problems (unavailability of micronutrients and phosphorous) in addition to the observed salinization and alkalization problems. Improvement of alkaline soils needs the application of sulfur to neutralize $CaCO_3$ through biochemical oxidation process, that also ultimately lower soil pH.

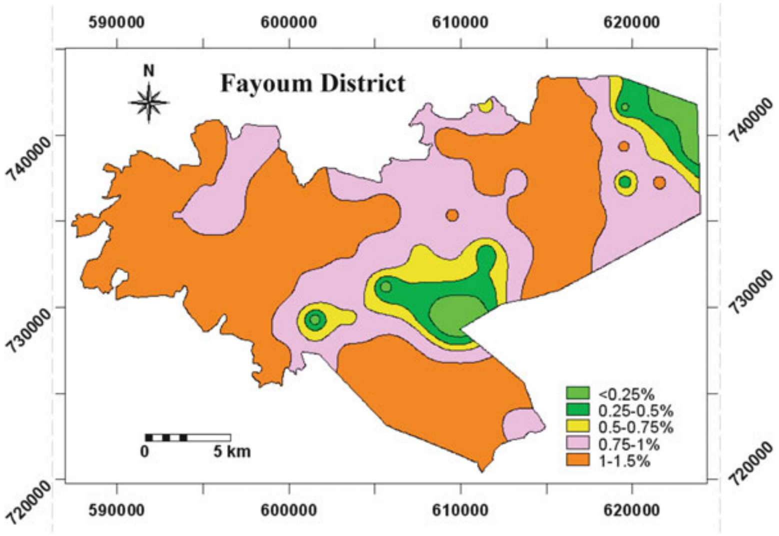
14.3.1.3 Soil Organic Matter in Soils of Tami and Fayoum Districts

Arid and semiarid soils are generally poor in soil organic matter contents, same trend was observed in the soils of Fayoum and Tamia Districts. The organic matter seldom exceeded 1% in Tamia soils and did not exceed 1.5% in Fayoum District area (Tables 14.1, 14.2 and Fig. 14.7). About 86% of Fayoum District topsoils contained more than 0.75% organic matter in comparison with 17.3% of Tamia District area. Less than 0.1% of Tamia soils contained >1% organic matter in comparison with 54.17% of Fayoum District. The poor organic contents in the soils of both districts necessitates the use of organic and biofertilizers to improve soil physical, chemical properties and fertility status that will ultimate increase crop production. Figure 14.8 illustrates relatively higher organic matter contents in the upper layer (0–30 cm) compared to subsurface (30–60 cm) in both districts.

14.3.1.4 Soil Texture in Soils of Tami and Fayoum Districts

Particle size analyses (sand, silt, and clay) of soils from both Fayoum and Tamia Districts revealed five texture classes: clay, sandy clay, sandy clay loam, sandy loam, and sandy soils. Heterogeneity in soil texture may be due to variation in location and topography, and the degree of interactions and dominance of the main groups of sediments formed Fayoum depression soils. The Nile sediments located within the depression have relatively fine textures, desertic sediments are coarser, and lacustrine are the sediments of the old lake and the recent deposits associated with the present Lake Qaroun composed of mainly clays and sand (Said 1962; Tamer 1968; Khalil 1970).

The levels of clay content and distribution throughout the study area are given in Tables 14.1 and 14.2 and Figs. 14.8, and 14.9. Data reveals soils (0–60 cm) of Fayoum District are heavier than Tamia. About 62.38% soils of Fayoum and 5.62% soils of Tamia at 0–30 cm depth present>45% clay. About 94.24% of Tamia soils and 37.62% of Fayoum soils contained 15–45% clay in the top 30 cm. The high clay contents in Fayoum



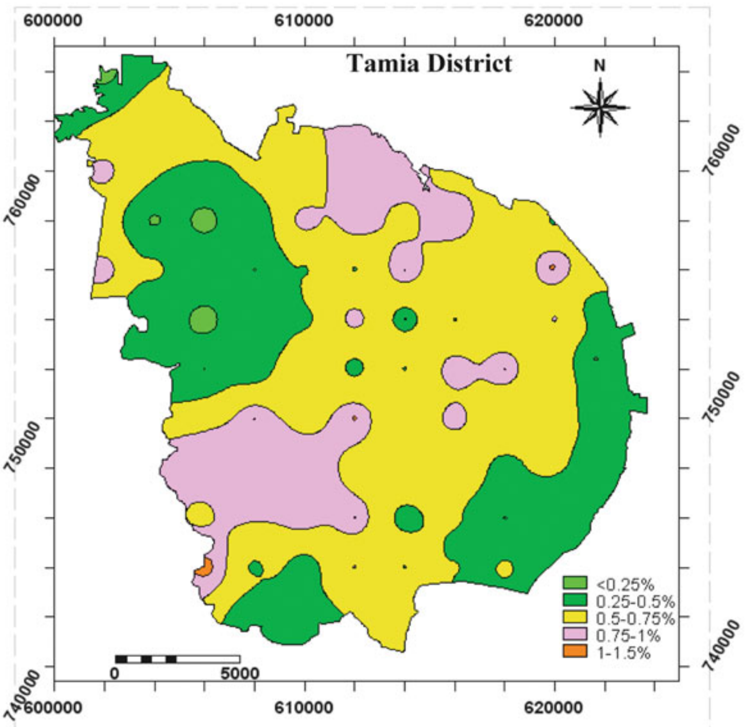


Fig. 14.7 Organic matter content in the upper 30-cm soil

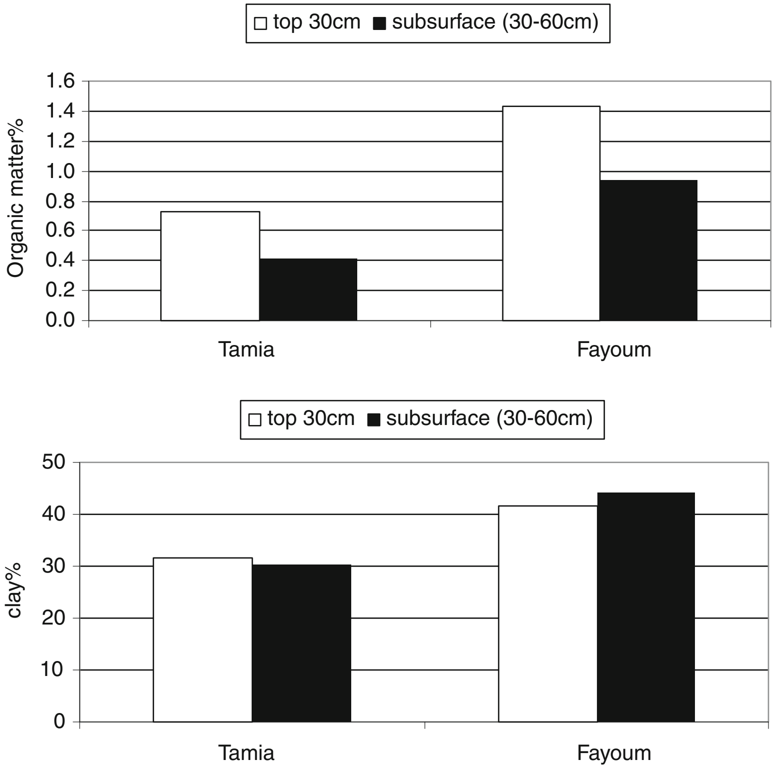


Fig. 14.8 Mean values of organic matter and clay contents in the soils of Fayoum and Tamia Districts

District soils can be explained by the nature of fluvial Nile sediment parent material (from which the soils are firmed) dominated at Fayoum District area. The high clay content in Fayoum District soils may reduce infiltration rate and permeability and cause poor drainage conditions. For the area where clay is recorded as more than 60%, special attention is to be given from management perspectives; such an area is recorded as 6.27% in Fayoum and 0.05% in Tamia Districts. Field observations supplemented with soil analysis also confirmed the presence of clay, saline, calcic, and/or gypsic layers (Tafla) in some areas of the two districts, both in the near soil surface or subsurface, ultimately impacting soil health leading to prevention of root penetration and water percolation. Special cares should be exercised while using these areas for crop production.

14.4 Conclusions

Present study identified problems of soil salinity in both the districts, soil salinity being higher in soil of Tamia than Fayoum. Soil improvement, such as efficient field drainage and irrigation systems, good agricultural practices, selection of suitable

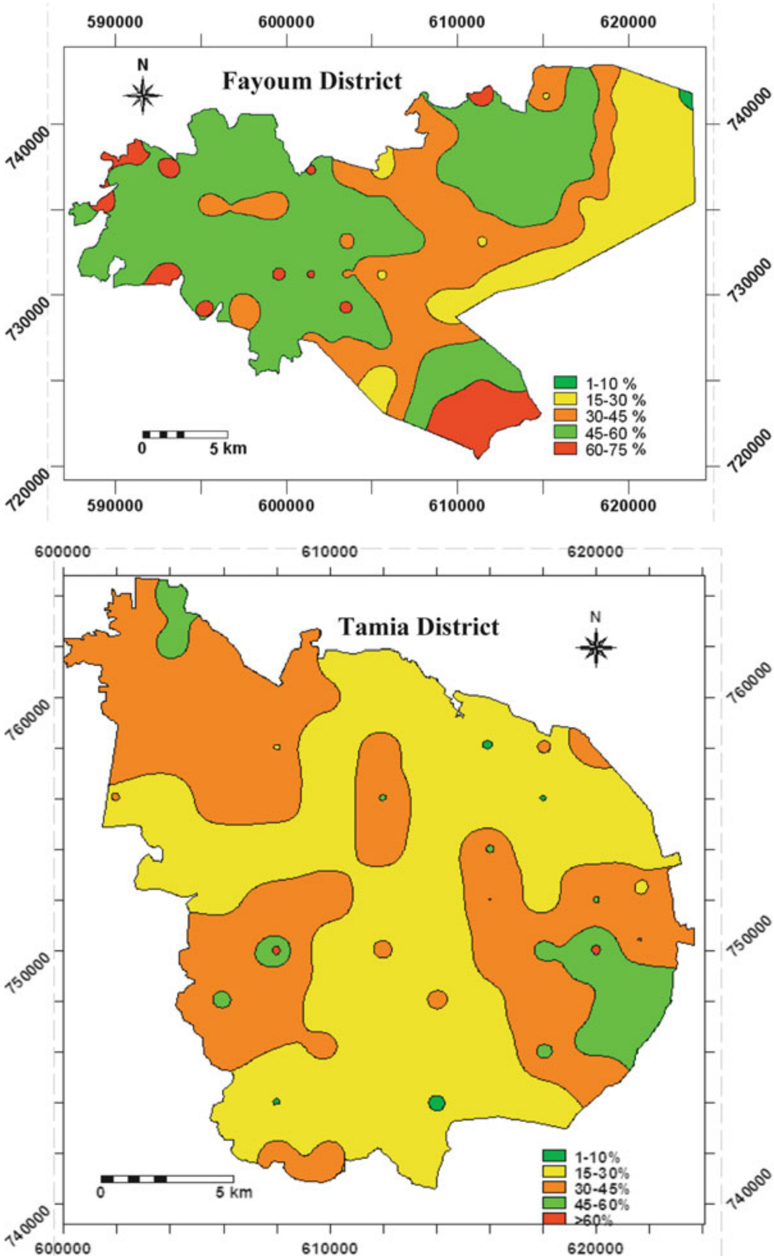


Fig. 14.9 Clay content in the upper 30-cm soil

plant species, and varieties, is essentially required. Fayoum soils are high in pH than Tamia soils; however, all samples present pH higher than the optimum pH level where most of the nutrients are available to plants and hence require use of amendments that reduce soil pH. In contrary to soil pH, $CaCO_3$ contents are higher in Tamia soils than Fayoum soils. Soils of both districts are poor in organic matter (less than 1.5%), suggesting addition of biofertilizers, organic matter, and other organic amendments. Five textural classes (clay, sandy clay, sandy clay loam, sandy loam, and sandy) are recognized in both areas; in general soils of Fayoum District are heavier than soils of Tamia. The high clay content of Fayoum soils can cause problems in crop production; therefore, these soils need careful management. It is recommended to further research in other four districts of Fayoum Governorate to complete assessment in the whole governorate.

References

Abd El Motaleb MH (2002) Contribution of geographic information systems for studying some environmental problems in El Fayoum, Egypt. Ph.D. thesis, Faculty of Agriculture at El-Fayoum, Cairo University, Egypt

Abdel Aal TS (1990) Cyclic formation of soils on different geomorphic features of Fayoum area, Egypt. Ph.D. thesis, Faculty of Agriculture at El-Fayoum, Cairo University, Egypt

Abo El-Einane SA (1977) Pedology and geomorphology relationship in El-Fayoum. MSc thesis, Faculty of Agriculture, Al-Azhar University, Egypt

Al Sharif AA (1987) Pedological and physical studies on the eastern fringe soils of Fayoum depression, Egypt. MSc thesis, Faculty of Agriculture at El-Fayoum, Cairo University, Egypt

Al Sharif AA (1994) Pedogenesis and geochemical investigations of calcic formation at the main sediments of El-Fayoum depression, Egypt. Ph.D. thesis, Faculty of Agriculture at El-Fayoum, Cairo University, Egypt

Bouyoucos GJ (1962) Hydrometer method improved for making particle-size analysis of soils. Agron J 53:464–465

Buringh P (1997) Introduction to the study of soils in tropical and subtropical regions. Center for Agriculture Publishing and Documentation, Wageningen, pp 17–28

Erian WF (1982) An approach to apply the American Soil Taxonomy on some soils of Egypt. MSc thesis, Faculty of Agriculture, Cairo University, Egypt

Euroconsult (1992) Environmental profile, Fayoum Governorate, Egypt. Al-Shorouk Press, Cairo

Ghassemi F, Jakeman AJ, Nix HA (1995) Salinization of land and water resources: human causes, extent, management and case studies. CAB International, Wallingford, p 526

Hammad MA, Abo El-Einane S, Abed F (1983) Pedological studies on the Fayoum area, Egypt. I. Landscape and soil morphology. Egypt J Soil Sci 23(2):99–114

Hanna FS, Labib F (1977) The soils of the Fayoum depression. Egypt J Soil Sci 17(1):33–43

Houba VJG, Van der Lee JJ, Novozamsky I (1995) Soil analysis procedures: soil and plant analysis, part 5B. Department of Soil Science and Plant Nutrition, Wageningen Agriculture University, Wageningen

Jackson ML (1979) Soil chemical analysis. Prentice-Hall, Inc., Upper Saddle River

Khalil EA (1970) Petrological studies on some soil sediments from Fayoum area and the Nile Valley, Egypt. MSc thesis, Faculty of Agriculture at El-Fayoum, Cairo University, Egypt

Massoud FI (1974) A world assessment of soil degradation: an international program of soil conservation. Report of an expert consultation on soil degradation, FAO, UNEP, Rome, pp 16–17

Said R (1962) The geology of Egypt. Elsevier Publishing Company, Amsterdam, pp 99–106

Seckler D (1996) The new era of water resources management: from "dry" to "wet" water savings. Consultative Group on International Agricultural Research (CGIAR), Washington, DC
Shendi MM (1984) Pedological studies on soils adjacent to Qaroun Lake, Fayoum Governorate, Egypt. MSc thesis, Faculty of Agriculture, Cairo University, Egypt
Tamer MA (1968) Subsurface geology of Fayoum regions. MSc thesis, Faculty of Science, Alexandria University, Egypt
US Salinity Lab Staff (1954) Diagnosis and improvement of saline and alkali soils. US Department of Agriculture (USDA), Handbook no. 60, 2nd edn. US Salinity Lab Staff, Washington, DC
Walter H (1950) Die vegetation Der: in Okologischer veb. Gustuv Fisher Verlogjenn. Soils Fert 32:2714

Chapter 15
Using Remotely Sensed Soil Conductivity to Monitor Restoration Activities on Vernal Pools, Northern Great Basin, USA

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Abstract The sagebrush-steppe of the northern Great Basin, USA, receives 120–500 mm of precipitation per year. Clay horizon formation in these semiarid/arid Pleistocene-lake landscapes allows development of seasonal wetlands (vernal pools) that are recognized critical habitat for several native animal species. Most pools were dug out to create livestock water holes in the early and mid-1900s. Restoration efforts are underway to restore these ecosystems. This study was undertaken to evaluate the pre- and post-restoration hydrology of several regraded vernal pools. Five total sites, one undisturbed and four dugouts, were mapped for apparent electrical conductivity (EC_a) using electromagnetic induction to evaluate hydrologic flow patterns. Two sites were subsequently regraded to fill in dugouts and redistribute excavated piles. EC_a for the restored sites was remeasured 1 year later. EC_a patterns of the dugout pools indicate that the hydrology is directed toward the low areas concentrating soluble salts in the dugout through evaporation. Patterns of the undisturbed site suggest a broader distribution of water and salts. Conductivity patterns of post-restoration show a marked difference in conductivity with a

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broadening out of the high-concentration area and a decreased difference between the former dugout area and surrounding area. The pattern after 1 year of hydrologic activity suggests that regrading allows the water to spread across a larger area and begins to develop hydrologic patterns similar to undisturbed pools, suggesting potential to restore desired ecological function. Results of this study will refine understanding of vernal pool hydrology and ecology for the region.

Keywords Ecology • Hydrology • Northern Great Basin • Vernal pools • USA

15.1 Introduction

15.1.1 Seasonal Wetlands

Seasonal wetlands occur in various climate regimes and landforms across the globe. Temporary ponds found in arid lands are of particular interest because of the regionally important water resource they provide in otherwise dry lands. Loss or degradation of this important ecological resource is common where human activity occurs.

Seasonal wetlands are characterized by the presence of seasonal plant cover and land areas that are submerged by water for only part of the year. Factors such as precipitation, evapotranspiration, infiltration rates, and groundwater inflow and outflow contribute to the fluctuations in water levels observed in seasonal pools (Bauder 2003; Deil 2005). Arid lands that support seasonal pools have a unique seasonal moisture regime associated with the pools.

Globally, seasonal pools are recognized for hosting diverse and unique plant species due to their unique hydrologic characteristics (Comer et al. 2005). Because of the relatively small size of the pools, the seasonal moisture regimes, and the isolated nature of the wetlands, seasonal pools can support a variety of plants that are adapted to living amidst seasonal extremes of both inundation and drought. Seasonal pools host plant species that may be regionally unique and often rare or endangered (Deil 2005).

15.1.2 Pools of the Northern Great Basin, North America

The northern Great Basin (NGB) encompasses roughly 45 million ha of the western United States (Pyke and Borman 1993). The NGB is comprised of the northern half of the Great Basin desert, including land area in Oregon, Washington, and Idaho (Fig. 15.1). This expanse is part of the Columbia Plateau physiographic province characterized by arid tablelands, intermountain basins, dissected lava plains, and widely scattered low mountains and the sagebrush-steppe plant community (Bureau of Land Management 2009). The NGB is a sparsely inhabited, arid expanse that is

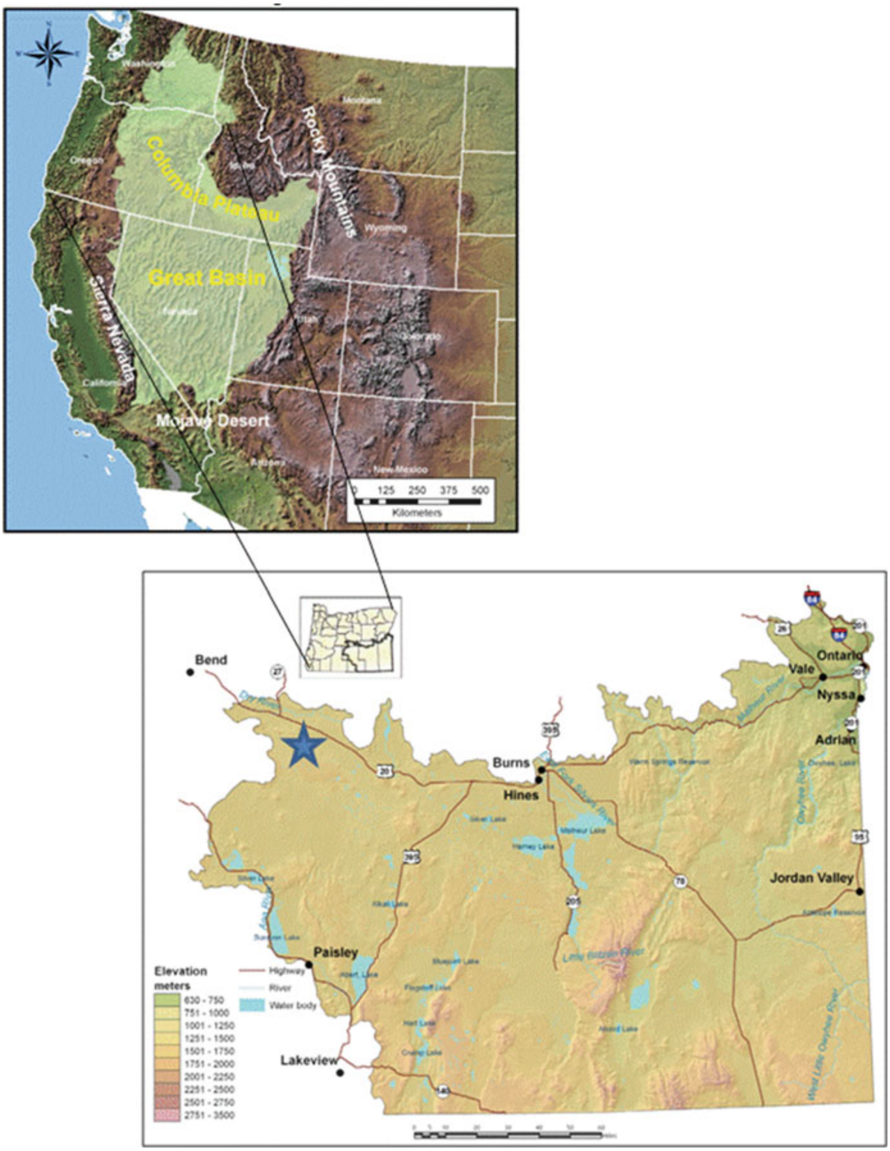

Fig. 15.1 Location of the northern Great Basin, USA, and the study area in Oregon. The *star* indicates the geographical center of the study area

characterized by a closed drainage system in which all surface water evaporates or percolates before reaching the ocean.

Oregon's high desert, a subarea of the NGB, is located in the rain shadow of the Cascade Mountain Range and is a part of the sagebrush-steppe plant community, the largest grassland-type region in North America (Rogers and Rickard 1988).

Sagebrush-steppe vegetation in the NGB is dominated by grasses and forbs with an open shrub layer. Natural fire regimes historically maintained a patchy distribution of shrubs and predominance of grasses (ODFW 2005).

In the arid and semiarid Mediterranean climates of the northern Great Basin of North America (Fig. 15.1), the two most common types of seasonal pools hold water or snow during parts of the winter and spring but desiccate during the summer months. These pools are considered to be geographically isolated wetlands (Tiner 2003) with no surface connection to flowing water (Leibowitz 2003). Typically, the pool is underlain with an aquitard such as a claypan or bedrock which restricts downward movement of water (Verrill and Smith 1998).

The mechanisms of seasonal pool hydrology, especially in the northern Great Basin, are poorly understood and have not been thoroughly examined. There is high seasonal variability and interannual variability in surface water amounts. Seasonal inundation can be attributed directly to seasonal rainfall and local surface drainage (Clausnitzer et al. 2003). In arid and semiarid lands, a particular pool may or may not pond at all during a particular year, or it may remain ponded for up to 3 years due in part to the frequency distribution of precipitation in the desert (Lichvar et al. 2006). Some isolated wetlands interact through subsurface groundwater connections (Tiner 2003), but in northern Great Basin pools, groundwater inflows are minimal due to relatively impermeable clay layers (Leibowitz 2003).

Studies in Californian seasonal (vernal) pools show that the pools are mostly rain-fed, simulating a mini-catchment system (Deil 2005). Central Oregon seasonal pool hydrology is assumed to operate in a similar manner as the pools in California. A piezometer study in Oregon seasonal pools found no free water in the subsoil between 25 and 200 cm, indicating that the subsoils at this depth were never saturated. This supports the hypothesis that water enters the pools through direct precipitation and surface run-on and becomes perched above a shallow, slowly permeable soil horizon (Clausnitzer et al. 2003). Perching layers reduce rates of recharge to underlying regional aquifers. Relatively little is known about how perched aquifers regulate hydrological, biogeochemical, and biological processes in wetland ecosystems in general and vernal pool landscapes in particular (Rains et al. 2006).

Temporary, isolated wetlands often shelter rare and isolated taxa (Semlitsch and Bodie 1998; Comer et al. 2005). The habitats are sensitive to human impact, and they are threatened in many parts of the world (Deil 2005). In many parts of the globe, seasonal pools are subjected to development pressures and landscape modifications. Such anthropogenic manipulations may degrade the biodiversity of isolated wetlands (Lougheed et al. 2008). Arid rangelands in the United States do not often face the same development pressures of semiarid climates, but are often impacted by livestock grazing pressures, both historical and modern. In the region of the northern Great Basin, a high percentage of seasonal pools have been modified by excavation to encourage water retention for livestock. The combination of grazing and disturbance of seasonal pools has been linked to a decline in the ecological health, specifically the vegetative diversity (Bauder and McMillan 1998; ODFW 2005), which can impact macro- and microfauna populations. Because rare taxa have specific niche requirements within the seasonal pool habitat, resilience under altered landscapes or climates has the potential to be low.

Regional land managers (United States Bureau of Land Management – BLM) have interests in restoring disturbed seasonal pools. The intent is to attempt to restore ecological function and biodiversity to these areas in support of threatened and endangered species. There is little information available regarding ecological health prior to disturbance activities such as excavation and grazing; indeed, what information exists is ancillary and qualitative. Setting restoration objectives therefore becomes onerous and a good deal of guesswork. Few undisturbed seasonal pools exist, and these tend to be smaller in size and geographically disparate from sites targeted for restoration.

A successful ecological restoration plan requires a clear objective and measurable goals. While limited information is available for these sites with respect to original ecological condition, we can make some approximations about pre-disturbance, disturbed, and restored hydrologic patterns. Near-surface and surface hydrology are strong variables of ecological processes at these sites, and the presence or absence of water leaves a signature in arid landscapes via spatial patterns of soluble salt accumulation. This study examines hydrologic patterns of disturbed seasonal pools before and after restoration activities using apparent soil conductivity (EC_a) as a surrogate of hydrology.

15.2 Methods

15.2.1 Sites Description

Five excavated seasonal pools were selected for EC_a measurement to assess hydrologic patterns. Due to infrequent occurrence and accessibility, only one undisturbed site was selected for EC_a. All sites are located in the northern Great Basin within an 18-km radius of each other (Fig. 15.1). Two of the excavated seasonal pools were selected by the land manager (BLM) for restoration activities; selection criteria were not in the control of the researchers, and selection was largely a capricious process due to social and political pressures from grazing allotment users.

Pool size varies considerably in the region. The areal extent of the pool prior to restoration was determined by the presence of silver sage (*Artemisia cana* Pursh), which is a wetland indicator species for the region. Silver sage extent was determined on-site and subsequently measured digitally from aerial imagery (Table 15.1). Outside of the area of silver sage, basin big sagebrush (*Artemisia tridentata* Nutt. ssp. *tridentata*), an upland species, dominates the shrub layer. All sites are mapped as having components of the Swalesilver soil series, Aquic Palexeralfs in US soil taxonomy. The soils in the Swalesilver series are deep and have a near-surface argillic horizon that restricts vertical water flow and hence ponds water at the surface.

Table 15.1 Sample playas and their attributes, including the electromagnetic (EM) measurement device(s) used at the site

Playa	Condition	Latitude (west)	Longitude (north)	Approximate area (m^2)	EM meter	EM frequency (kHz)
A	Undisturbed	120.47	43.67	4,500	GEO-300	14.6
B	Disturbed	120.44	43.74	8,600	GEO-300	14.6
C	Disturbed	120.67	43.86	27,000	GEO-300	14.6
D	Disturbed/ restored	120.61	43.70	10,700	EM-38 EM-31	14.6; 9.8
E	Disturbed/ restored	120.33	43.64	39,000	EM-38 EM-31	14.6; 9.8

Soil from the original excavations was piled in a berm near the excavated area. Excavations at each site were to a depth of 3–4 m. In contrast, total elevation difference at the undisturbed site was less than 1 m.

15.2.2 Apparent Soil Conductivity

Soil conductance is in part a function of soluble salts in a soil. Measuring apparent soil electrical conductivity (EC_a) can be done with electromagnetic induction (EMI) (McNeill 1980a; Hanson and Kaita 1997; Yoder et al. 2001; Lee et al. 2006; Noyges et al. 2006; Brevik et al. 2006). The induction and measurement of electromagnetic current through a geophysical body, such as soil, is dependent on variables such as magnetic susceptibility of the materials, soil texture, soil moisture, pore space, and presence of soluble salts (McNeill 1980a). For this study, we assume that soil textures are relatively consistent across sites. The induction wave travels through the whole of the adjacent soil; therefore, the return signal represents an averaging of a volume of soil, rather than a point measurement. Patterns of EC_a at these sites reflect changes in specific conductance of the soil and possibly changes in soil moisture across the site; spatial patterns of EC_a are indicative of hydrologic pattern for the site.

Three different EM meters, GEM-300 by Geophysical Survey Systems and EM-31 and EM-38 by Geonics, were used throughout this study (Table 15.1). All units have inphase and quadrature output; the quadrature output is converted to EC_a in mS m^{-1} (McNeill 1980b). The EM-38 and GEM-300 measurements reported in this study used a frequency of 14.6 kHz. The EM-38 has a single frequency of 9.8 kHz. Measurements for this study are reported for the horizontal dipole, which has an estimated depth of penetration of 0.5–1.0 m.

For each sampling period, EC_a readings were jointly collected with location information. A Trimble GeoXT handheld unit was used to collect satellite data in the field; these data were differentially corrected from files collected at the National Oceanic and Atmospheric Administration, Redmond, Oregon, base station. Horizontal accuracy for the study was submeter.

Fig. 15.2 Restoration of disturbed seasonal pool by regrading and infilling dugout

The EC_a point data was interpolated to a raster dataset using the inverse distance weighted (IDW) function in ESRI Spatial Analyst. The parameters in the IDW were a variable search radius for 12 points using a power of two. Cell size was automatically determined by the software. Because the analyst reports out the results as a grid, the IDW function is only valid within the area bounded by the most distant sample points; this area is indicated in the figures presented for this study.

15.2.3 Restoration Activities

Excavated areas at each site were regraded using a tracked bulldozer (Fig. 15.2). Grading consisted of creating a broad shallow depression of depth less than 1 m over the former excavation. After grading, a wildlife-accessible grazing exclusion fence was erected over half of the restored area to monitor the impact of grazing on restoration (e.g., plant response, compaction). Long-term vegetation plots were established at each site to track natural recovery of vegetation with and without cattle grazing.

15.2.4 Comparison

There are many potential confounding variables in comparing pre- and post-restoration EC_a for these sites. Measurements were collected in different years with different meters. Also, variations in soil moisture may affect readings, and direct measurement of soil moisture was not performed on-site to develop a correction factor. Additionally, EC_a measurements were not compared with direct soil conductivity measurements. Lastly, after infilling, the soil volume that was analyzed prior to restoration was under several meters of old piled soil; therefore, the soil volumes compared are not the same. In summary, there are spatial, disturbance, and temporal constraints to direct comparison of the EC_a data produced between sites and between samples collected at the same sites. The pattern of EC_a can be visually inspected but not mathematically compared.

15.3 Results and Discussion

15.3.1 Pre-restoration Patterns

Seasonal pools that have been dug out to increase late-season water availability have a very strong EC_a signal in the dugout area (Figs. 15.3 and 15.4). Pools B, C, D, and E all have a distinctly higher EC_a in the area of the dugout. The berms of excavated soil have a lower EC_a than the dugout and, in most cases, have a lower EC_a than the surrounding area of original surface. The seeming exception to this is pool C where the berm has obvious points of low EC_a. This is an artifact of the sampling density at this pool. The berm spatially separates the high EC_a dugout and slightly lowers EC_a area outside the berm. When the IDW was applied, the fewer sampling points on the berm allowed a coalescing of EC_a between the dugout and outside the berm; the berm was of a consistent height and fairly contiguous as shown, and higher point sampling on the berm would likely increase its EC_a contrast with the dugout and surrounding area.

The availability and accessibility of undisturbed pools is inconvenient. However, pool A, the sole undisturbed site that was sampled, shows a distinctly different pattern of EC_a. Spatial separation of high and low EC_a values is less distinct and likely reflects a broader dispersal of water within the pool which disperses the soluble salts. This dispersal is also supported by the fact that the elevational changes within the pool are minimal (generally less than 0.5 m) compared to the dugout pools, with elevation differences between the original surface and the bottom of the dugout as much as 7 m.

Observations of disturbed pools in the region, especially larger pools, indicate that surface elevation is naturally undulating and that water would likely spread broadly across the pool area with one or more shallow areas of concentration. This pattern is supported by the EC_a measurements of pool A, where there are at least three areas where EC_a has a higher value. However, the areas surrounding these zones have EC_a values that gradually decrease with distance. The dugout pools tend to have sharp boundaries between the high and low EC_a zones.

Restored sites would ideally also spread out water across the surface, likely resulting in less sharply defined boundaries. Redistribution of soluble salts within a

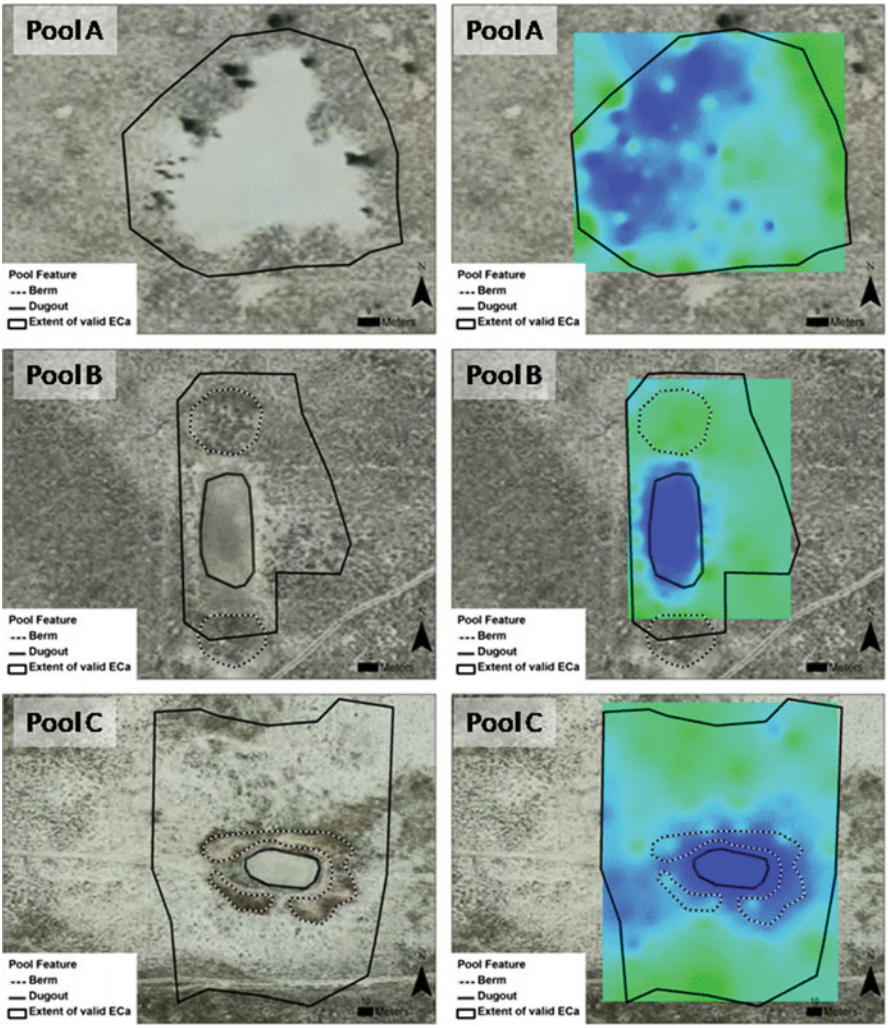

Fig. 15.3 Aerial imagery of three reference seasonal pools (*A*, *B*, and *C*) and their measured apparent electrical conductivity (EC_a); *green colors* represent low EC_a and *blue colors* represent high EC_a. Pool *A* does not have a dugout, while *B* and *C* have dugouts and berms of excavated soils. The *solid line* for each pool represents the extent to which the ECa grid is valid and is based on location of sampling points

restored pool would likely require some time; however, the soil mixing that occurs with reworking the soil piles and the soils in the dugout could help in redistributing the soluble salts.

Pools D and E were mechanically regraded. The pre-restoration EC_a patterns show clear differentiation between the dugout, the excavation berms, and the surrounding original surface. After restoration, pool D shows two zones of higher EC_a

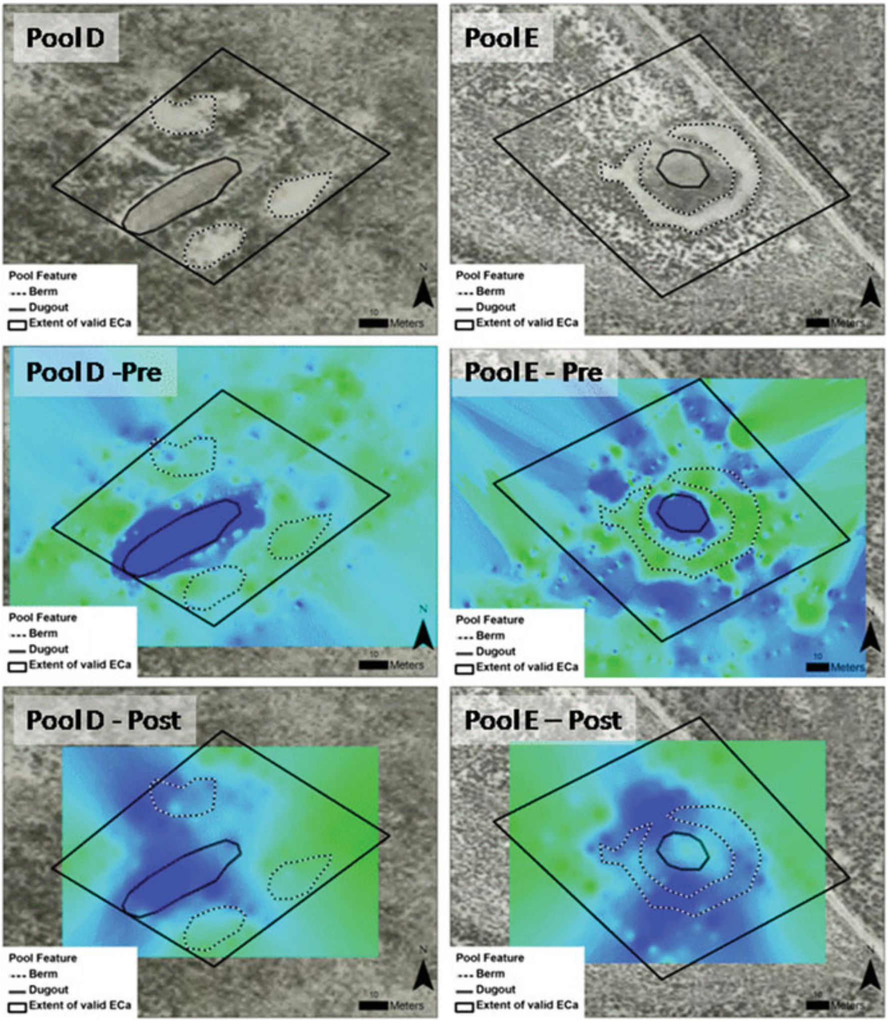

Fig. 15.4 Aerial imagery and pre- and post-restoration EC_a measurements for seasonal pools *D* and *E* (*green colors* represent low EC_a and *blue colors* represent high EC_a)

with a more gradual gradient from the high to low areas of EC_a. Indeed, there has been a shift in the positioning of the higher EC_a zone (Fig. 15.5). Interestingly, the spatial extent of both the pre and post highest EC_a values for playa D encompasses almost the same area (~780 m^2), but they clearly do not share the same space.

Pool D appears to have retained high EC_a values in part of the original dugout area. This is not unexpected as settling of the fill may result in shallow depressions where water can focus. In comparison, pool E, which had a distinctive

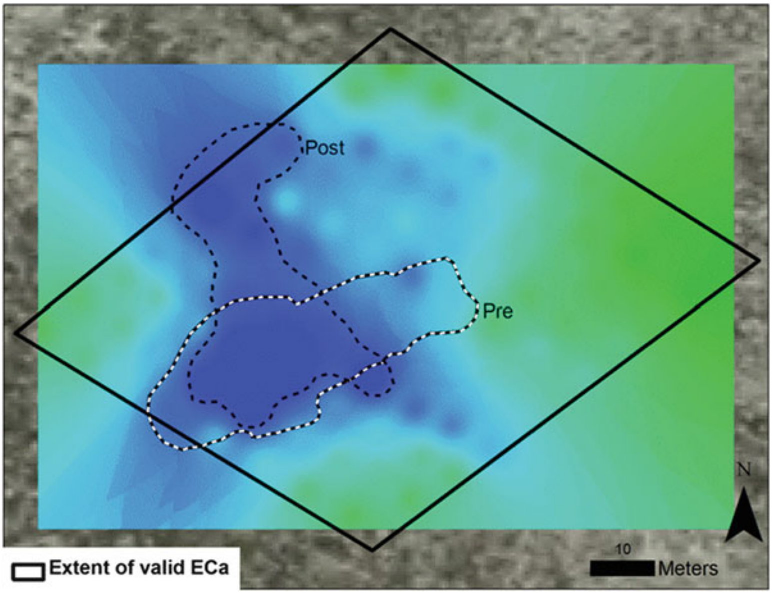

Fig. 15.5 Generalized boundaries of the higher ECa readings for pre- and post-restoration. The EC_a values represented are for post-restoration. Comparison to pre-restoration can be made with Fig. 15.4 (*green colors* represent low EC_a and *blue colors* represent high EC_a)

berm and dugout EC_a profile before restoration, has spatially shifted high EC_a values; the area of the dugout now is dominated by low EC_a values (Fig. 15.4). After restoration, pools D and E have begun redistributing water and soluble salts and possibly are developing spatial patterns expected for an undisturbed pool, such as pool A.

15.4 Conclusions

Historical excavation of seasonal pools in the northern Great Basin has altered the hydrology of these isolated wetlands by concentrating water in smaller and deeper pools. Undisturbed seasonal pools distribute seasonal water over a proportionally large area. Disturbance has been associated with decreased ecological health, and restoration of some of these sites has been receiving attention. Restoration projects require some method to assess success. The diffuse hydrology and associated soluble salts evidenced in undisturbed pools can be one measure of ecological function, and measuring these properties for restored pools may be a method to evaluate restoration success. This study shows that electromagnetic induction is one tool that can be applied to evaluate restoration activities in these arid and ecologically important wetlands.

References

Bauder ET (2003) The effects of an unpredictable precipitation regime on vernal pool hydrology. Freshw Biol 50:2129–2135

Bauder ET, McMillan S (1998) Current distribution and historical extent of vernal pools in southern California and Northern Baja California, Mexico. In: Witham CW, Bauder ET, Belk D, Ferren WR Jr, Orduff R (eds) Ecology, conservation, and management of vernal pool ecosystems. Proceedings of the 1996 conference, California Native Plant Society, Sacraments, CA, pp 56–70

Brevik EC, Fenton TE, Lazari A (2006) Soil electrical conductivity as a function of soil water content and implications for soil mapping. Prec Agric 7:393–404

Bureau of Land Management (2009) Partners in flight: physiographic area plans. Retrieved 19 Nov 2009 from: http://www.blm.gov/wildlife/pl_89sum.htm

Clausnitzer D, Huddleston JH, Horn E, Keller M, Leet C (2003) Hydric soils in a southeastern Oregon vernal pool. Soil Sci Soc Am J 67(3):951–960

Comer P, Goodin K, Tomaino A, Hammerson G, Kittel G, Menard S, Nordman C, Pyne M, Reid M, Sneddon L, Snow K (2005) Biodiversity values of geographically isolated wetlands in the United States. NatureServe, Arlington

Deil U (2005) A review on habitats, plant traits, and vegetation of ephemeral wetlands: a global perspective. Phytocoenologia 35(2):533–705

Hanson BR, Kaita K (1997) Response of electromagnetic conductivity meter to soil salinity and soil-water content. J Irrig Drain Eng 123:141–143

Lee BD, Jenkinson BJ, Doolittle JA, Taylor RS, Tuttle JW (2006) Electrical conductivity of a failed septic system soil absorption field. Vadose Zone J 5:757–763

Leibowitz SG (2003) Isolated wetlands and their functions: and ecological perspective. Wetlands 23(3):517–531

Lichvar R, Brostoff W, Spreecher S (2006) Surficial features associated with ponded water on playas of the arid southwestern United States: indicators for delineating regulated areas under the Clean Water Act. Wetlands 26(2):385–399

Lougheed VL, McIntosh MD, Parker CA, Stevenson RJ (2008) Wetland degradation leads to homogenization of the biota at local and landscape scales. Freshw Biol 53:2402–2413

McNeill JD (1980a) Electrical conductivity of soils and rocks. Technical note TN5, Geonics Limited, Ontario, Canada

McNeill JD (1980b) Electromagnetic terrain conductivity measurement at low induction numbers. Technical note TN6, Geonics Limited, Ontario, Canada

Noyges JD, Robinson A, Herrero J (2006) Incorporating electromagnetic induction methods into regional soil salinity survey of irrigation districts. Soil Sci Soc Am J 70:2075–2085

ODFW (2005) Oregon conservation strategy. Oregon Department of Fish and Wildlife, Salem

Pyke DA, Borman MM (1993) Problem analysis for the vegetation diversity project: a research and demonstration program to restore and maintain native plant diversity on deteriorated rangelands of the Great Basin and Columbia Plateau. USDI BLM Technical note, TIN: OR-936-01, Bureau of Land Management, Oregon State Office, Portland

Rains MC, Fogg GE, Harter T, Dahlgren RA, Wiliamson RJ (2006) The role of perched aquifers in hydrological connectivity and biogeochemical processes in vernal pool landscapes, central valley, California. Hydrol Processes 20:1157–1175

Rogers LE, Rickard WH (1988) Introduction: shrub-steppe lands. In: Rickard WH, Rogers LE, Vaughan BE, Liebetrau SF (eds) Shrub-steppe balance and change in a semi-arid terrestrial ecosystem, developments in agricultural and managed-forest ecology, vol 20. Elsevier, New York, pp 1–12

Semlitsch RD, Bodie JR (1998) Are small, isolated wetlands expendable? Conserv Biol 12:1129–1133

Tiner R (2003) Geographically isolated wetlands of the United States. Wetlands 23:494–516

Verrill WL, Smith DW (1998) Vernal pool-soil-landform relationships in the central valley, California. In: Witham CW, Bauder ET, Belk D, Ferren WR Jr, Orduff R (eds) Ecology, conservation, and management of vernal pool ecosystems. Proceedings from a 1996 conference, California Native Plant Society, Sacraments, CA, pp 15–23

Yoder RE, Freeland RS, Ammons JT, Leonard LL (2001) Mapping agricultural fields with GPR and EMI to identify offsite movement of agrochemicals. J App Geophys 47:251–259

Chapter 16
Mapping and Monitoring of Salt-Affected Soils Using Remote Sensing and Geographical Information System for the Reclamation of Canal Command Area of Jammu, India

V.K. Jalali and Sanjay Arora

Abstract Salt-affected soils in the canal commanded area of Jammu (Jammu and Kashmir) have been mapped on scale of 1:250,000 using remote sensing data from IRS LISS III satellite imagery. Ground truthing was made through field survey to characterize salt-affected soils under Ravi-Tawi canal command area. The canal command area is mainly located in the Kathua and Jammu districts in Jammu and Kashmir state, North India, and covering an arable area of 75,000 ha. The land use and landscape variability was assessed through integrating RS imagery and ground truthing. It has been found that an area of 25,670 ha becomes unproductive due to salinization and waterlogging. The soils are very strongly alkaline (pH 9.9), with dominance of exchangeable Na (ESP 25.3) and sodium adsorption ratio (SAR) of 78.41 (mmoles $L^{-1})^{0.5}$. Amongst cations, Na was dominant followed by Ca, Mg and K. The highest ESP was recorded in Tarore soil with ustic and aquic moisture regimes associated with hard surface crust, calcic and natric sub-surface horizons. Gypsum requirement (GR) to amend soil sodicity was measured on representative soil samples and applied at 100% GR basis; this application has increased rice and wheat yields 43.3 and 86.9%, respectively, over control treatment. Soil properties were also improved noticeably, pH was decreased from 9.70 to 8.84, bulk density decreased from 1.52 to 1.48 Mg m^{-3} and infiltration rate was slightly improved.

Keywords Land use • Remote sensing • Salinity mapping • Waterlogging • Watershed

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16.1 Introduction

Salt-affected soils and waterlogging are twin menaces hindering crop yields from irrigated agriculture lands especially in the arid and semiarid regions. It is, therefore, essential to pre-establish such problems for timely rectification leading to proper soil management to obtain optimum crop yields. Such information is prerequisite and perhaps the most valuable resource for progressive/modern farmers (Rao et al. 1995). In the present time, worldwide, integration of geographical information system (GIS) and fine-resolution remote sensing (RS) technology is extensively used for rapid assessment of natural resources including land and soil. The GIS-RS integration has proved to be very promising (rapid assessment, accurate and cost-effective) in mapping, delineating and monitoring of salt-affected and waterlogged soils (Dwivedi 1985).

Mapping of salt-affected soils in India was undertaken by National Remote Sensing Agency (NRSA) and associates in 1996 (1:250,000 scale map sheets), and an area of 67,275 km^2 has been surveyed (NRSA and Associates 1996). The 1:250,000 map sheets do not show salinity problem in Jammu. However, during the recent past, due to rapid agriculture and irrigation development, there is a shift of converting good lands to salinized lands in Jammu. Farmers and experts have reported the emerging salinity in some pockets in Jammu region. It is, therefore, for this reason that an attempt was made to assess the extent and nature of salinity and associated problems in Jammu soils.

The climate of Jammu is subtropical, with an average annual rainfall of 964 mm and average annual evapotranspiration of 862 mm (Rashid and Arora 2007). The Ravi-Tawi canal was started in the year 1978 to irrigate an area of about 66,700 ha. Due to the introduction of canal irrigation system, there has been significant increase in productivity in general and especially food grain production in Jammu region of North India. However, unscientific management of soils, water and crops and obstruction of natural drainage systems have disrupted the balance of inflow and outflow of water; cumulatively these problems have caused waterlogging and salinization. Owing to these twin menaces of soil salinization and waterlogging, large tracts of productive agricultural lands in the Ravi-Tawi command area of Jammu region have gone out of cultivation (Jalali et al. 2005).

Keeping in view the urgent need for the reclamation and management of salt-affected soils to improve the productivity of important crops, viz. wheat and rice in the area, present study was undertaken to determine the usefulness of GIS technology through Landsat MSS data for determining the aerial extent and delineation of salt-affected and waterlogged soils for their proper management in Ravi-Tawi command area of Jammu region. Land use mapping of Kandi belt adjoining the command area as well as some parts of command area of Jammu in relation to hydrology has been reported earlier (Kumar et al. 2004).

It is hoped that the scientific assessment of the extent of salt-affected soils of the region will lead in developing integrated strategies on reclamation for restoring productivity of the soils to meet the ever increasing food demand of the increased population and improving the livelihood and socio-economic status of the farming community in the region.

16.2 Materials and Methods

16.2.1 Study Area

The study area (170,000 ha) lies between 74°50′ and 75°39′ E and 32°17′ and 32°40′ N in Jammu region of Jammu and Kashmir state of India. The soils in the area are developed on alluvium. The climate of the area is subtropical with annual rainfall and annual evapotranspiration of 964 and 862 mm, respectively. Topographically the north side of the command area is hilly but slight sloppy on the southern part. The area acts as a basin for the run-off water brought by a number of canals. Not only the uneven topography obstruct the southward flow of drained water but also prevents the seepage of water to lower strata because of the presence of bedrock and shallow depth of soils. The Ravi-Tawi canal constructed in 1974 lacks natural drainage of the area, which accentuated waterlogging in the area (Fig. 16.1). The land use map of Ravi-Tawi canal command area is shown in Fig. 16.2.

16.2.2 Mapping of Salt-Affected and Waterlogged Soils

An integrated approach comprising the use of LISS III satellite data, survey of India (SOI) topomaps and limited field check was followed for the mapping of saline soils and wetlands. False colour composite (FCC) prints of path 93 row 48 were prepared from band 3 enlarged to 1:25,000 scale for monoscopic visual interpretation. Information of river, drainage and relevant ground features was incorporated from the Survey of India toposheets while preparing the base map. Delineation of soil

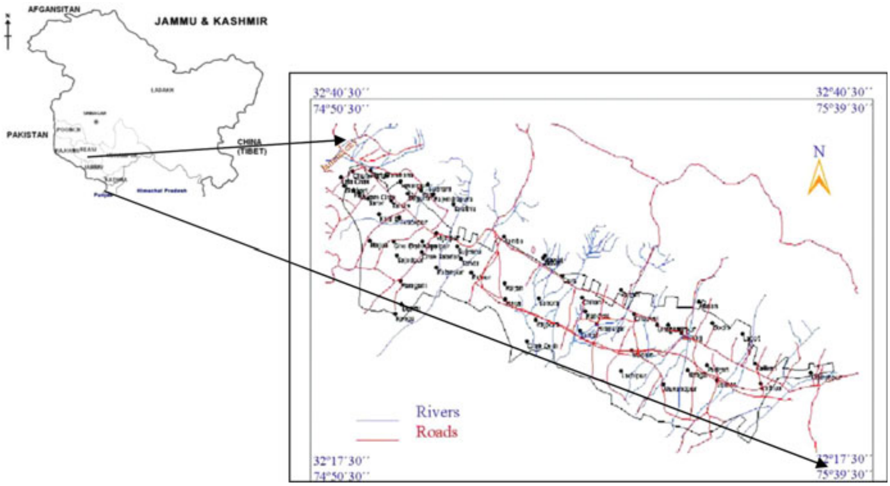

Fig. 16.1 Location map of the Ravi-Tawi canal command area (with drainage pattern)

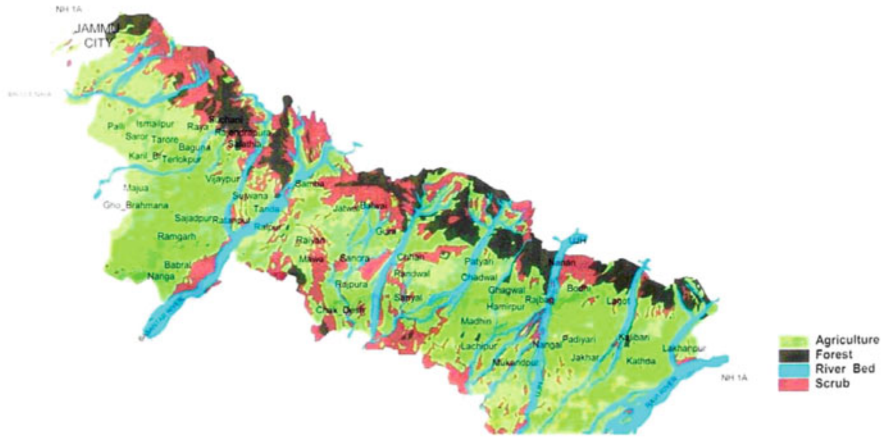

Fig. 16.2 Land use map of Ravi-Tawi canal command

salinity and waterlogging hazards was made using various image models and classifier, i.e. normalized difference water index (NDWI), normalized difference vegetation index (NDVI) and water vegetation index (WV) unsupervised classifier, respectively, on the imagery. A number of field visits were undertaken to ascertain ground truthing in the marked area.

16.2.3 Soil Characteristics

Field visits were made to determine soil characteristics and waterlogged conditions. Soil profiles representing the mapped area were described, and surface soil samples were collected for salinity appraisal and routine analyses using standard laboratory procedures.

Four soil profiles were exposed from different locations in the Ravi-Tawi command area, and soil samples were collected up to a depth of 100 cm. Morphological properties of soil profile were described during the field survey. Soil samples were processed for air-drying and sieving (<2 mm) prior to analysis. Saturated soil paste was prepared, and pH was measured, following by collection of saturated paste extract under vacuum. The saturation extracts were analysed for ECe expressed in dS m^{-1} and soluble cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (CO_3^{2-}, HCO_3^-, Cl^-) using standard procedures as given in US Salinity Lab. Staff Handbook 60 (Richards 1954). Using soluble cation data, sodium adsorption ratio (SAR) was calculated and exchangeable sodium percentage determined using SAR values in standard ESP calculation procedure.

Salt-affected soils in the Ravi-Tawi command area have been identified, demarked and mapped by using LISS III data and interpreted with the help of ERDAS software using ground truth soil characteristic data.

16.2.4 Reclamation of Salt-Affected Soils

A field experiment was conducted in Tarore village at farmers' field with paddy-wheat sequence to test the efficiency of gypsum based on gypsum requirements (GR) for the reclamation of sodic soil. Four treatments comprising of T_0 (control), T_1 (50% GR), T_2 (100% GR) and T_3 (150% GR) were used in a randomized block design, and the treatments were quadruplicated. Gypsum requirement of the sodic soil was determined as 12.38 Mg ha^{-1} (mega grams ha^{-1}). Gypsum was applied 1 month prior to transplanting paddy in *kharif* (summer) season. Rice seedlings of variety PC-19 were transplanted in *kharif* (2003) and wheat variety PBW-175 in *rabi* (winter) season (2003–2004). Recommended doses of N, P, K and Zn at 120:60:25 and 20 kg ha^{-1} in paddy and 120:60:40 kg ha^{-1} in wheat were applied at appropriate times as per crop requirements during the experimental period. Crops were harvested at maturity and yields were recorded for both crops.

Soil samples were collected to examine the changes in the physico-chemical characteristics of soil. Bulk density (standard core method) and infiltration rate (twin ring infiltrometer) was determined. Sodium Adsorption Ratio (SAR) and exchangeable sodium percentage (ESP) were also computed as mentioned by Richards (1954).

16.3 Results and Discussion

16.3.1 Land Use Variability in Command Area

Amongst various image elements, tone was found prominent in the identification and delineation of both alkaline and waterlogged soils. Other image elements, which facilitated identification and delineation, were land use, shape and drainage pattern. The catchment area of Ravi-Tawi canal is covered by forests with gentle to steep slopes. The command area where irrigation is targeted through Ravi-Tawi scheme has 0–2% slope and dominantly agricultural lands with rice-wheat and maize-wheat cropping systems apart from vegetable cultivation in some pockets.

It was observed that the Ravi-Tawi canal irrigation made a significant impact in *kandi* (drought-prone) region and considerably changed the land use of the area. The region has rolling topography, deep water table, coarse-textured soil and poor inherent soil fertility. The cropping pattern has now been changed from low-water-demand crops (maize, sorghum, bajra, moong) to high-water-demand crops (rice, maize, mustard, berseem, wheat, vegetables). Rolling plains and upper and lower piedmont plains are covered with single- and double-cropped areas with isolated patches of wastelands. The wastelands comprise of land with scrubs and barren rocky land. The scrub land is common on piedmonts, and it occupies substantial area. The area covered by streams, ponds and other water bodies also can be observed in several pockets.

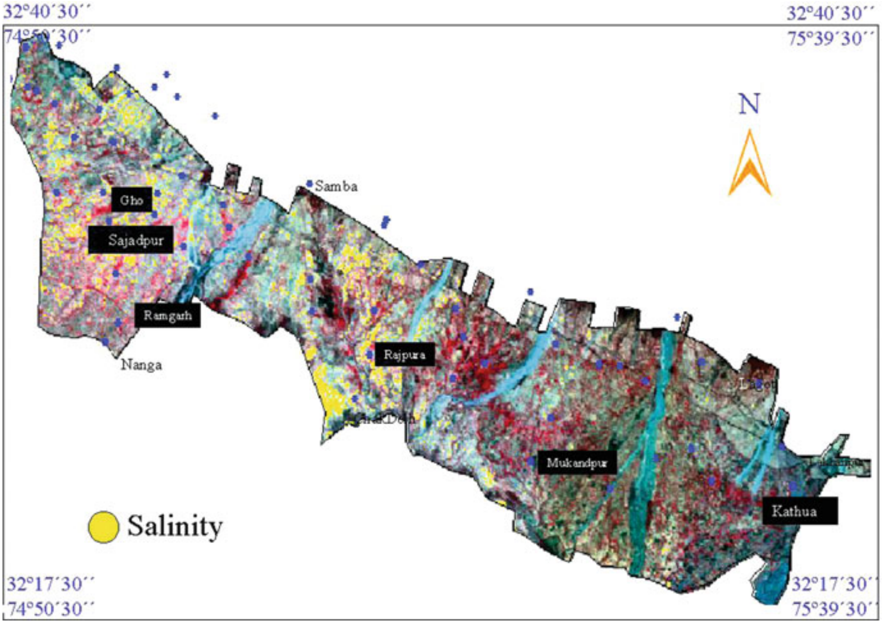

Fig. 16.3 Salt-affected area in the Ravi-Tawi command area of Jammu region

Horticultural plantations and agroforestry tree plantations were observed in several patches. The intensive double-cropped area falls in the command area of Ravi-Tawi canal where assured irrigation was available.

Crop productivity also increased to many folds, and cropping intensity increased to 185% in the region. Average coverage of area under various crops increased in cropping seasons of *kharif* from 30,600 to 51,720 ha and in *rabi* from 43,400 to 72,100 ha between the years 1987 and 1999.

16.3.2 Delineation of Salt-Affected Soils

The saline soils were imaged as yellow-coloured irregular patches (Fig. 16.3). The waterlogged area dotted with aquatic vegetation was imaged in blue and magenta tones. Recordings of water table depth at various sample points using the available open dug wells, and soil auger bore revealed the prevalence of shallow water table conditions. The water table in most of the cases was found to occur within a range of 1–2-m depth. Barren alkaline soils with 1–2-cm-thick surface salt crust appeared in similar tones. Salt-affected area was estimated through the image data to cover an area of 25,000 ha. Information on spatial distribution and extent is very important for managing problematic soils of an area. The salt-affected soils covering an area of 25,000 ha are mainly confined to the blocks of Gho, Sajadpur, Samba and Rajpura.

16.3.3 Soils Characteristics

The pHs ranged between 7.50 and 9.80 and ECe from 0.10 to 0.48 dS m^{-1}; the highest pHs was recorded in soils of Tarore village followed by Mawa and Jandi. Exchangeable Ca, Mg, K and Na ranged from 3.9 to 8.23, 1.50 to 3.20, 0.20 to1.01 and 0.22 to 8.70 cmol kg^{-1}, respectively (Table 16.1). Amongst cations, Na was dominant in Tarore soil profile followed by Ca, Mg and K. Exchangeable sodium percentage (ESP) varied from 3.87 to 47.49, and the highest ESP was recorded in Tarore soils and hence classified as alkali soil (Bajwa 2002).

Sodic soils were developed on Tarore soils with ustic and aquic moisture regimes associated with hard crust on surface, columnar to prismatic structure and calcic and natric sub-surface horizons. The colour of the soils ranged from 10YR4/1 to 10YR4/4. Selected physical and chemical analyses are presented in Table 16.1.

Soil texture varied from loam, sandy loam and clay to sandy clay loam. The pHs ranged from 7.8 to 9.9 (moderately to very strongly alkaline). The ECe of all soils were below 1.00 dS m^{-1}, and the highest CEC 11.04 cmol kg^{-1} was observed in Tarore soils. Ionic composition of the soil saturation extract showed dominance of (Ca^{2+}+Mg^{2+}) and Na^{+} in Shahzadpur, Jandi and Mawa soils, and their values ranged from 9.5 to 19.5 and 0.70 to 2.26 meq L^{-1}, respectively. The Tarore soils showed dominance of Na (3.3 to 68.2 meq L^{-1}). The content of exchangeable K was less than other cations, which varied from 0.08 to 1.31 meq L^{-1}. The anionic composition of the saturation extract revealed Cl^{-} as the dominant anion followed by HCO_3^{-} and SO_4^{2-}. Their values ranged from 7.4 to 11.0, 1.20 to 4.80 and 0.76 to 3.70 meq L^{-1}, respectively. Sharma and Bhargava (1988) reported that in a typical alkali soils, sodium constitutes the bulk, whereas calcium and magnesium become minimal. The high ESP in Tarore soils having a pH of 9.9 suggests these soils are alkaline in nature. The other soils, *viz*. Shahzadpur, Jandi and Mawa, were neither saline nor alkaline as their pH was less than 8.2 and ESP less than 15. The root zone is the most important zone to monitor ionic composition of the upper 20-cm soils of Shahzadpur, Jandi and Mawa soils displaying 10.5 and 1.52 meq L^{-1}, 19.50 and 6.13 meq L^{-1} and 13.50 meq L^{-1} and 0.70 meq L^{-1} for Ca + Mg and Na, respectively.

16.3.4 Amelioration of Soils and Effect on Paddy and Wheat Yield

Data on the grain yields of paddy and wheat (Table 16.2) showed significant increase in yield at different doses of gypsum. The highest yield of paddy was obtained when gypsum was applied at 100% GR; however, it was statistically at par with 150% GR treatment. Yield increase in paddy was 43.0% and in wheat 86.9% over the yield in control treatment. It is also obvious from the data that gypsum at 100% GR gave similar yield as gypsum at 150% GR (paddy only). Yield data further indicate that there was marked increase in wheat yield after giving gypsum treatments in the paddy. This is due to gradual improvement in soil properties during the *rabi* season.

Table 16.1 Physical and chemical characteristics of various sites

Location	pHs	ECe (dS m^{-1})	OC (%)	Clay	Silt	Sand	CEC (cmol kg^{-1})	ESP	Textural classes
Shahzadpur	7.5–8.3	0.16–0.43 (0.35)	0.17–0.37 (0.25)	20.1–26.9 (23.7)	23.8–26.6 (25.3)	46.5–54.3 (51.0)	9.04–10.49 (9.81)	3.87–4.54 (4.08)	SCL
Jandi	7.9–8.3	0.10–0.16 (0.13)	0.16–0.30 (0.22)	17.6–20.2 (19.5)	22.0–31.7 (27.1)	48.6–60.4 (52.9)	6.34–6.99 (6.75)	3.45–3.72 (3.56)	L
Mawa	7.8–8.5	0.19–0.39 (0.27)	0.15–0.22 (0.18)	22.2–23.2 (22.9)	23.2–28.1 (26.5)	48.7–54.6 (50.8)	7.92–8.03 (7.96)	5.35–5.56 (5.53)	SCL
Tarore	8.1–9.8	0.14–0.17 (0.16)	0.12–0.38 (0.22)	21.2–26.6 (24.1)	20.1–26.7 (22.9)	46.8–58.7 (52.9)	8.63–18.32 (14.25)	12.05–47.49 (28.23)	SCL
Badala	8.4–9.0	0.27–1.32 (0.80)	0.12–0.22 (0.16)	24.4–36.2 (29.5)	18.8–24.6 (21.4)	32.5–54.8 (50.2)	6.70–10.04 (8.40)	18.05–29.86 (23.50)	SCL

Figures in parenthesis are the weighted average; *OC* organic carbon, *CEC* cation exchange capacity, *ESP* exchangeable sodium percentage

Table 16.2 Relative efficiency of various doses of gypsum on crop yields (Mg ha^{-1})

Treatment	Paddy	Wheat
Control (T_0)	2.54	1.45
GR (50%) (T_1)	3.33	2.37
GR (100%) (T_2)	3.64	2.71
GR (150%) (T_3)	3.61	2.38
CD (p=0.05)	0.266	0.302

GR gypsum requirement

Table 16.3 Changes in soil properties after gypsum application in paddy-wheat

	pHs		ECe (dS m^{-1})		ESP		SAR (mmoles L^{-1})$^{0.5}$	
Treatment	A_P	A_W	A_P	A_W	A_P	A_W	A_P	A_W
Control	9.70	9.61	0.16	0.15	48.80	48.48	4.08	4.07
GR (50%)	9.41	9.12	0.14	0.13	30.55	29.57	2.05	1.91
GR (100%)	9.11	9.00	0.12	0.11	28.73	28.00	1.91	1.81
GR (150%)	8.91	8.84	0.11	0.10	26.54	23.63	1.74	1.46

GR gypsum requirement, A_P after paddy harvest, A_W after wheat harvest

16.3.5 Effect of Gypsum on Soil Properties

With increasing application of gypsum, a decreasing trend of pHs is recorded in soils after the harvest of both crops. In paddy soil, pH decreased from 9.70 to 8.91 and in wheat from 9.61 to 8.84 after wheat harvest (Table 16.3). This decrease in pHs is attributed to the addition of Ca^{2+} from gypsum and increased content of SO_4^{2-} apart from increased biological activity resulting in higher production of CO_2 evolution and carbonic acids. Similarly, ECe very slightly decreased after wheat, but no consistent trend was noticed after paddy. High application rate of gypsum increased the soluble Ca^{2+} content which replaced the exchangeable sodium and thus reduced the ESP and SAR (Yadhuvanshi 2001); however, the difference is insignificant.

Soil bulk density of the control soil at surface was greater than where soil water treated with gypsum. The bulk density was reduced from 1.52 to 1.48 Mg m^{-3} with treatment of gypsum in the sodic soils; this may be due to improved soil tilth and reduced compactness with the addition of amendment (Yadhuvanshi 2001). The initial average infiltration rate for gypsum-treated soil (2.40 cm h^{-1}) was much higher than that for the untreated sodic soil (1.80 cm h^{-1}). The average steady state infiltration rates for a period of 3 h were 0.07 and 0.04 cm h^{-1} which are nearly two times more in the treated soil than in untreated soil (Fig. 16.4). The average value for cumulative infiltration after 3 h was 3.58 cm h^{-1} in the treated and 2.69 cm h^{-1} in untreated soil. The increased water transmission in the treated soil is due to the improvement of soil structure, lower bulk density and availability of larger pores for water transmission (Patel and Suthar 1993). The infiltration rate was higher initially

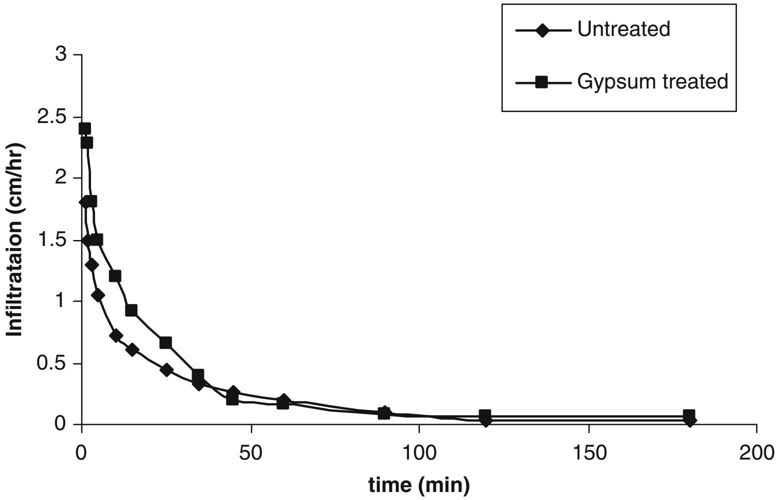

Fig. 16.4 Effect of gypsum treatment on infiltration rate

and remained almost steady after 3 h (Fig. 16.4). This steadiness in infiltration rate is due to decrease in potential gradient with time in the transmission zone caused by the presence of flow-restricting layer due to excess amount of exchangeable sodium (Sawhney and Baddesha 1989).

16.4 Conclusion

The results obtained on the basis of distinct colouration and unique pattern on FCC imageries and the separation of salt-affected and waterlogged soils are best suited for the existing topography in Jammu region. Mapping and geographical distribution of salt-affected and waterlogged soils through satellite imagery has proved to be very cost-effective. The results obtained from the study may be taken as guide for other studies in the state.

References

Bajwa MS (2002) Soil salinity and alkalinity. In: Fundamentals of soil science, Indian Society of Soil Science, Division of Soil Science and Agricultural Chemistry, IARI, New Delhi, pp 291–308

Dwivedi RS (1985) The utility of data from various air borne sensors for soil mapping. Int J Remote Sens 6:89–92

Jalali VK, Pareek N, Sharma V, Arora S, Bhat AK (2005) Relative efficiency of various doses of gypsum on reclamation of deteriorated sodic soil. Environ Ecol 23(2):459–461

Kumar V, Rai SP, Rathore DS (2004) Land use mapping of Kandi belt of Jammu region. J Indian Soc Remote Sens 32(4):323–328

NRSA and Associates (1996) Mapping salt-affected soils of India, 1:250,000 map sheets. National Remote Sensing Agency, Hyderabad

Patel MS, Suthar DM (1993) Effect of gypsum on properties of sodic soils, infiltration rate and crop yield. J Indian Soc Soil Sci 41(4):802–803

Rao BRM, Shankar TR, Dwivedi RS, Thamappa SS, Venkataratnam L, Sharma RC, Das SN (1995) Spectral behavior of salt-affected soils. Int J Remote Sens 16(12):2125–2136

Rashid G, Arora S (2007) Physiography in relation to sustainable agriculture in Jammu. In: Arora S, Kukal SS, Sharma V (eds) Natural resource management for sustainable hill agriculture. Soil Conservation Society of India, Jammu Chapter, Jammu, pp 93–100

Richards LA (ed) (1954) Diagnosis and improvement of saline and alkali soils. Agriculture handbook no 60, USDA, Washington, DC

Sawhney JS, Baddesha HS (1989) Effect of gypsum on properties of saline-sodic soil and crop yield. J Indian Soc Soil Sci 37(2):418–420

Sharma RC, Bhargava GP (1988) Landsat imagery for mapping saline soils and wetlands in Northwest India. Int J Remote Sens 9(1):39–44

Yadhuvanshi NPS (2001) Effect of five years of rice-wheat cropping and NPK fertilizer use with and without organic and green manures on soil properties and crop yields in a reclaimed sodic soils. J Indian Soc Soil Sci 49(4):714–719

Part II
Management and Reclamation of Salt-Affected Soils

Chapter 17
Management of Saline Lands in Oman: Learning to Live with Salinity

Mushtaque Ahmed, Nazir Hussain, and Salim Ali Al-Rawahy

Abstract Low rainfall, high temperature, and the past human activities resulted serious salinity problems in today's agriculture in the Sultanate of Oman. Secondary soil salinity has increased rapidly due to the persistent use of saline groundwater, and the extent is increasing due to increased pumping in Batinah region. The balance existing between total pumping and annual recharge before the 1990s has been disturbed that has resulted in the reduction of crop yields and gradual abandoning of lands for agriculture. In addition, seawater intrusion due to overpumping also occurs. In the year 2005, about 18.9–36.0 × 10^6 US$ was lost due to salinity. To tackle salinity problem, a project was undertaken at Sultan Qaboos University to mitigate soil and water salinity. The project focused on four approaches: soil rehabilitation, biosaline agriculture, fodder production, and integration of fish culture into crop production. The project was initiated with the objectives to develop scientifically sound and environment-friendly guidelines for farmers (a) to sustain cost-effective agricultural production in saline agriculture lands irrigated with saline groundwater, (b) to improve food security of Oman, and (c) to combat desertification in agricultural lands to avoid abandonment. The salt-tolerant varieties of tomatoes, barley, sorghum, and pearl millet have shown promising results for successful cultivation in saline soils. Surface mulching with a thin layer of shredded date palm residues resulted in lesser salt accumulation and more crop yield than other methods. The fodder grown in saline soils using saline irrigation water did not affect growth and meat quality of sheep fed with this fodder. The incorporation of aquaculture in saline areas was proven feasible and profitable.

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Keywords Biosaline agriculture • Fish culture • Oman • Salinity • Soil rehabilitation

17.1 Introduction

Soil salinity has emerged the most significant problem of present-day irrigated agriculture in the Sultanate of Oman. Due to hyperarid conditions, scanty rainfall and high temperature caused the soils to become saline. The past human activities of using saline groundwater in agriculture proved driving factor to form secondary soil salinity, which is persistently increasing at an alarming rate due to increased pumping in Batinah region. The region is the main focus for agriculture encompassing 80,000 ha (Cookson and Lepiece 2001), where salinity is seriously threatening sustainable agriculture. General soil survey of the region also indicated the severity and extent of the problem (MAF 1990).

The balance between the annual pumping and recharge before 1990s has significantly been disturbed, which has initially reduced the ultimate crop yields and gradually led to abandoning lands for agriculture. Seawater intrusion due to consistent overpumping also influenced agriculture in near sea areas, and good productive lands are desertified. Currently, 44% of the total geographical area is affected to varying degrees of salinity, which accounts to 70% of area suitable for agriculture. Recently, Hussain (2005) has reported 18.9–36.0 million US$ annual losses due to only salinity. The abandoning of land for agriculture increases unemployment and hence disturbed the socioeconomic status of the society. It is now obvious that salinity mitigation is a prerequisite to keep agriculture alive in Oman.

The integrated study of North Batinah indicated the upward trends of salinity buildup in agriculture areas. The study recommended ways to tackle salinity problem through creating balance between groundwater pumping and annual recharge. A shift in cropping strategy was also emphasized through replacing perennial grasses by seasonal fodders and farm crops (MAF 1993). The importance of the problem has been highlighted from time to time (Qureshi 1995). A comprehensive review (Ahmed et al. 2004) also enlightened the salinity problem and indicated the prospects of biosaline agriculture in Oman. Follow-up to this review, a 10-year (2005–2015) strategic salinity management plan was prepared (Hussain 2005). This plan identified short-, medium-, and long-term salinity management strategies for the stakeholders such as government, farmers, extension workers, and the researchers. The plan also pointed out that past efforts were inadequate to successfully address the problem.

Realizing the problem of salinity increase in Oman, a budget of 95,000 Omani rials (1 OR = 2.58US$) was allocated from HM Fund to implement a project on "Management of Salt-Affected Soils and Water for Sustainable Agriculture" during 2006–2009. The project was started with the objectives (1) to conduct research and evolve techniques to mitigate soil and water salinity (Ahmed et al. 2010; Al-Rawahy et al. 2010) and (2) to identify and promote of appropriate solutions which are environmentally sustainable. Such an important project was necessary due to the need to utilize marginal lands. To achieve the objectives, the project was focused on four approaches: soil reclamation, biosaline agriculture, fodder production, and integration of fish culture into crop production to explore compensatory economic returns to the farmers.

17.1.1 Climate, Soils, and Water of Oman

The Sultanate of Oman is located in the southeast corner of the Arabian Peninsula. It is an arid country with a mean annual rainfall of less than 100 mm. Rainfall is irregular from year to year, and most of the months around the year can be totally dry. Groundwater is the main water resource of the country. The net annual natural recharge to the groundwater has been estimated to be around 1,260 million cubic meters (MCM). The total water demand is around 1,650 MCM of which 90% is used for agriculture. The deficit of 390 MCM is drawn from the groundwater reserves (Abdel Rahman and Abdel-Majid 1993). In Al-Batinah, the main agriculture zone of Oman, the mean annual temperature is 28.6 °C, relative humidity is 58%, wind speed is 221 km day^{-1}, and sunshine hours are 9.7 h day^{-1}.

The land resources suitable for agriculture are limited, as only 7.07% of the soils are suitable for agriculture, equaling to 2.22 million ha of the total land of Oman, which is not insufficient for the population of the country, with the condition that sufficient water is available and all the land is exploited for agriculture; however, this is not the current situation, and hence, Oman has to import food to meet its food demand. The Al-Batinah plain is formed from very thick alluvial, marine, and aeolian sediments (MAF 1993). In the last three decades, there has been tremendous growth in agriculture; as a consequence of this growth, excessive pumping of groundwater resulted in seawater intrusion into the coastal aquifers and has caused the problem of soil salinity in many parts of the Al-Batinah plain. Major crops grown in this area include date palm, lime, alfalfa, vegetables, fruits, Rhodes grass, and other fodder crops. According to a study conducted by MAF (1993), 50% of the agricultural area in the South Al-Batinah is reported to be affected from slight to moderate salinity ($EC_e > 4$ dS m^{-1}) levels, and the major part of the salt-affected soils is Gypsiorthids (gypsiferous). In Oman, salt-affected soils belong to two soil orders (Aridisols and Entisols), and four suborders – Salids, Psamments, Fluvents, and Orthents (Hussain et al. 2006). The soils of South Al-Batinah are mostly moderately alkaline (pH 7.9–8.4). Calcium and magnesium are the main cations saturating the soil exchange complex. Organic carbon and nitrogen contents are usually low (less than 1%). The average topsoil calcium carbonate equivalents are about 37% in Barka and 26% in Masanaa and Suwayq areas (Qureshi 1995). In the North Al-Batinah, about 50% of the total cultivated land is irrigated with water of EC more than 3 dS m^{-1}, and approximately 38% is irrigated with water of $EC > 5$ dS m^{-1} (MAF 1997).

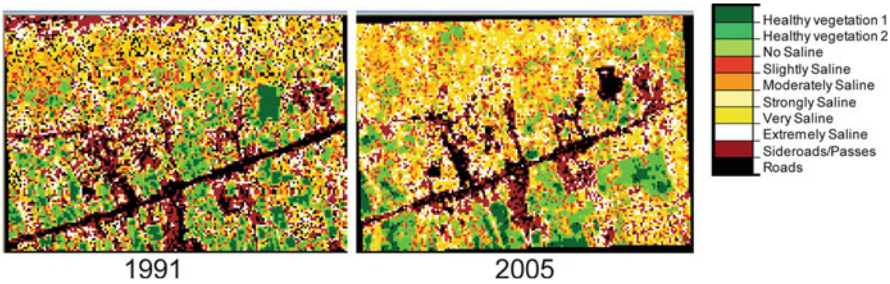

Fig. 17.1 NDSI analyses on 1991 and 2005 satellite image show clearly how soil salinity increased in 2005 (Adopted from Al-Mulla and Al-Adawi (2009))

17.1.2 Losses Due to Salinity

The salinity problem was timely highlighted in the integrated study of the Batinah area; however, necessary actions were not taken to address this menace. Resultantly, the problem has aggravated further in Al-Batinah. Recent study (Al-Mulla and Al-Adawi 2009) has indicated significant expansion of salt-affected soils in Al-Batinah area (Fig. 17.1), and as a consequence of this, many date palm farms have been abandoned. Thus, the earning source and the livelihood of the farmers were taken off by the salinity, and many become jobless. In other farms which are presently under cultivation, yield is gradually decreasing, leading to uneconomical farming. In 2005, it was realized that current estimates on the extent of salinity and its affect on the losses do not exist; therefore, some estimates were made by Hussain (2005). To estimate the losses, some assumptions were made, e.g., 25 and 50% yield losses and the gross margins are coming from crops/trees which could be grown on the abandoned lands due to salinity. The area under different land utilization types and the gross margin values were taken from the Integrated Studies of Batinah (1993–1997). It was estimated that in Oman, annual losses due to soil salinity are from 6.7 to 13.3 million Omani rials. If the losses from abandoned date palm farms are also included, then the losses range between 7.3 and 14.0 million OR per annum.

17.1.3 Salinity Research in Oman

17.1.3.1 Basic Principles

The following principles for future research in Oman are suggested as a guide to all researchers and managers of the related fields:

- The techniques to be evolved should be cost-effective and acceptable to the farmers. The concept of applied research should remain the main focus. Basic

research should only be undertaken when it is essentially required to understand or verify certain concepts and phenomena under prevailing conditions of Oman.
- All future research concepts should be central to water-saving strategies.
- All modern technologies including but not limited to tissue culture and manipulation of DNA should be adapted in addition to conventional methodologies.
- Duplicity of research with respect to time and space must be avoided.
- Multidisciplinary and integrated approach to be used to address complex salinity problem.

17.1.3.2 Future Research Priorities

The short-, medium-, and long-term strategies devised by Hussain (2005) and modified to fit Omani conditions, to effectively achieve the future goals of salinity research should be considered and undertaken stepwise.

Short-term research priorities (*1–3 years*)

- Assessment, mapping, and monitoring of soil and water salinities to understand the changing trends for better resource use and management.
- Evolving of economically sound, socially accepted, and easily adaptable management practices to utilize saline waters.
- Understanding of nutrient dynamics for crops grown in saline environments.
- Management and revegetation of saline soils using salt-tolerant crops/plants.

Medium-term research priorities (*1–5 years*)

- Establish leaching requirements/leaching fraction of saline waters for important crops and fruit trees grown in Oman.
- Conduct salt tolerance studies involving major crops, bushes, and fruit plants grown in Oman.
- Establish fertilizer requirements of fruit trees in saline environment.
- Monitoring and management of salt accumulation in plant root zone when using drip and bubbler irrigation systems.
- Evaluate critical limits of water EC on different crops to establish salt burn effects under sprinkler irrigation.
- Conduct research on the reuse of saline drainage water from agricultural fields.

Long-term research priorities (*more than 5 years*)

- Identification, screening, and domestication of natural and exotic salt-tolerant genetic material, and testing of new plants capable of withstanding seawater salinity and are of economic importance.
- Conduct breeding/grafting experiments (using salt-tolerant root stock) for salt tolerance.
- Conduct multidisciplinary and integrated long-term research trials.

17.2 Recent Research Findings

17.2.1 Effect of Mulching

Surface mulching has significantly reduced water losses through evaporation. Mulching has conserved moisture in the root zone and decreased salt accumulation. This study was conducted to compare the effects of two different mulching materials (date palm leaves and black plastic in addition to control without any mulch) and resultant growth of sorghum (Al-Dhuhli et al. 2010). There were two levels of water salinity (3 and 6 dS m^{-1}) and three levels of water application rates (ETc., 1.2 ETc., and 1.4 ETc.). The study revealed that date palm leaf mulch was more effective in conserving soil water content, reducing salt accumulation in the soil, reducing soil temperature, and resulting in higher yield of sorghum compared to the plastic mulch that was successful to maintain moisture at even higher level than date palm mulch, but use of plastic cover raised soil temperature that resulted in lowering the yield of sorghum.

17.2.2 Leaching Requirements

A field experiment was conducted to investigate the effect of saline water irrigation and leaching fraction on barley (*Hordeum vulgare* L.) growth (Al-Busaidi et al. 2010a). For this purpose, highly saline water was diluted to the salinity levels of 3, 6, and 9 dS m^{-1} and applied by drip irrigation at 0.0, 0.15, 0.20, and 0.25 leaching fractions (LF). The results of the experiment showed that both quantity and quality of water regulated salt distribution within the soil. The salts were found higher near or immediately below the soil surface. An enhanced LF carried more salts down the soil horizon, but there was no significant difference in plant yield between different treatments of leaching fractions; however, the saline water significantly impaired barley growth. The good drainage of sandy soil enhanced leaching process and minimized the differences between leaching fractions. The increment of salts in irrigation water treatments added more salts and stressed the plant growth. It is visualized that the conjunctive use of marginal water at appropriate LF could be effective to enhance the yield potential of crops in water-scarce areas.

17.2.3 Crop Selection: Tomato

Pot experiments were conducted to evaluate the effects of saline water irrigations on five varieties of tomato (4, 22, 38, 46, and 54) (Al-Busaidi et al. 2010b). These varieties are commercially available in Thailand and Pakistan but have not been specifically tested for salinity tolerance. Plants were irrigated with diluted seawater adjusted to three levels of electrical conductivity: freshwater (control) and 3 and

6 dS m^{-1}. The results of the experiment showed that saline waters remarkably affected the evapotranspiration rate, soil moisture, salts accumulation, and plant biomass production. Saline irrigation had the ability to keep much water in the soil with higher level of salt content. Low-salinity treatment exhibited highest plant growth and lowest soil moisture and salt deposition. The difference in soil moisture is due to higher water uptake by plants in low salinity condition as well as reduction of evaporation for saline water. Variety numbers 38 and 46 gave the highest values for fruits number and weight. Whereas, variety number 22 got the lowest values. However, variety number 4 was the tallest and had the highest value for green matter even under high-salinity treatment. Overall, under saline conditions, it was observed that all plant parameters of different varieties were reduced compared to the control except for the number of fruits of some varieties such as 38, 46, and 54. However, fruit weight for variety number 38 was enhanced by saline irrigation which could be a good sign for salt tolerance in saline conditions.

Growing tomatoes using saline water and in conditions where soil has low nitrogen and other essential nutrient contents is of great challenge. A field experiment was conducted on using different levels of saline water and fertilizer for growing tomatoes (Al-Yahyai et al. 2010). The objectives of this work were (1) to examine the yield and quality of tomato (*Lycopersicon esculentum* L.) grown under three levels of saline water and (2) to study the effect of different types of fertilizers on the yield and fruit quality of tomatoes grown under saline conditions. A two-factor completely randomized design experimental plot was set up at the Agricultural Research Station, Rumais, Oman. Tomatoes were grown in sandy soil and irrigated with three levels of saline water ($EC_w = 3$, 6, and 9 dS m^{-1}). Three types of fertilizers were applied including: inorganic NPK, organic (cow manure), and a mixed fertilizer of both. Tomato plants were grown during the months from November to April and for two consecutive seasons. Total fruit number and weight of harvested tomatoes were determined. Results indicated that growing tomatoes under 3 and 6 dS m^{-1} irrigation water produced the highest yield, whereas irrigating with 9 dS m^{-1} significantly reduced the final fruit number and fruit weight. Tomatoes grown using cow manure produced the least amount of yield compared to those fertilized with inorganic and mixed fertilizers. Measured fruit quality attributes were not significantly affected by salinity or fertilizer treatments. The data on fruit quality and yield suggest that the best growing conditions for tomatoes were in plots irrigated with 6 dS m^{-1} water and with mixed fertilizer.

17.2.4 Crop Selection: Pearl Millet

Five genotypes of pearl millet (*Pennisetum americanum* L. Leerke), namely, IP 19586, Sudan Pop III, IP 6104, IP 6112, and IP 3616, proven superior in performance against salinity were subjected to study their response to four levels of irrigation water salinity, namely, control (1 dS m^{-1}), 3, 6, and 9 dS m^{-1}, consecutively, during summer seasons of 2007 and 2008 (March–April to May–June) under field conditions

(Nadaf et al. 2010). The results indicated that the effects of years and salinity were significant ($p<0.05$) to highly significant ($p<0.01$) for plant height, number of tillers, leaf length, chlorophyll content, green matter, and dry matter yields. The main effect of years was found to be highly significant ($p<0.01$) for number of leaves, leaf width, and % dry matter. Besides, interaction effect of years x salinity was significant ($p<0.05$) to highly significant in respect of plant height, leaf width, chlorophyll content, and % dry matter, whereas interaction effect of genotypes x salinity was significant ($p<0.05$) only for chlorophyll content. However, main effect of genotypes and other interaction effects were found to be nonsignificant ($p>0.05$).

Salinity tolerance of pearl millet genotypes was assessed using the concepts of both stress susceptibility index at each higher salinity level in relation to control and mean value over the salinity treatments with respect to each character. The most tolerant genotypes were selected considering the information of all the characters under study. Mean values across the salinity treatments could discern the general ability of salinity tolerance of these genotypes, as these were originally selected for their superior performance under irrigation water salinity ranging from 5 to 11 dS m^{-1}. Hence, their mean performance over tested salinity levels was found to be insignificant ($p>0.05$) in respect of each character. However, salinity tolerance of the genotypes for each salinity level in comparison with their performance at control could be accessed through their stress susceptible index (SSI) values. Among all the genotypes tested at 3 dS m^{-1}, salinity tolerance of IP 3616 was of higher degree and more consistent as it scored low SSI values in respect of four characters, namely, plant height, number of leaves, leaf width, and chlorophyll content, out of eight characters studied. At 6 dS m^{-1}, salinity tolerance of IP 6104 was of higher degree and more consistent as it scored low SSI values in respect of five characters, namely, plant height, number of tillers, leaf width, green, and dry matter yields, out of eight characters studied whereas at 9 dS m^{-1}, salinity tolerance of IP 3616 was of higher degree and more consistent as it scored low SSI values in respect of four characters, namely, plant height, leaf length, leaf width, and chlorophyll content, out of eight characters studied. However, IP 6112 was also found to possess higher degree of tolerance because of its low SSI values for both green and dry matter yields. All other genotypes, however, responded differentially to different levels of salinity for different characters.

17.2.5 Salinity and Soil Microbiology

A study was conducted to investigate the effect of salinity on growth, reproduction, and production of pectolytic enzymes by *P. aphanidermatum*, the main causal agent of damping-off and wilt diseases of many vegetable crops in Oman (Al-Sadi et al. 2010). A survey in 129 greenhouses from different districts in Oman showed that the salinity level of irrigation water in greenhouses varies from 0.41 to 7.7, with an average of 1.47 dS m^{-1}. About 26% of greenhouses in Oman were found to be irrigated with water having an EC above 1.7 dS m^{-1}. Increasing irrigation water salinity from 0.01 to 50 dS m^{-1} showed negligible effects on growth of *Pythium* in sand culture. There was no effect of salinity on the growth of *Pythium* at salinity levels between 0.02 and 5 dS m^{-1}. In addition, oospore production by *Pythium* was not affected at salinity levels below 5 dS m^{-1}, but no oospores were produced above 20 dS m^{-1}. The activity of pectolytic enzymes produced by *P. aphanidermatum* is decreased but not prevented at high salinity levels. Findings from this study show limited effects of salinity on growth, reproduction, and pectolytic enzyme production by *P. aphanidermatum*.

17.2.6 Fodder Production Under Saline Conditions

Alfalfa is one of the major crops grown in the Batinah region. However, current high water salinity presents a challenging situation to grow this crop especially if we consider efficient water use in forage production. A study was conducted to evaluate the performance of alfalfa in terms of productivity and water-use efficiency (WUE) under different regimes of water salinity levels and irrigation levels (Al-Lawati et al. 2010). Three levels of water salinity were applied: 1, 3, and 6 dS m^{-1}. Three levels of irrigation were applied: 125% (125ETc), 100% (100ETc), and 75% (75ETc) of actual evapotranspiration (ETc.). Split-plot design was used, where water salinity level was the main plot and irrigation level was the sub-plot factor. Results showed that productivity of alfalfa of cumulative fresh biomass yield was significantly ($p \leq 0.05$) higher for the treatment of irrigation levels of 125ETc (13.90 kg m^{-2}) compared to 100ETc (12.45 kg m^{-2}) and 75ETc (10.90 kg m^{-2}) at salinity level of 1 dS m^{-1}. Productivity decreased with increasing water salinity, and the differences in productivity among irrigation levels were diminished. Water-use efficiencies were higher at 1 dS m^{-1} across the irrigation levels and generally decreased with increasing water salinity levels. Water-use efficiency was significantly ($p \leq 0.01$) higher for irrigation level of 75ETc than 100ETc and 125ETc across all salinity levels. The highest WUE was for the treatment of 75ETc and salinity level of 3 dS m^{-1} (0.804 kg of dry matter m^{-3}), and the lowest was for the treatment of 125ETc and salinity level of 6 dS m^{-1} (0.407 kg of dry matter m^{-3}). These results suggest that increasing irrigation water level up to 125% of ETc. for low water quality of 6 dS m^{-1} will not perform well either for increasing alfalfa productivity or WUE. Efficient water use for such water quality may reach within the range of 75ETc and 100ETc.

17.2.7 Effect of Feeding Fodder Grown in Saline Lands on Animals

This study was conducted to use salt-tolerant sorghum (*Sorghum vulgare*, *S. bicolor* L.) that has a potential to use saline soil and provide a good source of roughage for livestock feeding in Oman (Al-Khalasi et al. 2010). Sorghum variety Super Dan was planted and irrigated with three levels of saline waters: S3 (3 dS m^{-1}), S6 (6 dS m^{-1}), and S9 (9 dS m^{-1}). Sorghum was manually harvested, dried, chopped, and fed to experimental animals. Thirty-two, 3-month-old male Omani lambs were randomly distributed according to body weight (BW) into four groups of eight lambs each. The first group was fed a control diet of Rhodes grass hay (RGH) plus a commercial concentrate. The other groups were given sorghum hay irrigated with the three different levels of water salinity (3, 6, 9 dS m^{-1}) each. Daily feed intakes and weekly body weights were determined. A digestibility trial was carried out on 12 animals (three sheep per diet) consisting of 10 days of adaptation and a subsequent 10 days collection period for feces and urine. Blood samples were drawn three times during the experiment and analyzed for hematological and serum biochemistry levels. At the end of the trial, the animals were slaughtered. Chemical analyses indicated that RGH had higher mineral content than sorghum forage grown under various levels of salinity. Animals fed with sorghum-based diets did not show signs of ill-health. Hematological and biochemistry investigations showed no treatment effects on blood parameters. There were no differences ($p > 0.05$) in digestibility coefficients of acid detergent fiber and neutral detergent fiber and ether extract between RGH, S1, S2, and S3 diets. However, the S1 diet had lower DM, Ca, CP, P, and energy digestibilities but higher ash content. There were no treatment effects on hay, concentrate, or total feed intake; total body weight gain; or gain per kg per body weight of experimental animals. Sheep fed with RGH, S1, S2, and S3 diets had average daily body weight gains of 96, 84, 82, and 68 g day^{-1}, respectively. There was no diet effect on rumen condition except that RGH-fed animals had lower N-ammonia and butyric acid concentration. Also there were no significant differences on body composition, carcass characteristics, and meat quality or minerals contents. However, the RGH-fed animals had higher S and Zn contents in feces and S content in their meat. The heart weights were significant with S2 group having the highest. Transmission electron microscopy for sheep kidneys and livers showed no morphological and pathogenic problems for all animals at different treatments. This study indicated that sorghum forage grown under high salinity levels may be used for feeding Omani sheep without adverse effects on health, performance, or carcass and meat quality characteristics.

17.2.8 Fish Farming in Salt-Affected Farms

Since 2003, integrated tilapia culture has been introduced at a number of sites in the Sultanate of Oman. Nile tilapia (*Oreochromis niloticus*) and red hybrid tilapia (*Oreochromis* sp.) have been grown successfully across a range of salinities (0–20 ppt) confirming previous studies on optimal salinities for growth conducted elsewhere. In order to study the mineral cycle, the mineral content of commercial fish feed and effluent from experimental fish production tanks was determined (Goddard et al. 2010). The tanks were supplied with brackish groundwater at 3 and 6 ppt and stocked with red hybrid tilapia (initial stocking density 100 kg m^{-3}). When tilapia were cultured intensively in tank systems, with low daily water exchange, some dissolved nutrients including magnesium, calcium, sulfur, and boron accumulated to approach or exceed levels suitable for fertilizing vegetable crops. Some key nutrients, including nitrogen, potassium, and phosphorus were deficient. In a preliminary trial, low-salinity, tilapia effluent was shown to support the early growth of tomato plants in a hydroponic culture system.

17.2.9 Salinity Monitoring

Al-Mulla and Al-Adawi (2009) worked on mapping changes in soil salinity with time in Al-Rumais (near Barka) using remote sensing analysis (Al-Mulla 2010). They used two satellite images, a 1991 Landsat (TM) and a 2005 Landsat (ETM+) (Fig. 17.1). They performed different image enhancements on the two satellite images in order to separate between the features in these images to assist in delineating salt-affected soils. They included the use of different spectral indices like NDVI, II, SAVI, and Normalized Difference Salinity Index (NDSI) in addition to detection of temporal changes in soil salinity using change analysis techniques.

17.2.10 Socioeconomic Impacts of Salinity

The farming in Batinah region has deteriorated to a significant extent during the last two decades. Besides the technical reasons like salinization of lands, seawater intrusion in the area, and worsening of groundwater quality that affected crop yields adversely, there have been socioeconomic considerations that have contributed toward this deterioration. Therefore, it was warranted that such socioeconomic reasons and background facts must be investigated, identified, and enlisted for future accurate planning so that these are properly addressed. For this purpose, a socioeconomic survey was undertaken (Zekri et al. 2010). Sixty-one sample farms spread throughout in the Batinah region were randomly selected for this study with the help of local agricultural extension workers. All the socioeconomic data were collected through interviews, while soil and water samples were collected and analyzed with the help of technical personnel.

The collected data indicated that farmers of age 25–80 years were engaged in farming with an average family size of 13 members. None of the farmers is merely and solely dependent upon farm income only. Rather, most of them are farming partially because either they are retired from jobs or still in government or private job. Single ownership is about 69%, while the rest is combined with brothers, sisters, and other relatives. Majority of farms (61%) are less than 4.2 ha in size. The number of workers per farm varies from 2 to 6 with 113–164 working days per cropped ha and having salaries of 62–77 OR per month. The affected area from salinity was found mainly (60%) in small farms of less than 2.1 ha, while it was 23% in farms of size over 4.2 ha. All the Willayat were affected from salinity problem, but Shinas was the worst (47% area) in this regard followed by Musanaa (35%) and Barka (30%), respectively, while Suwaik was relatively better (7%) in this regard. The total area under perennials (date palms, mango, lemon, banana, and fodder crops) and seasonal vegetables was almost equal (51:49), but bigger farms were growing seasonal crops on more areas (58%) than medium (43%) or small farms (12%) because highly saline (>7,040 mg l^{-1}) water was more on small farms (15% out of 21% for the area). Potato was the crop giving the highest gross margin (OR 2519) followed by mango (OR 1395) and water melon (water melon OR 1031 and melon OR 1010) when the irrigation water was of low salinity (<3,840 mg l^{-1}). The gross margin decreased significantly with increasing salinity of irrigation water, especially for seasonal crops.

17.3 Salinity Management

Soil and water salinity will remain as a serious problem in the Sultanate of Oman as long as the highly saline water is going to be utilized for irrigation by the farmers. Farmers are forced to use this water due to severe scarcity of good-quality water. As stated earlier, unplanned pumping of good-quality groundwater in the Batinah plain created a large deficit between annual recharge and utilization. This not only increased the usage of highly saline groundwater, but also seawater intrusions have occurred. As a result, land degradation, salinization, desertification, abandoning of fertile date palm orchards, and significant losses in yield of crops are clearly visible. This situation demands clear policy decision by the government and framing of laws to implement such decisions. The farmers, researchers, and agricultural extension workers have to work together rigorously to formulate techniques for the management of saline waters and lands in such a way that not only no further losses should occur to the natural resource base but also gradual improvement and reversion to the original level should be encouraged. Some of such policy decisions, activities, techniques, and strategies (short, medium, and long term) have been suggested in this chapter.

17.3.1 National Policy Issues

There are certain policy issues and actions essential for tackling soil salinity problem. However, these can only be considered by the government for implementation:

- Construction of recharge dams and dikes at all potential sites to collect rainwater. Recharge of aquifer through rain water will keep the groundwater quality reasonable. It is only possible if recharge is regularly and consistently occurring.
- Banning of farming and pumping of groundwater for lands upstream declared unsuitable for agriculture in National Soil Survey, 1990.
- Establishing a net balance between annual total pumping and recharge should be the ultimate target. Regulations are needed to be prepared and implemented for

the replacement of Rhodes grass with seasonal fodders like pearl millet and sorghum that have been proved to be relatively salt tolerant but require far lesser water than Rhodes grass.

- Subsidies should be provided to rehabilitate abandoned saline lands that were originally having good potential. If a farmer wants to sell his saline land at all or change its use from agriculture to nonagriculture, his land may be acquired by the government, and he may be compensated with alternate land that has been declared unsuitable for agriculture due to different limitations but can be used for nonagricultural purposes. The agricultural lands were developed over thousands of years and must be protected and quality preserved as a national nonrenewable resource for the future generation. In this regard, necessary regulations can be formulated and implemented by the government, especially the Ministry of Agriculture (MoA).
- It is strongly recommended to establish an independent National Soil Salinity Research Institute in Oman to address all salinity-related issues and research activities and provide technical support. As a beginning, a specialized soil salinity unit should be established within MoA, which has all essential resources (infrastructure, equipment, and manpower) to address salinity issues from assessment, mapping, and monitoring to modeling and conducting salinity-focused research.
- Special budget allocation for salinity research should be earmarked, and multidisciplinary projects addressing all aspects of salinity should be prepared and implemented.
- Separate training programs for researchers, extension workers, and farmers regarding management of soil and water salinity should be implemented.
- A gradual change in cropping system must be encouraged and implemented at government level. Perennial crops and grasses should be replaced by annual crops and vegetables to save the excessive pumping of water. A law should also be framed and implemented to control unlimited and unnecessary pumping of groundwater.

17.3.2 Proposed Soil Salinity-Related Activities for the Agricultural Extension Staff

Continuous, collaborative, and concerted joint efforts of all stakeholders are required to deal the soil salinity problem in the country. Agricultural extension workers have to play a key role in minimizing soil salinity effects through technology transfer from research institutes to the end users (the farmers and owners of salt-affected lands) in the following ways:

- Document the extent and temporal variation of soil salinity in the respective area of each worker. The cumulated values will ultimately give the accurate estimate for the region and the country. Thus, the extent and location of the affected area will become available.

- Inventory of farmers who have abandoned their lands due to salinity problem.
- Learn the new techniques evolved by research organizations to use and manage saline lands and waters and the research organizations to conduct specialized training programs to educate farmers about new technologies and also to conduct field days to demonstrate the success stories.
- Transfer the established technologies through farmer meetings, training programs, radio and TV talks, and distribution of brochures and pamphlets.
- Render advisory service to farmers through relevant organizations. Soil and water testing from farmers' fields should be completed and based to formulate appropriate recommendations and their implementation at farmers' field through relevant research organizations and agricultural extension workers in a close and collaborative manner.

Guidelines for the farmers

- Close contact of extension and research workers with farmers to learn site-specific problems and seeking solutions.
- Provide recommendations to farmers based on soil and water testing results.
- Convince farmers for gradual replacement of Rhodes grass with seasonal fodders like sorghum, barley, wheat, oats, and fodder beet.
- Guide the farmers for successful shifting from conventional to modern irrigation systems.
- Guide the farmers in water-saving techniques to avoid wastage and for optimum water use for crops.
- Lobby the farmers to avoid the change of land use and selling lands for nonagricultural uses.

17.3.3 General Recommendations for the Management of Saline Lands and Water

The following techniques and options can be adopted for the management of saline water and land by the farmers and land owners to use these marginal resources effectively to avoid further degradation (Hussain et al. 2010):

- Farmers should make soil and water testing on a regular basis to understand the changing faces of soil and water salinity in their farms.
- Where salinity is showing effects, it is recommended to grow only salt-tolerant crops like date palm, sorghum, pearl millet (ICBA varieties; IP 3616, IP 6104 and IP 6112) wheat, barley, tomato, spinach, and alfalfa, matching the salinity level of soil and water for the specific farm.
- The integrated and mixed farming comprising of arable crops, livestock, cow and goats, and fish ponds can be adopted to increase income and employment. Sorghum irrigated with water up to EC 9 dS m^{-1} may be used safely as a feed for Omani sheep because no health problems such as diarrhea, constipation, or anorexia was observed in experiment on animals.

- Saline water should be used 20–30% more than the crop requirements (to meet leaching requirements) to flush salts from root zone to minimize harmful effects on plants. However, when the water is highly saline (EC > 9 dS m^{-1}), this strategy may not work, and some other nonconventional plants have to be grown.
- Application of organic matter or organic fertilizers are recommended to improve physical properties of sandy soils (to improve water- and nutrient-holding capacity), to provide to some extent the essential nutrients, and to mitigate the adverse effects of saline water. In heavy soils, these organic materials improve soil structure and increase soil permeability and help leaching salts below root zone through improving drainage conditions.
- Using the date palm leaves as mulch for growing tomato and sorghum proved useful. It reduces evaporation, decreases accumulation of salts, saves water and keeps the soil moist for longer time, and keeps the root zone cool.
- Modern irrigation system like drip or bubbler can save water, but sprinkling of highly saline water should be avoided, as it may cause salt injury to leaves.
- Lands should be kept leveled for uniform water distribution.
- Deep plowing should be used where dense or harder layer exists to improve drainage to avoid salt buildup.
- Root zone should be washed prior to sowing to leach the salts. Frequent irrigations during growth of crops will be helpful to avoid harmful effects of salts.
- High seeding rate, more number of seedlings per unit area, and soaking of seed in saline water (to be used for irrigation subsequently) for 6–8 h is a useful practice and can easily be adopted by the farmers.
- Transplantation of nursery of comparatively more age often is useful because seedlings become somewhat hardier.
- Sowing of seed on the shoulder of ridges-furrow irrigation (the zone comparatively low in salts) has often been found conducive for good results.
- Higher rates of fertilizer as compared with normal soils are generally required when crops are grown in salty lands or irrigated with saline water. Band placement of fertilizers such a phosphorous may be adopted for highly calcareous soils to reduce P-fixation.
- Fields should be kept plowed, especially where soils are loamy and clayey. Field boundaries should be kept strong, in particular before seasonal rains, so that useful rainwater capable of carrying salts to down profile may not be wasted as runoff.
- Scraping of salts (3–5 cm) is often recommended where the surface salinity is very high; the salts should be disposed safely. The remaining soil will become low in salinity that can be used for sowing of crops. This is a temporary solution; salts may build up at surface if site is not properly managed.

17.3.4 Conclusions

In spite of concerted efforts made to combat salinization, in many countries including Oman, the problem remained fully unresolved and persistent. This is due to poor understanding of salinity process and limited resources to combat salinization on a permanent basis. This suggests that learning as how to live with the salinity rather than abandoning agricultural areas may be a better strategy. This requires developing careful policies for implementation in the country. The results and outcomes of recent investigations have showed new ways to tackle soil and water salinity in Oman. The socioeconomic study has confirmed that salinity is a serious social problem because farmers are facing great crop yield decline, culminating into income decreases manifold when farmers use moderately or highly saline water for irrigation. However, some of the results are highly encouraging. These results showed the way forward and direction of future policies for the government, new horizons for the salinity researchers, and modified tasks of the agricultural extension workers in the national interest and helped to formulate guidelines for the farmers for crop yield improvements.

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References

Abdel Rahman HA, Abdel-Majid IS (1993) Water Conservation in Oman. Water Int 18:95–102

Ahmed M, Esechie H, Al-Ajmi A (2004) Biosaline agriculture: perspectives from Oman. Presented at a Workshop on Biosaline Agriculture, 27–30 June 2004, Wageningen, The Netherlands

Ahmed M, Al-Rawahy SA, Hussain N, Rahman HA, Al-Lawati A, Shahid SA, Al-Rasbi S (2010) Biosaline agriculture in Oman: a critical review. Published in the monograph on Management of Salt-Affected Soils and Water for Sustainable Agriculture (Mushtaque A, Al-Rawahi SA, Hussain N (eds)). Sultan Qaboos University, Oman, pp 9–16

Al-Busaidi A, Rabeea J, Al-Rawahy SA, Ahmed M (2010a) Estimating leaching requirements for barley growth under saline irrigation. Published in the Monograph on Management of Salt-Affected Soils and Water for Sustainable Agriculture (Mushtaque A, Al-Rawahi SA, Hussain N (eds)). Sultan Qaboos University, Oman, pp 35–39

Al-Busaidi A, Rabeea J, Al-Rawahy SA, Ahmed M (2010b) Growing tomato in salt soil: screening response of different tomato cultivars to saline irrigation. Published in the Monograph on Management of Salt-Affected Soils and Water for Sustainable Agriculture (Mushtaque A, Al-Rawahi SA, Hussain N (eds)). Sultan Qaboos University, Oman, pp 25–33

Al-Dhuhli H, Al-Rawahy SA, Prathapar S (2010) Effectiveness of mulches to control soil salinity in sorghum fields irrigated with saline water. Published in the Monograph on Management of Salt-Affected Soils and Water for Sustainable Agriculture (Mushtaque A, Al-Rawahi SA, Hussain N (eds)). Sultan Qaboos University, Oman, pp 41–46

Al-Khalasi SS, Mahgoub O, Kadim IT, Al-Marzooqi W, Al-Rawahi SA (2010) Salt tolerant fodder for Omani sheep (Effects of salt-tolerant sorghum on performance, carcass, meat quality and health of Omani sheep). Published in the Monograph on Management of Salt-Affected Soils and Water for Sustainable Agriculture (Mushtaque A, Al-Rawahi SA, Hussain N (eds)). Sultan Qaboos University, Oman, pp 67–81

Al-Lawati A, Al-Wahaibi H, Al-Rawahy SA, Al-Dhuhli H, Al-Rashdi M, Al-Habsi SS (2010) Production and water-use efficiency of alfalfa under different water quantity and quality levels. Published in the Monograph on Management of Salt-Affected Soils and Water for Sustainable Agriculture (Mushtaque A, Al-Rawahi SA, Hussain N (eds)). Sultan Qaboos University, Oman, pp 61–65

Al-Mulla Y (2010) Salinity mapping in Oman using remote sensing tools: status and trends. Published in the Monograph on Management of Salt-Affected Soils and Water for Sustainable Agriculture (Mushtaque A, Al-Rawahi SA, Hussain N (eds)). Sultan Qaboos University, Oman, pp 17–24

Al-Mulla YA, Al-Adawi S (2009) Mapping temporal changes of soil salinity in Al Rumais region of Oman using geographic information system and remote sensing techniques. American Society of Agricultural and Biological Engineers (ASABE) Annual International Meeting. Paper No. 095777. Reno, NV

Al-Rawahy SA, Ahmed M, Hussain N (2010) Management of salt-affected soils and water for sustainable agriculture: the project. Published in the Monograph on Management of Salt-Affected Soils and Water for Sustainable Agriculture (Mushtaque A, Al-Rawahi SA, Hussain N (eds)). Sultan Qaboos University, Oman, pp 1–8

Al-Sadi AM, Al-Habsi NA, Al-Kiyumi KS, Al-Said FA, Al-Rawahy SA, Ahmed M, Deadman ML (2010) Effect of salinity on growth, reproduction and pectolytic enzyme production by *Pythium aphanidermatum*: a serious soil borne pathogen of vegetable crops in Oman. Published in the Monograph on Management of Salt-Affected Soils and Water for Sustainable Agriculture (Mushtaque A, Al-Rawahi SA, Hussain N (eds)). Sultan Qaboos University, Oman, pp 95–98

Al-Yahyai R, Al-Ismaily S, Al-Rawahy SA (2010) Growing tomatoes under saline field conditions and the role of fertilizers. Published in the Monograph on Management of Salt-Affected Soils and Water for Sustainable Agriculture (Mushtaque A, Al-Rawahi SA, Hussain N (eds)). Sultan Qaboos University, Oman, pp 83–88

Cookson P, Lepiece A (2001) Could date palms ever disappear from the Batinah? Salination of a coastal plain in the Sultanate of Oman. In Water in the Arabian Peninsula: Problems and Policies (KA Mahdi (ed))

Goddard S, Al-Busaidi AS, Al-Kendi UKHS (2010) Fish culture and hydroponics at low salinities. Published in the Monograph on Management of Salt-Affected Soils and Water for Sustainable Agriculture (Mushtaque A, Al-Rawahi SA, Hussain N (eds)). Sultan Qaboos University, Oman, pp 89–94

Hussain N (2005) Strategic plan for combating water and soil salinity in Sultanate of Oman for 2005–2015. Ministry of Agriculture and Fisheries, Oman (unpublished)

Hussain N, Al-Rawahy SA, Rabee J, Al-Amri M (2006) Causes, origin, genesis and extent of soil salinity in the Sultanate of Oman. Pak J Agric Sci 43(1–2):1–6

Hussain N, Al-Rawahy SA, Ahmed M, Shahid SA (2010) Living with salinity: policy issues, recommendations, future research and guidelines for extension workers and Omani farmers. Published in the Monograph on Management of Salt-Affected Soils and Water for Sustainable Agriculture (Mushtaque A, Al-Rawahi SA, Hussain N (eds)). Sultan Qaboos University, Oman, pp 115–117

MAF (1990) General soil map of Oman. Ministry of Agriculture and Fisheries, Oman

MAF (1993) South Batinah integrated study. Directorate General of Agricultural Research, Ministry of Agriculture and Fisheries, Oman

MAF (1997) Integrated study of North Batinah. Directorate General of Agricultural Research, Ministry of Agriculture and Fisheries, Oman

Nadaf SK, Al-Hinai SA, Al-Farsi SM, Al-Lawati AH, Al-Bakri AN (2010) Differential response of salt tolerant pearl millet genotypes to irrigation water salinity. Published in the Monograph on Management of Salt-Affected Soils and Water for Sustainable Agriculture (Mushtaque A, Al-Rawahi SA, Hussain N (eds)). Sultan Qaboos University, Oman, pp 47–60

Qureshi RH (1995) Final report. Visit of Prof. Riaz Hussain Qureshi, Salinity Expert at ARC, Rumais, August 1, 1994 to January 31, 1995. Faisalabad

Zekri S, Al-Rawahy SA, Naifer A (2010) Socio-economic considerations of salinity: descriptive statistics of the Batinah sampled farms. Published in the Monograph on Management of Salt-Affected Soils and Water for Sustainable Agriculture (Mushtaque A, Al-Rawahi SA, Hussain N (eds)). Sultan Qaboos University, Oman, pp 99–113

Chapter 18
Rice Production in Salt-Affected Soils of Pakistan Using Different Reclamation Techniques

M. Javaid Ahmad, Muhammad Arif, Arshad Iqbal, Muhammad Khalid, and Naseem Akhtar

Abstract A large area of Pakistan is suffering from salinity problem. Being situated in arid and semiarid region, the process of salinization and sodification remains in progress. Bringing these marginal lands into agriculture production is essential from food security perspectives for rapidly growing population. To develop comprehensive technology for the reclamation of these soils, field experiments were conducted to grow rice crop in salt-affected soil using different amendment technologies. The treatments used were T_1 = control, T_2 = 100% gypsum requirement (GR), T_3 = 50% GR with wheat straw at 2 t ha^{-1}, T_4 = 50% GR with rice straw at 2 t ha^{-1}, and T_5 = 50% GR with rice and wheat straw at 2 t ha^{-1} in the ratio of 50:50. The *N*, *P*, and *K* were applied at 100, 80, and 60 kg ha^{-1}, respectively. Fertilizer sources were urea, triple super phosphate (TSP), and sulfate of potash (SOP) for N, P, and K, respectively. Canal water was used to irrigate the crop based on crop requirement. The results revealed that rice biomass and paddy yield was increased significantly in all the treatments over control. Biomass of 14.60 t ha^{-1} and paddy yield of 3.50 t ha^{-1} were achieved in T_2 (100% GR) compared to the values under control treatment, that is, 7.22 and 1.62 t ha^{-1} for biomass and paddy yield, respectively. The yield in treatment T_5 was close to the highest yield obtained in T_2. Post harvest soil analysis indicated the decrease in ECe, pHs, and SAR values in all the treatments compared to the values in control.

Keywords Biomass • Gypsum • Paddy • Pakistan • Rice • Salt-affected soil

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18.1 Introduction

Lands which are marginal for crop production are distributed worldwide. Among these marginal lands, those which are affected to varying degrees of salinity and sodicity occur in over 100 countries, and no continent is free from such soils (Shahid and Rehman 2011). Salt-affected soils are serious constraints for the strengthening of agriculture in many countries. In arid and semiarid regions, salinity and sodicity is a serious problem, usually resulted from adverse climatic conditions and through mismanagement of agricultural lands using saline and brackish water for irrigation. With the changing face of food security in most of the developing countries including Pakistan, it is essential to utilize these marginal lands for sustainable agriculture to offset the increasing food demand of the existing and growing population. Global extent of salt-affected area is 955×10^6 ha (Szabolcs 1994). Large proportions of these soils have recently been brought under cultivation through reclamation using chemical and organic amendments or rice-based crop rotations due to high tolerance of rice to exchangeable sodium and being effective in reclamation of saline-sodic soils. Apart from the use of amendments and crop selection, proper nutrients management is highly important to achieve the satisfactory results during the initial years of reclamation of salt-affected soils.

Pakistan is predominantly an agricultural country, and agriculture sector has a prominent effect on the economy and gross domestic product (GDP) of the country. Being its geographical location in arid and semiarid region, the annual precipitations are insufficient to leach excessive soluble salts below root zone. As a result of high evapotranspiration rates, salinization and sodification processes remain in progress. In Pakistan, about 6.68×10^6 ha area is suffering due to salt problem; of 6.68×10^6 ha area, about 3.37×10^6 ha (54%) is saline and 2.91×10^6 ha (46%) classified under saline-sodic and sodic category (Khan 1998). Recently, Shahid et al. (2010) published hypothetical soil salinization cycle, which also represents salinization process in Pakistan. Due to low rainfall and high temperature, there is net upward movement of subsurface water through capillary rise, and subsequent evaporation accumulates salts at soil surface. Such salts accumulation at the surface and near surface zone (root zone) affects the physical properties of the soil and disturb osmotic potential that ultimately results in low yields of crops. Excessive quantities of soluble salts adversely affect nutritional and water balance of plants, while excessive exchangeable sodium affects plant growth directly as well as by soil structure degradation.

Salts affect the plant growth through various biochemical and physiological processes. Salinity may inhibit the cell division and enlargement in growing plants (Munns et al. 1982). Salt stress may be resulted in the osmotic inhibition of water uptake by roots which may cause direct toxicity (Serrano et al. 1999). In some plants, photosynthesis per unit leaf area is reduced due to inhibition of oxygen release (Passera and Albuzio 1997).

Reclamation is the process by which these problem soils can be brought to normal crop production conditions provided the prerequisites of soil reclamation (availability of sufficient quantity of water, amendments, and absolute drainage) are available. Worldwide different approaches have been used for the reclamation of salt-affected soils, such as, hydrological, chemical, agronomical, and biological techniques (Shahid 2002; Shahid and Rehman 2011). If these approaches are integrated, response to soil reclamation can be achieved in short time. Reclamation of saline-sodic soils involves not only the leaching of soluble salts but also improvement of soil physical conditions to enhance the vertical movement of water in soil. The crop yields and fertilizer use efficiency in these soils can be enhanced by using amendments like gypsum with organic/inorganic materials which helps in improving yields, soil health, and fertilizer efficiency (Swarup 2004).

Gypsum ($CaSO_4 2H_2O$) is commonly used to reclaim soil sodicity through replacing excessive sodium (excess of ESP 15) from the soil exchange complex that ultimately improves the physical and chemical properties of soil and facilitate optimum nutrient uptake for plant growth (Khan et al. 1990). Better ameliorative response of gypsum may be due to its high calcium contents, which is helpful for the management of soils high in exchangeable sodium (Bressler et al. 1982). Crop residues enhance the soil fertility and also improve the physical conditions of soil. These inputs release essential plant nutrients, conserve the soil moisture, reduce the soil erosion, and enhance reclamation process in saline-sodic and sodic soils (Maskina et al. 1993). It was concluded by Verma (2001) that incorporation of organic residues in soil decreases pH, ECe, and sodium adsorption ratio (SAR) and increases the organic matter and water holding capacity of soil within 2–3 years.

Rice and wheat straw are the farm products, which can be used in the reclamation of salt-affected soils to improve the physical condition of soil and to some extent productivity of soil. Composting of rice straw in the salt-affected soils may be helpful in improving moisture holding capacity, good air circulation, drainage of excessive water, and dilution of salts in soil solution (El Etreiby et al. 1996). Massoud et al. (1989) concluded an increase in rice yield through the application of gypsum and manure; however, he further reported that the combination of these responded better. Ibrahim et al. (2000) reported that organic manures were effective in increasing yields and good physical conditions of soil.

Keeping in view the importance of gypsum and organic amendments in the reclamation of salt-affected soils, the present study was conducted to determine the rice production in salt-affected soils using gypsum in combination with rice and wheat straw as organic amendments.

18.2 Materials and Methods

18.2.1 Selection of Site

The study was conducted in an agriculture village of district Faisalabad, Punjab (Fig. 18.1), Pakistan, for two consecutive years in a saline-sodic field. The soil of experimental site falls under Khurrianwala soil series. The soils in this series are dense, saline-sodic belonging to order Aridisols, and cover about 752-km^2 area in districts of Faisalabad, Jhang, Multan, Gujrat, Sahiwal, and Sheikhupura in the Punjab province of Pakistan (Soil Survey of Pakistan). Composite soil samples were collected from all the treatment plots before the sowing of rice crop. These samples were processed for air-drying, grinding, and sieving through 2-mm sieve (fine earth fraction) and analyzed for

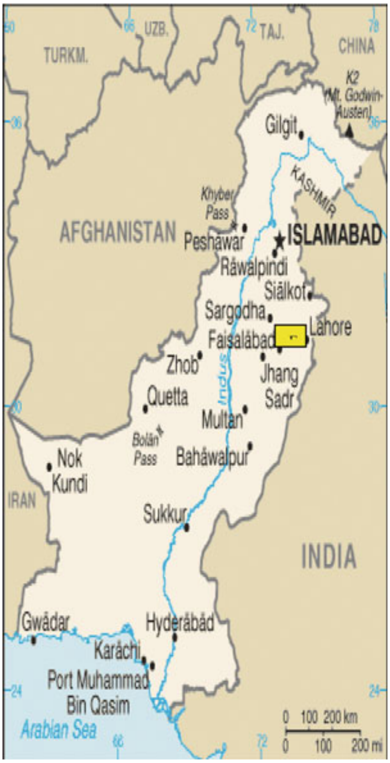

Fig. 18.1 Site location map

the selected physical and chemical characteristics. Particle size distribution analyses (PSDA) was completed using standard Bouyoucos hydrometer method according to Koehler et al. (1984) and textural class determined using USDA textural triangle (Soil Survey Division Staff 1993). Soil pH and electrical conductivity was estimated as per methods described in USDA Handbook 60 (Richards 1954). Soil pH was determined on saturated soil paste and ECe determined on extract from saturated soil paste using conductivity meter. Organic matter (%) was determined by method as described by Nelson and Sommers (1996) using potassium dichromate as an oxidizing agent. Physical and chemical characteristics of soil are given in Table 18.1.

18.2.2 Treatments

The experiment includes the five treatments:

1. T_1 = control
2. T_2 = 100% gypsum requirement (GR)
3. T_3 = 50% GR + 2 t ha^{-1} wheat straw
4. T_4 = 50% GR + 2 t ha^{-1} rice straw
5. T_5 = 50% GR + 2 t ha^{-1} (wheat + rice straw in the ratio of 1:1).

Table 18.1 Physical and chemical characteristics of original soil at sowing

Characteristic	Unit	Value
Clay	%	14.2
Silt	%	40.6
Sand	%	45.2
Textural class	–	Sandy loam
pH	_	8.92
ECe	dS m^{-1}	5.28
SAR	(m moles $L^{-1})^{1/2}$	37.60
OM	%	0.58
Total N	%	0.041
Available P	mg kg^{-1}	7.12
Extractable K	mg kg^{-1}	184

18.2.3 Experimental Plan

The field was prepared using conventional tillage practices, and trial was arranged in randomized complete block design (RCBD) with three replications. Gypsum requirement (GR) was determined using Schoonover method (Schoonover 1952) as given in the USDA (US Salinity Lab Staff 1954) Handbook 60 (method 22d). Gypsum alone and in combination with wheat and rice straw was incorporated into the soil surface before the sowing of crop. A basal dose of N–P–K at 100–80–60 kg ha^{-1} was applied in the form of urea, triple super phosphate, and sulfate of potash, respectively. Soil was prepared well, and rice nursery (Basmati super) was transplanted in the field in the month of July each year. Good quality canal water was used for irrigation till the maturity of the crop. Standard agronomic practices were followed for the crop production. All the agronomic operations were kept uniform for every treatment plot. At maturity, crop was harvested, and the data regarding biomass and paddy yield was recorded. Grain samples were analyzed for nitrogen and phosphorus contents. Soil samples were collected from all the plots after crop harvest each year and analyzed for pHs, ECe, OM, and SAR. The data collected were analyzed statistically following randomized complete block design according to Steel et al. (1997). The differences among treatment means were compared at 5% probability by applying the Duncan's multiple range tests (Duncan 1955).

18.3 Results and Discussion

The experiment was conducted in a saline-sodic field for 2 years. The results are presented and discussed in the following sections.

Table 18.2 Effect of reclamation techniques on biomass yield (t ha^{-1})

Treatment	First crop	Second crop	Average
T_1	6.84c	7.60c	7.22c
T_2	13.85a	15.35a	14.60a
T_3	11.10b	12.50b	11.80b
T_4	11.55b	13.05b	12.30b
T_5	12.75ab	13.85ab	13.30ab
LSD	1.205	1.521	1.376

Values with same letters does not differ significantly at $P = 0.05$

Table 18.3 Effect of reclamation techniques on paddy yield (t ha^{-1})

Treatments	First crop	Second crop	Average
T_1	1.34c	1.90c	1.62c
T_2	3.23a	3.77a	3.50a
T_3	2.48b	3.00b	2.74b
T_4	2.47b	3.23b	2.90b
T_5	2.78ab	3.45ab	3.10ab
LSD	0.4822	0.5342	0.4744

Values with same letters does not differ significantly at $P = 0.05$

18.3.1 Yields

18.3.1.1 Biomass Yield

The data regarding the biomass yield is given in Table 18.2. Table 18.2 illustrates that the application of gypsum alone and in combination with rice and wheat straw significantly increased the biomass yield over control. Maximum average yield of 14.60 t ha^{-1} was found in T_2 where 100% gypsum requirement was applied. It was closely followed by T_5 showing value of 13.30 t ha^{-1} where wheat and rice straw was used as amendment with 50% gypsum requirement (GR). However, in treatments where rice and wheat straw was used separately with 50% GR, the results were also encouraging with the yield figures of 11.80 and 12.30 t ha^{-1} for wheat and rice straw, respectively. In a previous study, Muhammad et al. (1990) reported the increase in biomass yield using gypsum with organic amendments. The increase in biomass yield of rice was also reported by Zaka et al. (2005) during the reclamation of saline-sodic field with gypsum alone and in combination with organic amendments.

18.3.1.2 Paddy Yield

Yield data of rice paddy presented in Table 18.3 indicated the significant increase in all the treatments as compared to control where no gypsum or other amendments were used. The highest value of 3.5 t ha^{-1} was noted in the treatment with 100% GR compared to the value of 1.62 t ha^{-1} from control plots. The increase was 116% over the control. This treatment was closely followed by the combination of 50% GR with wheat and rice straw indicating 91% increase in the paddy yield. Other two treatments

Table 18.4 Effect of reclamation techniques on pHs of soil

Treatments	Pre sowing	After first crop	After second crop
T_1	8.90	8.70a	8.65a
T_2	8.78	8.45c	8.20c
T_3	8.80	8.65ab	8.25bc
T_4	8.85	8.58b	8.30b
T_5	8.90	8.42c	8.12d
LSD		0.0833	0.0720

Values with same letters does not differ significantly at $P = 0.05$

also responded well in respect of paddy yield. In an earlier study, Zaka et al. (2005) reported an increase in paddy yield in saline-sodic field with the application of gypsum alone and in combination with organic amendment. It was concluded by Haq et al. (2001) that paddy yield was increased in saline-sodic field with the use of gypsum in combination with press mud. The increase in wheat yield was also recorded by Chang and Sipio (2001) during the reclamation of saline-sodic soil with rice husk.

18.3.2 Effect on Soil pH

High soil pH is an indication of the presence of exchangeable sodium and carbonate/bicarbonates abundance. The data presented in Table 18.4 indicated a decrease in soil pH with the use of gypsum and rice and wheat straw to the saline-sodic field. The maximum decrease was found in the combination of rice and wheat straw with 50% GR. The decrease was from 8.90 to 8.12 after harvest of second crop. The treatment of 100% GR also showed a good decrease in soil pH values from initial reading of 8.78 at the start of experiment to 8.20 after harvest of second crop. Other two treatments were also proved better in reducing pH values as compared to control in which no significant decrease was recorded. Muhammad and Khaliq (1975) in a field experiment concluded similar results of soil pH reduction. The decrease in soil pH with the use of rice husk in reclamation of salt-affected field was also noted by Chang and Sipio (2001). Similar findings were also reported by Haq et al. (2001) while reclaiming the salt-affected soils.

18.3.3 Effect on the ECe of Soil

The ECe values after crop harvest are evident from Table 18.5 indicating the presence of soluble salts in the soil. These salts can be leached down with the application of heavy irrigations. The data revealed a decreasing trend of ECe with the application of amendments. It is interesting that ECe values lowered down to the safe limits (<4 dS m^{-1}) in all the treatments except the control. The decrease in the ECe value was also

Table 18.5 Effect of reclamation techniques on ECe (dS m^{-1}) of soil

Treatments	Pre sowing	After first crop	After second crop
T_1	5.23	4.75a	4.10a
T_2	5.15	4.0bc	3.10b
T_3	5.18	4.30b	3.12b
T_4	5.25	4.20b	3.15b
T_5	5.09	3.75c	2.82c
LSD		0.2632	0.2153

Values with same letters does not differ significantly at $P = 0.05$

Table 18.6 Effect of reclamation techniques on SAR (m moles L^{-1})$^{1/2}$ of soil

Treatments	Pre sowing	After first crop	After second crop
T_1	37.84	33.20a	30.85a
T_2	36.52	24.42c	16.17c
T_3	38.00	25.35bc	18.55b
T_4	35.78	26.10b	19.00b
T_5	36.64	24.15c	15.82c
LSD		1.4520	1.3377

Values with same letters does not differ significantly at $P = 0.05$

found in some control plots; this might be due to leaching of soluble salts with canal water. However, reduction process was more effective and dominant in all other treatments indicating the efficiency of reclamation techniques. The treatment of 50% GR with wheat and rice straw showed the maximum decrease in ECe from the initial value of 5.09–2.82 dS m^{-1} after second crop harvest. The results were in line with the findings of Verma (2001) who observed the reduction in ECe during reclamation of saline-sodic soil with organic amendments. The decrease in ECe was concluded by Sharma et al. (1982) with reclamation approaches in saline-sodic fields. Chang and Sipio (2001) also reported the decrease in soil pH with the use of rice husk in saline-sodic field.

18.3.4 Effect on Soil SAR

Table 18.6 revealed that the SAR of the soil was decreased significantly with all reclamation techniques in rice production in comparison with control. The treatment with 100% GR was the leading treatment in which SAR value was 36.64 at the start of experiment which declined to 15.82 after harvest of second year rice crop. The decreasing trend was observed in all the treatments except control where decrease was minimal. The decrease was found within the range of 46–56%. It is due to the leaching of excessive sodium replaced from the soil exchange complex (clay particles) and removal of bicarbonates from the soil solution. As the sodium is removed from the soil, its SAR values lower down to the limits that facilitate plant growth positively. Zaka et al. (2005) found that SAR was decreased significantly during rice production in saline-sodic soil treated with gypsum and organic amendments. Similar results were recorded by Chang and Sipio (2001) when they used rice husk for the reclamation of salt-affected fields.

Table 18.7 Effect of reclamation techniques on soil OM (%)

Treatments	Pre sowing	After first crop	After second crop
T_1	0.62	0.61b	0.63c
T_2	0.61	0.68a	0.71ab
T_3	0.58	0.65a	0.68b
T_4	0.60	0.64ab	0.66b
T_5	0.60	0.66a	0.74a
LSD		0.0485	0.05565

Values with same letters does not differ significantly at $P = 0.05$

Table 18.8 Effect of reclamation techniques on rice grain N and P contents (average of 2 years)

Treatments	% N content	% P content
T_1	1.52c	0.400c
T_2	1.76a	0.440b
T_3	1.68b	0.423b
T_4	1.71ab	0.418b
T_5	1.83a	0.452a
LSD	0.1343	0.0215

Values with same letters does not differ significantly at $P = 0.05$

18.3.5 Effect on OM Content of Soil

The presence of organic matter in the soil is an indication of good fertility and favorable environments for plant growth. Soils with high organic matter contents respond more effectively toward increases in crop yields. The analysis of post harvest soil samples for % OM is mentioned in Table 18.7. It is clear from the data that soil OM contents were improved in the reclamation techniques, but there was no increase in control plots. Maximum OM content (0.74%) was found in the treatment where gypsum was applied at 50% GR with the rice and wheat straw. It was the treatment with 100% GR which also contributed well in the increase in organic matter with figure of 0.71%. Similar trend was noticed by Chang and Sipio (2001) while growing rice in saline-sodic field using different reclamation methods. The increase in organic matter contents through the addition of organic amendments was also reported by Verma (2001) during studies on the reclamation of saline-sodic soils.

18.3.6 Effect on the N and P Content of Rice Grain

The data in Table 18.8 indicated the increase in N and P content of rice grains in all the treatments over control. Maximum values (N=1.83%, P=0.452%) were observed in the treatment T_5 (combination of gypsum with rice and wheat straw). It was closely followed by T_2 where gypsum was applied at 100% GR. It is evident from the data that all the treatments were found better in terms of rice grain N and

P content as compared to control. It indicates the better availability of nutrients for plant growth in the plots where reclamation approaches were applied. El-Ashtar and El-Etreiby (2006) also derived an increase in nutrient content of rice by compost and gypsum application during the reclamation of saline-sodic soil.

18.4 Conclusion

From the present study on the reclamation of saline-sodic soil in Pakistan, it can be concluded that rice paddy and biomass yield was increased with all chemical and organic reclamation amendments in saline-sodic field as compared to control. Gypsum application at the rate of 100% gypsum requirement was the leading treatment indicating high yields closely followed by treatment where 50% GR was applied in combination with wheat and rice straw. The treatment of 50% GR with wheat and rice straw was found more effective in reducing pHs, ECe, and SAR and increasing soil organic matter.

References

Bressler EB, McNeal BL, Carter DL (1982) Saline and sodic soils: principles-dynamics-modeling. Springer, New York, p 236

Chang MH, Sipio QA (2001) Reclamation of saline sodic soils by rice husk. J Drain Water Manage 5(2):29–33

Duncan DB (1955) Multiple ranges and multiple F-test. Biometrics 11:1–42

El Etreiby F, Shehata N, Sheta T, Scalbroeck JJ (1996) The influence of composting on the fertilizer value of rice straw and evaluation of these composts on soil properties and rice productivity. Alex Sci Exch 17(2):141–153

El-Ashtar A, El-Etreiby F (2006) Influence of leaching with gypsum and compost of rice straw on improvement of salt affected soil and rice growth. Alex Sci Exch 27(2):214–221

Haq I, Khatak SG, Rahman H, Ali A, Salim M (2001) Effect of various amendments on the yield of rice crop under saline-sodic conditions in Mardan/Swabi districts. Int J Agri Biol 3(3):289–291

Ibrahim M, Rashid M, Nadeem MY, Mehmood K (2000) Integrated use of green manuring, FYM, wheat straw and inorganic nutrients in rice-wheat crop rotations. In: Proceedings of symposium on IPNS NFDC, Islamabad, pp 86–95

Khan GS (1998) Soil salinity/sodicity status in Pakistan. Soil Survey of Pakistan, Lahore, pp 5–20

Khan NH, Haq MI, Rauf A (1990) Gypsum use efficiency in saline-sodic soil as affected by water quality and organic matter. In: Proceedings of the 2nd National Congress of Soil Science, Faisalabad 20–22 Dec 1990, pp 66–79

Koehler FE, Moudre CD, McNeal BL (1984) Laboratory manual for soil fertility. Washington State University, Pullman

Maskina MS, Power JF, Doran JW, Withlem WW (1993) Residual effects of crop residues on corn yield and nitrogen uptake. Soil Sci Soc Am J 57(6):155–161

Massoud FI, Abrol IP, Yadav JSP (1989) Salt affected soil and their management. Soil Bull 39:177. FAO, Rome

Muhammad S, Khaliq A (1975) Comparison of various chemical and organic amendments for reclaiming saline sodic soils. Bull Irrig Drain Flood Control Res Council 5:50–54

Muhammad S, Ghafoor A, Hussain T, Rauf A (1990) Comparison of biological, physical and chemical methods for reclaiming salt-affected soils. In: Proceedings of the 2nd National Congress of Soil Science, 20–22 Dec 1988, pp 35–42

Munns R, Greenway H, Delane R, Gibbs R (1982) Ion concentration and carbohydrate status of elongating tissue of *Hordeum vulgare* under high external NaCl. J Exp Bot 33:574–583

Nelson DW, Sommers LE (1996) Total carbon, organic carbon and organic matter. In: Bigham JM (ed) Methods of soil analysis: Part 3, chemical methods. American Society of Agronomy, Madison, pp 961–1010

Passera C, Albuzio AA (1997) Effect of salinity on photosynthesis of two wheat species. Can J Bot 56:121–126

Richards LA (ed) (1954) Diagnosis and improvement of saline and alkali soils. USDA handbook no 60. USDA, Washington, DC

Schoonover WR (1952) Examination of soils for alkali. University of California Extension Service, Berkeley (Mimeographed)

Serrano R, Culianz F, Moreno V (1999) A glimpse of the mechanism ion homeostasis during salt stress. J Expt Bot 5:1023–1026

Shahid SA (2002) Recent technological advances in characterization and reclamation of salt-affected soils in Arid zones. In: Al-Awadhi NM, Taha FK (eds) New technologies for soil reclamation and desert greenery. Amherst Scientific Publishers, Amherst, pp 307–329

Shahid SA, Rehman K (2011) Soil salinity development, classification, assessment and management in irrigated agriculture. Book Chapter in Handbook of Plant and Crop Stress, 3rd edn (Mohammed Passarakli (ed), The University of Arizona, Tucson, AZ 85721), pp 23–39. Published by CRC Press, Boca Raton

Shahid SA, Abdefattah MA, Omar SAS, Harahsheh H, Othman Y, Mahmoudi H (2010) Mapping and monitoring of soil salinization-remote sensing, GIS, modeling, electromagnetic induction and conventional methods – case studies. In: Ahmad M, Al-Rawahy, SA (eds) Key note paper published in the proceedings of the international conference on soils and groundwater salinization in arid countries, Sultan Qaboos University, Muscat, Keynote papers, 1:59–97

Sharma DP, Mehta KK, Yadav JSP (1982) Effect of reclamation practices on soil properties and crop growth on farmers field. J Ind Soc Soil Sci 29:336–360

Soil Survey Division Staff (1993) Soil survey manual. Agricultural handbook 18. USDA-Natural Resources Conservation Service, Washington, DC

Steel RGD, Torrie JH, Dicky DA (1997) Principles and procedures of statistics – a biometrical approach, 3rd edn. McGraw-Hill Book International Co., Singapore, pp 204–227

Swarup A (2004) Chemistry of sodic soils and management. In: Advances in sodic land reclamation. International conference on sustainable management of sodic lands, Lucknow, 4–9 Feb 2004, pp 27–52

Szabolcs I (1994) Soil and salinization. In: Pessarakali M (ed) Handbook of plant and crop stress. Morckell Dekkar, New York, pp 3–11

US Salinity Lab Staff (1954) Diagnosis and improvement of saline and alkali soils, USDA handbook no 60. US Salinity Lab Staff, Washington, DC

Verma KP (2001) Effect of crop residues incorporation and nitrogen on succeeding wheat. Ind J Agron 46(45):665–669

Zaka MA, Rehman OU, Rafa HU, Khan AA (2005) Integrated approach for reclamation of salt affected soil. J Agric Soc Sci 1(2):94–97

Chapter 19
Marginal-Quality Water Use as an Ameliorant for Tile-Drained Saline-Sodic Soils in a Rice-Wheat Production System

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Abstract Appropriate use of marginal-quality waters coupled with crop rotation(s) and management interventions on saline-sodic soils have the potential to transform such water and soil resources from environmental burdens into economic assets. Several long-term field studies in the Indus basin of Pakistan were carried out to evaluate different irrigation and soil management options of using saline-sodic waters on saline-sodic soils for reclamation in a rice-wheat production system. The effect of different amendments like gypsum (gypsum requirement on water RSC basis and on soil SAR basis) and farm manure along with conjunctive use of fresh and saline-sodic waters for irrigating rice and wheat crops was evaluated. The effects of applied amendments were evaluated in terms of change in the physical and chemical properties of soils, yield-based crop growth response and economic implications. The results showed significant improvement in physical and chemical properties of soils with good yields of crops with the application of amendments specially gypsum and farm manure along with conjunctive use of fresh and saline-sodic waters. Salt removal (kg ha^{-1}) was the highest with the application of two pore

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volume (PV) water. In general, it was concluded that after the application of four irrigations of different PV, highest leaching fraction removed maximum salts from loamy sand soil. Salt removal remained the highest with first two irrigations and then decreased subsequently. Overall, the greatest net benefit was obtained from gypsum plus cyclic use of saline-sodic and fresh waters. It was found that the farmers' management skills were crucial in the overall success to improve crop yields during reclamation of saline-sodic soils. Based on the results, we propose that saline-sodic water could be used to reclaim saline-sodic soils by using a rice-wheat rotation and a site-specific combination of soil amendments and water application strategies.

Keywords Ameliorant • Marginal water • Reclamation • Rice-wheat • Pakistan

19.1 Introduction

About one-third food and fibre is harvested from irrigated areas of the world, which occupy only about one-sixth of the crop land (Hillel 2000). The growing rate of global population warrants increase in the area under irrigated agriculture to meet the future food and fibre demands, which will need additional water. Although the annual renewable freshwater resources for the foreseeable future are now largely allocated to different sectors, there may be some areas where freshwater resources increase or decrease according to rainfall changes due to climate change; however, these are likely to occur at the level that is small compared to the increased future demands for freshwater (Wallace 2000). With more pressing demands for nonagricultural sectors, availability of quality surface water is falling short of the crop requirement, particularly in arid regions like Pakistan. In order to meet this shortage, more than 0.8×10^6 tube wells have been installed in the Indus basin of Pakistan (Anonymous 2007). About 70–80% of pumped water is of marginal to hazardous quality owing to high electrical conductivity (EC), sodium adsorption ratio (SAR) and/or residual sodium carbonate (RSC). The Indus basin comprises a vast area of alluvial plains deposited by the Indus and its tributaries and a small area of loess plains. The soils developed are sub-recent or recent in origin, calcareous and low in organic matter (<1 %). The experimental area falls within the canal command area (CCA) of the Indus plain of Pakistan. Irrigation with low-quality water seems to continue and even may increase in developing, arid and semiarid regions where there is high population growth, and thus, severe environmental concerns are natural (Qadir et al. 2007). The use of such hazardous water is a means to convert normal soils in to salt-affected soils. According to Szabolcs (1994), the total salt-affected area of the world has increased from 148.1×10^6 ha to 954.83 from 1960 to 1989, and the process is still in progress.

Saline conditions dominated by divalent cations (such as calcium) generally have favourable effects on soil structure stability (Quirk and Schofield 1955). The adverse effects of electrical conductivity (EC) on crops stem from two aspects: increasing the osmotic pressure and thereby making the water in soils less available for plants and specific ion effects to cause ion imbalances. On the other hand, irrigation-induced sodicity in soils exhibits structural problems created by certain processes (slaking, swelling, dispersion and translocation of clays and deposition in conducting pores to reduce size or complete blockage) and specific conditions like surface crusting and hard setting (Shainberg and Letey 1984; Shahid and Jenkins 1992; Sumner 1993; Qadir and Schubert 2002). Such problems affect water and air movement, plant-available water holding capacity, root penetration, seedling emergence, runoff, erosion, and tillage and sowing operations. In addition, imbalances and induced deficiencies in plant-available nutrients in salt-affected soils may affect plant growth adversely.

Scientific management of saline-sodic waters and soils seems essential and has been proved beneficial for several reasons (Oster and Grattan 2002). For example, use of high-electrolyte waters with low sodium (Na^+) levels has usefulness for initial amelioration of salt-affected soils (Ghafoor et al. 2004; Singh 2005). Use of such water would affect favourably the infiltration rate, bulk density and structure of surface soils (Oster and Schroer 1979). In this context, the use of saline-sodic waters and salt-affected soils for crop production has potential in saving freshwater for good soils and decreasing disposal problems of low-quality drainage waters. This way, bringing barren lands into cultivation will contribute to environment conservation through carbon sequestration (Lal 2001; Hassan 2004), an increase in farm employment, and a decrease in rural to urban migration and rural poverty reduction.

19.2 Materials and Methods

19.2.1 Experimental Sites and Treatments

Different studies had been conducted in the Fourth Drainage Project Area (FDPA) on different salt-affected soils belonging to Sodic Haplocalcids, Typic Aquisalids, Typic Calciargids and Fluventic Aquicambids between the year 2001 and 2010. The geographic location of the experimental sites had been indicated on the map. The studies were aimed to evaluate the efficiency of different soil reclamation treatments using brackish irrigation waters. The treatments include different rates of farm manure, green manure, gypsum using fresh water, saline-sodic water and their combinations. Site location map is shown in Fig. 19.1.

19.2.2 Soil Sampling and Analysis

After layout of the experiments, three subsamples from each treatment plot were composited to obtain representative soil samples from each treatment plot at 0–15 and 15–30 cm depths. Soil bulk density was determined by standard soil core method and steady-state infiltration rate by double ring infiltrometers in triplicate for each treatment. These measurements were carried out before the application of treatments and then at termination of studies.

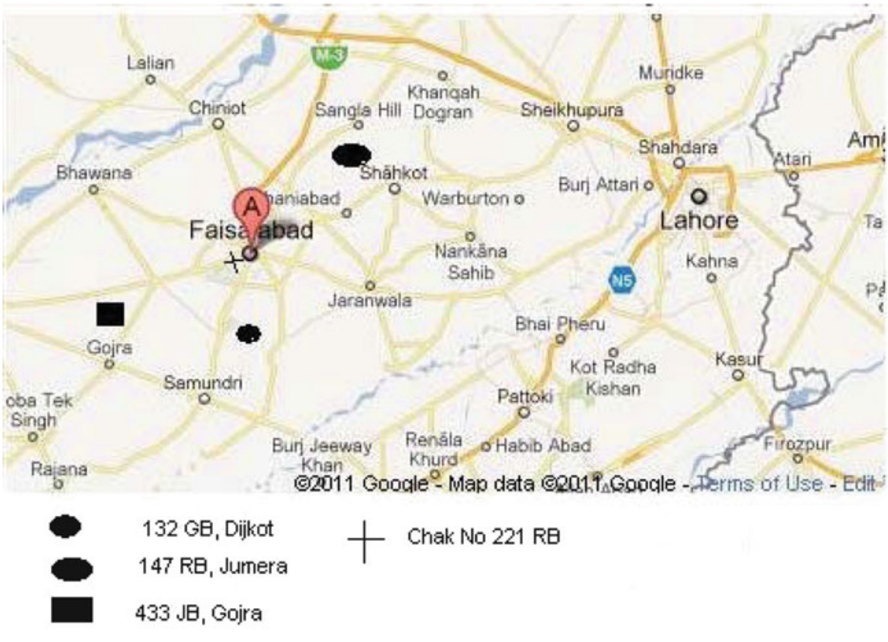

Fig. 19.1 Site location map

Saturated soil paste extracts were analysed for electrical conductivity (EC_e) by HANNA HI 8033 EC meter, pH_s by JENCO Model-671P pH meter, soluble $Ca^{2+}+Mg^{2+}$ (titration with standard versinate solution), CO_3^{2-} and HCO_3^- (titration with standard H_2SO_4), Cl^- (titration with standard $AgNO_3$) and Na^+ (flame photometrically) using methods described by the US Salinity Laboratory Staff (1954) and Page et al. (1982). Sodium adsorption ratio (SAR) was calculated by Eq. 19.1 using concentrations of the Na^+, Ca^{2+} and Mg^{2+} in $meqL^{-1}$.

$$\mathrm{SAR}\left(\mathrm{mmoles\ L^{-1}}\right)^{0.5} = \frac{\mathrm{Na^+}}{\left[\left(\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}}\right)/2\right]^{0.5}} \quad (19.1)$$

19.2.3 Leaching Requirement

The treatment efficiency for leaching salts was calculated by the following formula:

kg salts leached per m^{-3} water = initial kg salts – kg salts at termination/volume of water added (m^3)

The salt leaching efficiency after each crop was calculated by the following formula:

kg salts leached m^{-3} water = average initial kg salts – average kg salts after each crop/cumulative m^{-3} water added

The weight of soil calculated for each treatment consisting bulk density (BD) of respective treatment, initial and final EC_e converted into per cent by multiplying it with average factor of 0.064, and average EC_e of all treatments for a particular crop was used to compute salt removal after each crop. Further, it is assumed that there is no salt precipitation in soil, insignificant salt addition and removal by crops during the given period of time.

The leaching fraction was calculated with the following formula:

$$\text{Leaching fraction} = \frac{\text{depth of drainage water}}{\text{depth of applied water}}$$

Pore volume was calculated with the help of saturation percentage and bulk density using the formula

$$\text{PV (cm}^3) = \theta_v \pi r^2 l \text{ (Jury et al. 1991)}$$

The salts removed were computed with the following formula:

$$\text{Salt removal (mg leachate}^{-1}) = \text{EC of leachate (dS m}^{-1}) \times 640 \times \left\{ \frac{\text{vol. of leachate (mL)}}{\text{PV of water (mL)}} \right\}$$

19.2.4 Crop Growth and Economic Evaluation

Different crops (rice, wheat, cotton) were grown according to their agronomic requirements and were harvested at maturity. The data regarding different yield parameters was recorded to evaluate the crop response under salt-affected conditions along with reclamation treatments. In these studies, the total cost included cultivation, seed and seedbed preparation, pesticides applied, amendments (gypsum and farm manure), harvesting, threshing, petroleum, oil and lubricants (POL) for tube wells and labour for amendment incorporation. Gross income was calculated from the support prices of different crops, while income from straw was that realized by open auction. Net income was calculated as the difference between gross income and total cost.

19.3 Physical Characteristics of Soils

19.3.1 Infiltration Rate (IR)

The IR is of particular importance for managing poor-quality waters for crop production both on productive and salt-affected soils. An IR of <0.3 cm h^{-1} is considered low, while an IR > 1.2 cm h^{-1} is relatively high (Ghafoor et al. 2004). Low IR reflects slow response of soils to reclamation treatments. The effect of different amendments remained significant on IR of a saline-sodic soil having low IR (Fig. 19.2) than critical limit of 0.25 cm h^{-1} (US Salinity Laboratory Staff 1954).

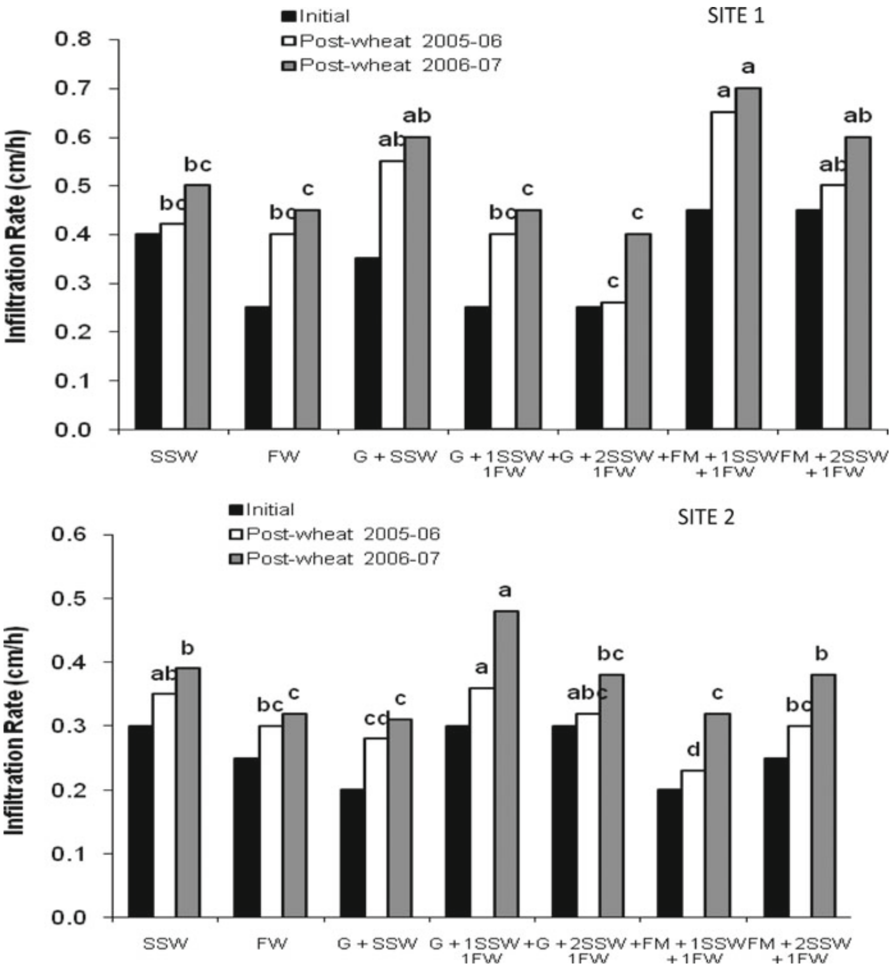

Fig. 19.2 Soil infiltration rate (cm h^{-1}) post-wheat 2006–2007 (values sharing same letter(s) are statistically similar at $P = 0.05$; *SSW* saline-sodic water, *FW* fresh water, *G* gypsum, *FM* farm manure)

Murtaza et al. (2009) conducted experiments on two soils having initial average pH_s of 8.7–9.8, EC_e 19–44 dS m^{-1}, SAR 118–319 (mmol $L^{-1})^{0.5}$, IR 0.25–0.45 cm h^{-1} and bulk density 1.70–1.83 Mega grams per cubic meter (Mg m^{-3}) with sandy clay loam texture near Dijkot, Faisalabad, and pH_s 9.1–9.6, EC_e 9–17 dS m^{-1}, SAR 83–204 (mmol $L^{-1})^{0.5}$, IR 0.20–0.30 cm h^{-1} and bulk density 1.37–1.61 Mg m^{-3} with silty clay loam texture near Gojra, Toba Tek Singh.

After the harvest of four crops (two wheat and two rice), it was concluded that overall gypsum along with saline-sodic water alone or in conjunction with fresh water performed better in improving IR of these saline-sodic soils. Since adsorbed

Na^+ on clays is considered mainly responsible for soil dispersion, gypsum alleviated soil dispersion by maintaining high Ca:Na ratios in the soil solution and thus decreased Na^+ adsorption (Muhammed et al. 1969). Improvement in IR was observed in the medium texture and dominance of illite-type clays (Ranjha et al. 1993) which are less prone to dispersion than high CEC smectite-type clays (Bresler et al. 1982).

19.3.2 Bulk Density (BD)

Soil bulk density is an important physical property of soils. The BD > 1.50 Mg m^{-3} reflects soil deterioration, i.e. Na^+ induced dispersion (Gupta and Abrol 1990) and restricted movement of water and air. A significant decrease in BD of two saline-sodic soils for both depths (0–15 and 15–30 cm) with the application of gypsum and farm manure compared to that with saline-sodic water (SSW) alone (Fig. 19.3) on these soils (Murtaza et al. 2009) was recorded. The application of amendments like gypsum and FM provides Ca^{2+} which flocculates soil and improves soil structure by decreasing its BD. The improved BD at the soil surface was partly attributed to high EC of applied water (Al-Nabulsi 2001), physical manipulation through ploughing and addition of organic matter through plant residues. It was reported that for an appreciable decrease in soil BD, ratio of solid to pore space must be altered physically through soil mixing or normal ploughing (Hamza and Anderson 2002). Gypsum with or without farm manure helped sustain electrolyte concentration and relatively high EC_e to SAR ratio in soil solution and thus an increase in IR (Ghafoor et al. 2008).

19.4 Chemical Properties of Soils

19.4.1 Soil Reaction (pHs)

Soil pH has considerable impact in controlling the plant nutrients, particularly the availability of micronutrients such as Zn, Cu, Fe and Mn (Naidu and Rengasamy 1993). The saline-sodic water irrigation without amendment, in general, tends to increase pH_s that caused imbalance in nutrient availability, rendering plant's malnutrition (Curtin and Naidu 1998; Grattan and Grieve 1999). Different studies on solution chemistry suggest that as the soil solution concentration increases, first Ca^{2+} precipitates as $CaCO_3$ and, to a lesser extent, as $CaSO_4$, leaving preponderance of Na^+ in soil solution that subsequently induces Na^+ adsorption (Suarez 1981) to increase the pH_s. This phenomenon was evident when changes in pH of different soil depths were evaluated. At 0.3–0.6 m soil depth, pH_s increased as a consequence of accumulation of Na^+ through its movement from upper soil layer. A significant

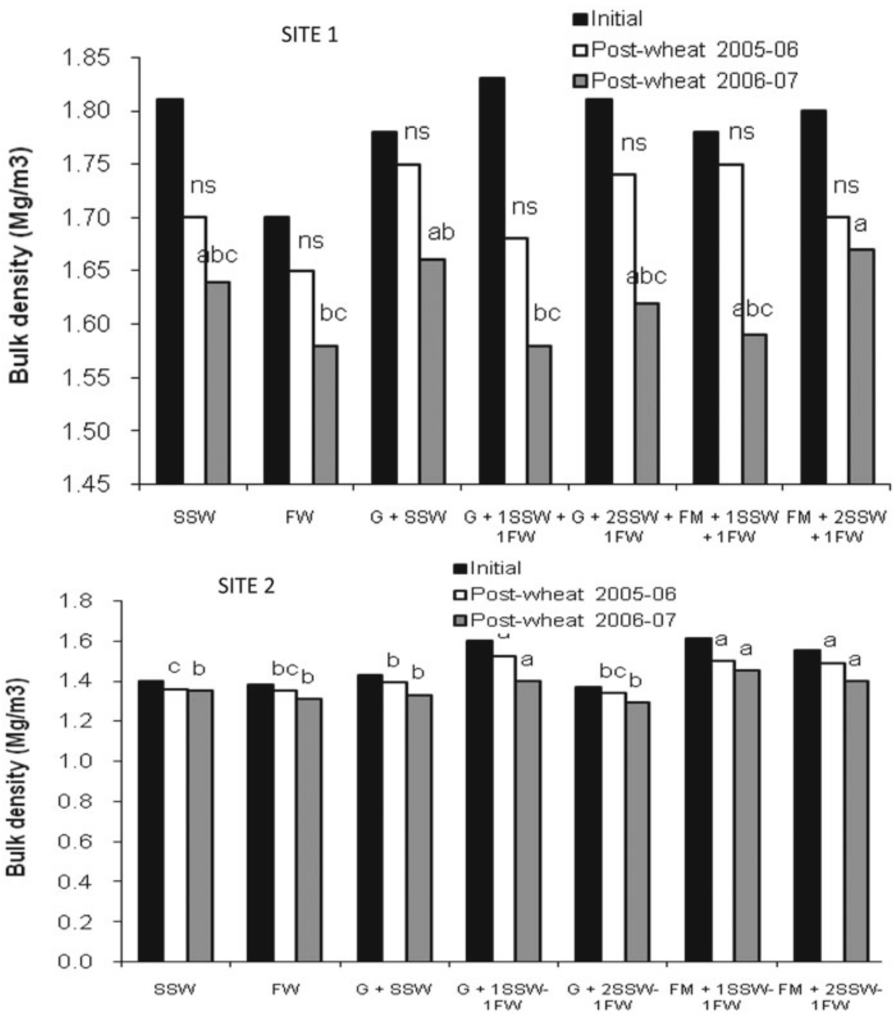

Fig. 19.3 The bulk density (Mg m^{-3}) post-wheat 2006–2007 for 0.10–0.15 m soil depth (values sharing same letter(s) are statistically similar at $P = 0.05$; *SSW* saline-sodic water, *FW* fresh water, *G* gypsum, *FM* farm manure)

decrease in pH_s was recorded after the harvest of wheat 2006–2007 (4th crop in sequence) in two different saline-sodic soils, being the highest with gypsum and FM along with conjunctive use of brackish and fresh water at 0.00–0.15 m and 0.15–0.30 m soil depths, respectively. Maximum decrease over the initial pH_s was observed with FM along with conjunctive use of brackish and fresh water at both soil depths which could partially be attributed to the formation of carbonic acid (H_2CO_3) upon the release of CO_2 during bio-oxidation of manure coupled with that from root respiration.

19.4.1.1 Soil Salinity (EC_e)

Soil EC exerts osmotic effects on plants (Maas and Hoffman 1977; Grattan and Grieve 1999) and often causes physiological drought if the salinity levels are greater than the threshold limits of crops. A considerable increase in EC_e was recorded at both (0–15 cm and 15–30 cm) soil depths (Murtaza et al. 2006). Similar increases occurred in the gypsum-treated plots, but the Ca^{2+} concentration in soil solution favoured the IR sustainability and facilitated Na^+ leaching. In general, the EC_e values were higher after wheat than after cotton, which appears the consequence of salt redistribution from lower depths to surface soil during the hot and dry months of April and May (Qadir et al. 2001). In addition, time laps between the last irrigation to wheat and time of soil sample collection also favoured salt accumulation in surface layer.

A small decrease in EC_e with gypsum application compared to that with farm manure was recorded because of low solubility of gypsum which otherwise is useful for sustaining electrolyte concentration in soil solution for longer times (Murtaza et al. 2009). The resultant better hydraulic conductivity is an asset for the reclamation of saline and/or sodic soils (Ghafoor et al. 2004). Heavy input of irrigation water to grow rice does enhance leaching of soluble salts to affect lower EC_e in upper soil layers. Rice is grown under submerged conditions which could cause a high leaching fraction that would result in greater leaching of soluble salts to lower soil depths during this crop (Qadir et al. 2001). This decline in soluble salts leads to conclude that rice may be preferred as the first crop during reclamation program of saline-sodic soils. The studies indicate that saline-sodic water can be used successfully for initial reclamation of most of the calcareous salt-affected soils by following rice-wheat cropping sequence.

19.4.1.2 Soil Sodicity (SAR)

Water and soil sodicity is expressed in terms of SAR; high SAR have the potential for soil structure deterioration, low infiltration rate, specific ion effects and deficiencies of several nutrients such as K, Cu, Fe, Mn and Zn (Sumner 1993; Naidu and Rengasamy 1993; Qadir and Schubert 2002). In Punjab (Pakistan), fertilizer nutrients (N, P, K, Zn, Cu, Fe, Mn, B, etc.) are removed by plants at rates higher than their addition resulting negative nutrient balance and leading to mining soil fertility. It is estimated that by the end of 2014–2015, depletion of soil fertility will be very critical unless proper measures are not adopted (Ghafoor et al. 2002). This situation is further aggravated in most of the tube well irrigated soils since an increase in soil sodicity will decrease absorption and bio-assimilation even nutrients are present in soils. Today this fact is reflected by stagnant crop yields, and the crop yields might start decreasing in future.

Murtaza et al. (2006) carried out a 3-year field study in the Indus plains of Pakistan to evaluate different irrigation and soil management strategies for using saline-sodic water to grow cotton and wheat on a sandy loam soil (EC_e = 1.31–1.76 dS m^{-1},

pH_s = 8.47–8.61, SAR = 5.50–7.41, infiltration rate = 0.6–0.8 cm h^{-1}, BD = 1.56–1.61 Mg m^{-3}). The treatments were (1) irrigation with freshwater from a nearby canal (FW); (2) irrigation with saline-sodic water (EC = 3.32 dS m^{-1}, SAR = 16.29, SAR_{adj} = 18.24, RSC = 5.25 meq L^{-1}) (SSW); (3) cyclic use of fresh and saline-sodic water through alternate irrigations (FW − SSW); (4) soil application of farm manure at 25 Mg ha^{-1} $year^{-1}$ and irrigation with saline-sodic water (FM + SSW); and (5) soil application of gypsum equivalent to gypsum requirement of saline-sodic water and irrigation with the same water (G + SSW). An increase in SAR was recorded with the use of saline-sodic water alone while decreased with cyclic use of fresh water. The most appropriate management practice for saline-sodic water irrigation was soil-applied gypsum equivalent to RSC of water to each crop. Gypsum application sustained high electrolyte concentration dominated by Ca^{2+} ions to favour infiltration rate and salt leaching. The relatively high soil SAR after wheat harvest could be explained on the basis of increased salt accumulation which caused precipitation of $CaCO_3$ and $CaSO_4$ like salts leading to high Na^+ concentration and thus SAR.

The coarse texture of soil promoted accumulation of incoming Na^+ at lower soil depths. It appears that for high SAR and/or RSC waters, addition of farm manure alone might not be as effective as gypsum. Farm manure does favour plant growth through the supply of additional nutrients, improves physical properties of soils, increases cation exchange capacity to affect dilution of adsorbed ions, and helps increase dissolution of native soil calcite to mobilize soluble Ca^{2+} to forward reclamation of sodic and saline-sodic soils. Decrease in soil SAR with time using canal water for leaching results owing to in situ mineral weathering (Rhoades et al. 1968, Oster and Shainberg 1979), supply of Ca^{2+} + Mg^{2+} in irrigation water (Ghafoor 1999), valence dilution (Eaton and Sokoloff 1935) and the action of plant roots (Qadir and Oster 2002, 2004).

19.4.2 Relationship Between IR and BD with Soil EC and SAR

An increased IR was reported by Murtaza et al. (2006) with increasing EC_e, while BD decreased. The response of IR and BD was different with increasing sodicity. Infiltration rate decreased, while bulk density increased with an increase in soil sodicity. However, the "r" values for EC_e relationship between IR or BD and that of SAR with IR or BD remained statistically similar owing to narrow range of EC_e and soil SAR values as well as relatively coarse texture of soil under investigation. In this study, SSW [EC 3.32 dS m^{-1}, RSC 5.25 meq L^{-1}, SAR 16.29 and SAR_{adj} 18.24 (mmoles L^{-1})$^{0.5}$] irrigation caused little damage to soil due to sodicity because the EC of irrigation water was high enough to counter the dispersion effects induced by water sodicity (Oster and Schroer 1979). The improvement in soil IR could be of relatively coarse texture dominated by illite-type clays (Anonymous 1986). It was concluded that IR decreased with increasing SAR and with decreasing total cation concentration (Oster and Schroer 1979). The results suggested that total cation concentration is a better parameter for the prediction of IR than SAR.

Table 19.1 Salt leaching efficiency (kg m^{-3} water) during reclamation of saline-sodic soils

	Site 1		Site 2	
Treatment/site	0–0.15 m	0.15–0.30 m	0–0.15 m	0.15–0.30 m
SSW	1.35	0.77	0.24	0.24
FW	1.10	0.71	0.24	0.33
G + SSW	1.23	0.60	0.35	0.33
G + 1SSW + 1FW	1.26	0.53	0.32	0.41
G + 2SSW + 1FW	1.18	0.47	0.28	0.33
FM + 1SSW + 1FW	1.40	0.76	0.60	0.33
FM + 2SSW + 1FW	1.40	0.78	0.43	0.31

SSW saline-sodic water, *FW* fresh water, *G* gypsum, *FM* farm manure

Table 19.2 Salt leaching efficiency (kg m^{-3} water) during reclamation for rice and wheat crops

	Site 1		Site 2	
Crop/site	0–0.15 m	0.15–0.30 m	0–0.15 m	0.15–0.30 m
Post-rice 2005	2.92	1.24	0.75	0.75
Post-wheat 2005–2006	1.93	0.98	0.28	1.40
Post-rice 2006	1.50	0.78	0.44	0.40
Post-wheat 2006–2007	1.28	0.66	0.35	0.51

19.4.3 Salt Leaching Efficiency

The leaching efficiency of different treatments was compared by Murtaza et al. (2009) on two different sites (Table 19.1). It was obvious from the results that farm manure (FM) application with alternate irrigation of saline-sodic water (SSW) and FW proved better probably due to favourable effects of FM on physical properties of soils. The salt leaching efficiency decreased over time at both sites, being the highest after the first rice crop of 2005 (Table 19.2), and decreased consistently with time at both sites. This pattern shows that presence of salts (high EC) at the beginning of studies helped to achieve high salt leaching efficiency through favourable and sustainable effects on water-conducting properties of both soils. However, again the leaching efficiency remained higher at both depths of site 1 soil than that of site 2, mostly because of tile drainage provision at site 1. At both sites, the salt leaching efficiency was found higher after rice compared to that after wheat probably owing to high drainable surplus during rice (Zia et al. 2006, 2007) since rice fields were mostly kept submerged. Gharaibeh et al. (2009) recorded greater leaching of Na^+ and total soluble salts at the beginning of experiment, and the effectiveness of treatments decreased subsequently during soil reclamation using gypsum and calcium chloride.

Ghafoor et al. (2012) carried out a 3-year field experiment in the Indus plains of Pakistan on salt-affected soil (EC_e 15.67–23.96 dS m^{-1}, pH_s 8.35–8.93, SAR

Table 19.3 Salt leaching efficiency (kg m^{-3} water) by treatments over the entire experiment period

	Depth (m)	
Treatment	0–0.15	0.15–0.30
Control	0.34	0.36
SM	0.55	0.59
SGR	0.61	0.48
GSM	0.73	0.67

Table 19.4 Salt leaching efficiency (kg m^{-3} water) during reclamation for rice and wheat crops

Crop	0–0.15 m soil depth	0.15–0.30 m soil depth
Post-rice 2001	1.87	1.48
Post-wheat 2001–2002	0.83	1.16
Post-rice 2002	0.90	0.84
Post-wheat 2002–2003	0.78	0.74
Post-rice 2004	0.66	0.60
Post-wheat 2003–2004	0.56	0.53

70–120, IR 0.72–0.78 cm h^{-1}, BD 1.70–1.80 Mg m^{-3}) having tile drainage in place. The 3-year cropping sequence consisted of rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) crops in rotation. These crops were irrigated with groundwater having EC 2.7 dS m^{-1}, SAR 8.0 (mmol $L^{-1})^{0.5}$ and RSC 1.3 meq L^{-1}. Treatments were (1) irrigation with brackish water without amendment (control), (2) Sesbania (*Sesbania aculeata*) green manure each year before rice (SM), (3) applied gypsum at 100% soil gypsum requirement (SGR) and (4) applied gypsum as in treatment 3 plus Sesbania green manure each year (GSM). It was concluded that salt leaching efficiency of treatments was much higher compared to that with the control at both soil depths but was generally higher at upper than that at the lower soil depth (Table 19.3). This seems the result of tile drainage installed in 1991 in the experiment area with a designed drainage coefficient of 0.3 (Bhutta 1990). At 0.15 m soil depth, treatments ranked for leaching efficiency in the decreasing order of gypsum + Sesbania green manure (GSM) > gypsum at 100% soil gypsum requirement (SGR) > Sesbania green manure (SM) > control, while order was GSM > SM > SGR > control at 0.15–0.30 m depth. It is obvious that GSM treatment proved better probably due to favourable effects of gypsum and Sesbania on physical and chemical properties of soils (Qadir et al. 1996; Ahmad 2002). The salt leaching efficiency decreased over time at both depths, being the highest after the first rice crop of 2001 (Table 19.4). This pattern shows that presence of salts (high EC) at the beginning of experiment helped to achieve high salt leaching efficiency of treatment which decreased as the salts in source decreased. Further improved IR with time due to treatments and crop root activities enhanced water infiltration including pore bypass which decreased the salt leaching efficiency.

19.4.4 Leaching Fraction

The downward flow of water, carrying excess soluble salts and Na^+ through soils, is essential for successful reclamation of saline-sodic soils. The leachate volume is a key factor for the movement of salts within and out of soils. Soil texture, pore volume (PV) and indirectly leaching fraction (LF) are important to amelioration process. Kahlon (2011) conducted pot experiment in which different pore volumes of water were added to evaluate the leaching response of different textured soils. For leaching cycles, tap water having EC = 0.89 dS m^{-1}, SAR = 1.55 and RSC = 1.02 meq L^{-1} was applied. Treatments were T_1 = 1.0 PV (application of 1.0 PV water), T_2 = 1.5 PV (application of 1.5 PV water), T_3 = 2.0 PV (application of 2.0 PV water) and T_4 = 2.5 PV (application of 2.5 PV water). The highest amount of salts was removed from sandy clay loam soil (SCL), (1,943 kg ha^{-1}) with LF 0.59 with the application of four PV water. The decreasing order of treatment effectiveness for salt removal was $T_3 > T_2 > T_4 > T_1$ with LF 0.69, 0.64, 0.61 and 0.60, respectively. The EC_e of 0–25 cm columns (post-experiment) decreased from 8.2 to <4 dS m^{-1} in loamy sand (LS) with 2.0 PV (1.88 cm); from 33.9 to < 4 dS m^{-1} in SCL with 2.5 PV (2.67 cm) of applied water and silty clay loam (SiCL) with 2.5 PV (2.72 cm) of water, it decreased from 23.9 to <4 dS m^{-1} only of 0–10 cm of soil layer. Regarding SAR, 2.5 PV of applied water decreased SAR to <13 in LS up to 0–20 cm depth, 0–10 cm soil depth of SiCL and 0–15 cm soil depth of SCL. It was found that leaching of soluble salts does occur with simple addition of water of any quality in different textured saline-sodic soils but could convert these into sodic soils if external source of Ca^{2+} is not added.

19.4.5 Amount of Salts Removed

Highest salt removal (kg ha^{-1}) was with T_3 followed by T_2, T_4 and T_1 with values as 1,913, 1,622, 1,605 and 1,157. Salt removal was higher in L_1 followed by L_2, L_3 and L_4 having values as 2,417, 1,806, 1,230 and 885 kg ha^{-1}. In general, it was concluded that after application of four irrigations of different PV, highest LF (0.75) for LS removed 1,375 kg ha^{-1} salts. After application of four irrigations of different PV with T_2, T_3, T_4 and T_1, having LF of 0.69, 0.64, 0.61 and 0.60 could remove 1,622, 1,913, 1,605 and 1,157 kg ha^{-1} salts, respectively. It was also observed that salt removal was the highest with first two irrigations and then decreased subsequently, and consequently, the salt removal was high in initial leachates which decreased progressively with time for all soils and treatments. Coarse textured soils (LS) have relatively low total porosity but possess mostly macropore that is why higher volume of leachate and thus salt removal occurred. While fine-textured soil (SiCL) contain relatively high total pore space, mainly micropores which remained filled with water for a considerable period of time, so relatively less salt removal was observed (Mostafazadeh et al. 2008).

19.4.6 Plant Growth Response Under Salt-Stressed Soils

19.4.6.1 Rice

It is generally considered that the rice is relatively better tolerant to SAR than EC_e. A slightly elevated SAR (30–35) is considered an asset as this will decrease water percolation which would help maintain submergence throughout the growth period (Ghafoor et al. 1997, 2002) that is an ecological requirement for good rice production in this region (Ghafoor et al. 2004). Submergence helps suppress weeds, which would affect better utilization of production inputs. It has been reported that 50 % reduction in paddy yield is affected at SAR 60 and crop fails at SAR ≈ 80 (Bresler et al. 1982; Ayers and Westcot 1985). A relatively higher yield was found with farm manure and gypsum-treated plots receiving cyclic irrigation of fresh and saline-sodic water that may be attributed to their favourable effects on soil physical and chemical properties, particularly in a favourable Ca^{2+}:Na^{+} ratios in soil solution (Murtaza et al. 2009).

19.4.6.2 Wheat

Wheat is a common winter crop in the Indus plains of Pakistan and is preferred by the farmers on normal soils as well as during reclamation of salt-affected soils. Gypsum application with or without green manuring resulted in better wheat yield than that of rice (Ghafoor et al. 2008). The infiltration rate with these two treatments increased to a greater extent, which was an appropriate condition for the growth of wheat but not for rice. There was a maximum grain yield of wheat with FM with cyclic use of fresh and saline-sodic waters (Murtaza et al. 2009). Although, rice proved a better crop for soil reclamation, wheat produced better grain yield than that of rice which could be attributed to different genetic makeup of these crops. Gypsum and farm manure improved soil infiltration which was more beneficial for wheat than that for rice. It is safe to conclude that gypsum-based treatments are essential for crops and soil reclamation even if poor-quality water is used for irrigation. After achieving a near steady state, soils and crops will need irrigation with better quality water to sustain effects of reclamation.

19.4.7 Economic Output of Different Amendments Under Salt-Stressed Soils

Agriculture on stress-land is generally discouraged because of the initial cost of soil and/or water treatment. In the present studies, economics of treatments was computed using the market prices of common and variable inputs while support prices of paddy and wheat grain. Several scientists have evaluated economics of treatments mainly on the basis of rice and wheat crops grown during reclamation of soil (Murtaza et al. 2009). Maximum net benefit was obtained from gypsum-based treatments even with the irrigation of low-quality irrigation water. These benefits continue to become further favourable with time. Generally, more income have been received from wheat than that from rice since paddy yield of first rice crop is low due to high EC_e and SAR at the start of studies. However, mostly cost of inputs used in these studies were recovered from first 2–3 crops of wheat and rice. In addition, the indirect benefits of soil reclamation include appreciation in land value, increased farm employment and an increase in food production.

19.5 Conclusions

Considering pH_s, EC_e and SAR, gypsum with or without farm manure affected better and faster amelioration. Medium-textured soils, waters with SAR and RSC higher than the critical levels of 10 (mmoles $L^{-1})^{0.5}$ and 2.5 $mmol_c\ L^{-1}$, respectively, could enhance reclamation of saline-sodic soils following rice-wheat crop rotation if it is used in cyclic fashion. However, there seems strong possibility that salination and sodication may reoccur, if irrigation with low quality waters is continued, particularly under arid climate for which gypsum has to be added again. Rice proved a better crop for soil reclamation, while wheat gave better yields and thus increased net benefit to farmers. It was found that leaching of soluble salts does occur with simple addition of water of any quality in different textured saline-sodic soils but could convert these into sodic soils if external source of Ca^{2+} is not added. The relationship between PV of applied water and amount of salts leached from soil columns indicated a positive effect on amount of salt leached. It is concluded that there is a decrease in salt leaching efficiency over time, being the highest after the first rice crop in tile-drained fields under the agro-climatic conditions of the central Punjab, Pakistan.

References

Ahmad S (2002) Effectiveness of biological, chemical and bio-cum-chemical amelioration strategies for calcareous saline-sodic soils. Ph.D. thesis, Department of Soil Science, University of Agriculture, Faisalabad, Pakistan

Al-Nabulsi YA (2001) Saline drainage water, irrigation frequency and crop species effects on some physical properties of soils. J Agron Crop Sci 186:15–20

Anonymous (1986) Profile descriptions, analytical data and on site discussions. In: Ahmad M, Akram M, Baig MS, Javed MY, Amin R (eds) Proceedings of the XII International Forum on Soil Taxonomy and Agrotechnology Transfer, Lahore, Pakistan, pp 66–250

Anonymous (2007) Pakistan statistics year book. Federal Bureau of Statistics, Statistical Division, Government of Pakistan, Islamabad, Pakistan

Ayers RS, Westcot DW (1985) Water quality for agriculture. Irrigation and Drainage paper 29. Food and Agriculture Organization, Rome

Bhutta MN (1990) Effect of varying discharges on the equity of water distribution in the irrigation system. PhD thesis, University of Engineering and Technology, Lahore, Pakistan

Bresler E, McNeal BL, Carter DL (1982) Saline and sodic soils: principles – dynamics – modelling. Springer, New York, pp 1–77

Curtin D, Naidu R (1998) Fertility constraints to plant production. In: Sumner ME, Naidu R (eds) Sodic soil: distribution, management and environmental consequences. Oxford University Press, New York, pp 107–123

Eaton FM, Sokoloff VP (1935) Adsorbed sodium in soils as affected by soil to water ratio. Soil Sci 40:237–247

Ghafoor A (1999) Concentration of Ca^{2+} in irrigation water for reclaiming saline-sodic soils. Pak J Agric Sci 36:145–148

Ghafoor A, Chaudhry MR, Qadir M, Murtaza G, Ahmad HR (1997) Use of drainage water for crops on normal and salt-affected soils without disturbing biosphere equilibrium. International Waterlogging and Salinity Research Institute (IWASRI). Publication no. 176. IWASRI, Lahore, Pakistan

Ghafoor A, Qadir M, Murtaza G (2002) Agriculture in the Indus Plains: sustainability of land and water resources. Int J Agric Biol 4:429–437

Ghafoor A, Qadir M, Murtaza G (2004) Salt-affected soils: principles of management. Allied Book Centre, Urdu Bazar, Lahore, Pakistan

Ghafoor A, Murtaza G, Ahmad B, Boers TM (2008) Evaluation of amelioration treatments and economic aspects of using saline-sodic water for rice and wheat production on salt-affected soils under arid land conditions. Irrig Drain 57:424–434

Ghafoor A, Murtaza G, Rehman MZ, Saifullah, Sabir M (2012) Reclamation and salt leaching efficiency of treatments for tile drained saline-sodic soil using marginal quality water for irrigating rice and wheat crops. Land Degrad Dev 23:1–9

Gharaibeh MA, Eltaif NI, Shunnar OF (2009) Leaching and reclamation of calcareous saline-sodic soil by moderately saline and moderate-SAR water using gypsum and calcium chloride. J Plant Nutr Soil Sci 172:713–719

Grattan SR, Grieve CM (1999) Salinity-mineral nutrient relations in horticultural crops. Sci Hortic 78:127–157

Gupta RK, Abrol IP (1990) Salt-affected soils: their reclamation and management for crop production. Adv Soil Sci 11:223–288

Hamza MA, Anderson WK (2002) Improving soil physical fertility and crop yield on a clay soil in Western Australia. Aust J Agric Res 53:615–620

Hassan W (2004) Effectiveness of application rate of Ca^{2+} for the reclamation of different textured saline-sodic soils. MSc (Hons) thesis. Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan

Hillel D (2000) Salinity management for sustainable irrigation: integrating science, environment, and economics. The World Bank, Washington, DC, p 92

Jury WA, Gardener WR, Gardener WH (1991) Soil physics, 5th edn. Wiley, New York

Kahlon UZ (2011) Effects of amendments and irrigation water composition on salt leaching from different textured soils and amelioration of saline-sodic soils for crop production. PhD thesis, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan

Lal R (2001) Potential of desertification control to sequester carbon and mitigate the greenhouse effect. Clim Change 51:35–72

Maas EV, Hoffman GJ (1977) Crop salt tolerance: current assessment. J Irrig Drain Div 103:115–134

Mostafazadeh BF, Heidarpour M, Aghakhani A, Feizi M (2008) Effects of leaching on soil desalinization for wheat crop in arid region. Plant Soil Environ 54:20–29

Muhammed S, McNeal BL, Bower CA, Pratt PF (1969) Modification of high salt water method for reclaiming sodic soils. Soil Sci 108:249–256

Murtaza G, Ghafoor A, Qadir M (2006) Irrigation and soil management strategies for using saline-sodic water in a cotton-wheat rotation. Agric Water Manage 81:98–114

Murtaza G, Ghafoor A, Owens G, Qadir M, Kahlon UZ (2009) Environmental and economic benefits of saline-sodic soil reclamation using low-quality water and soil amendments in conjunction with a rice-wheat cropping system. J Agron Crop Sci 195:124–136
Naidu R, Rengasamy P (1993) Ion interactions and constraints to plant nutrition in Australian sodic soils. Aust J Soil Res 31:801–819
Oster JD, Grattan SR (2002) Drainage water reuse. Irrig Drain Sys 16:297–310
Oster JD, Schroer FW (1979) Infiltration as influenced by irrigation water quality. Soil Sci Soc Am J 43:444–447
Oster JD, Shainberg I (1979) Exchangeable cation hydrolysis and soil weathering as affected by exchangeable sodium. Soil Sci Soc Am J 43:70–75
Page AL, Miller RH, Keeney DR (1982) Methods of soil analysis. Part II. ASA Monograph 9. ASA, Madison
Qadir M, Oster JD (2002) Vegetative bioremediation of calcareous sodic soils: history, mechanisms, and evaluation. Irrig Sci 21:91–101
Qadir M, Oster JD (2004) Crop and irrigation management strategies for saline-sodic soils and waters aimed at environmentally sustainable agriculture. Sci Total Environ 323:1–19
Qadir M, Schubert S (2002) Degradation processes and nutrient constraints in sodic soils. Land Deg Dev 13:275–294
Qadir M, Ghafoor A, Murtaza G (2001) Use of saline-sodic waters through phytoremediation of calcareous saline-sodic soils. Agric Water Manage 50:197–210
Qadir M, Qureshi RH, Ahmad N, Ilyas M (1996) Salt-tolerant forage cultivation on a saline-sodic field for biomass production and soil reclamation. Land Deg Dev 7:11–18
Qadir M, Sharma BR, Bruggeman A, Choukr-Allah R, Karajeh F (2007) Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. Agric Water Manage 87:2–22
Quirk JP, Schofield RK (1955) The effect of electrolyte concentration on soil permeability. J Soil Sci 6:163–178
Ranjha AM, Mehdi SM, Qureshi RH (1993) Clay mineralogy of some selected alluvial soils of Indus Plains. Pak J Soil Sci 8:3–7
Rhoades JD, Krueger DB, Reed MJ (1968) The effect of soil mineral weathering on the sodium hazard of irrigation waters. Soil Sci Soc Am Proc 32:643–647
Shahid SA, Jenkins DA (1992) Micromorphology of surface and subsurface sealing and crusting in the soils of Pakistan. In: Vlotman WF (ed) Proceedings of 5th international drainage workshop, 8–15 Feb 1992, Lahore, Pakistan, vol 2, pp 1.77–1.89
Shainberg I, Letey J (1984) Response of soils to sodic and saline conditions. Hilgardia 52:1–57
Singh NT (2005) Irrigation and soil salinity in the Indian subcontinent: past and present. Lehigh University Press, Bethlehem
Suarez DL (1981) Relation between pH_c and sodium adsorption ratio (SAR) and an alternative method of estimating SAR of soil or drainage waters. Soil Sci Soc Am J 45:469–475
Sumner ME (1993) Sodic soils: new perspectives. Aust J Soil Res 31:683–750
Szabolcs I (1994) Soils and salinization. In: Pessarakli M (ed) Handbook of plant and crop stress, 1st edn. Marcel Dekker Inc., New York, pp 3–11
US Salinity Laboratory Staff (1954) Diagnosis and improvement of saline and alkali soils, USDA handbook 60. US Salinity Laboratory Staff, Washington, DC
Wallace JS (2000) Increasing agricultural water use efficiency to meet future food production. Agric Ecosyst Environ 82:105–119
Zia MH, Ghafoor A, Murtaza G, Saifullah BSMA (2006) Growth response of rice and wheat crops during reclamation of saline-sodic soils. Pak J Bot 38:249–266
Zia MH, Saifullah SM, Ghafoor A, Murtaza G (2007) Effectiveness of sulphuric acid and gypsum for the reclamation of a calcareous saline-sodic soil under four crop rotations. J Agron Crop Sci 193:262–269

Chapter 20
Reclamation of Degraded Vertisols Under Cassava in Arid Environments of India

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Abstract A major portion of the area under cassava in India is under irrigated Vertisols, and the farmers face a number of soil-related constraints which significantly reduce the tuberous root yield of cassava. In order to reclaim these arid lands and to increase the yield and profitability of farmers, farmer-friendly technologies have been developed based on field experiments conducted during the past 7 years since 2003. Three different on-farm experiments were conducted to study these problems and to develop a sustainable reclamation strategy. Major components of the technology include adoption of deep tillage with a chisel plough, application of neem cake, application of biofertilizers such as N fixer, P-solubilizing bacteria and AM fungi and biocontrol agents like *Trichoderma* and *Pseudomonas*. Besides this, a balanced fertilization schedule based on site-specific nutrient management (SSNM) approach have also been developed to address the problems due to imbalance in nutrient applications by farmers in those arid environments. Studies have shown that these technologies have resulted in significant increase in tuberous root yield and income of farmers besides improving soil health and soil quality.

Keywords Arid • Biofertilizer • Cassava • India • Tillage

20.1 Introduction

Cassava (*Manihot esculenta* Crantz), one of the most important tropical root crops, yields an energy of 250,000 cal ha^{-1} day^{-1} compared to maize (200,000 cal ha^{-1} day^{-1}), rice (176,000 cal ha^{-1} day^{-1}) or wheat (110,000 cal ha^{-1} day^{-1}).

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Cassava is the most important root crop and fourth most important source of food calories in the tropics, which is a staple for more than 800×10^6 people. In India, cassava is consumed as a secondary staple along with the staple, rice, and many rural poor consume it as the staple in different forms of preparations. Approximately 300,000 t of sago and starch are also manufactured from cassava roots by nearly 1,200 factories. Cassava adapts well to very poor soil, and since it is grown mostly by resource poor farmers with little or no inputs, the soils growing cassava get degraded (Byju and Anand 2009a, b; Haripriya and Byju 2008). Cassava is grown mostly in Vertisols (cracking clay soils) in Tamil Nadu state, India, in poorly managed fields that has resulted in degradation of the land leading to problems such as reduced yield, incidence of root rot caused by the soil-borne fungus *Phytophthora palmivora*, very poor soil fertility and soil physical conditions and many other related problems such as iron chlorosis (Byju et al. 2006, 2008a, b).

These Vertisols are subject to frequent tractor traffic associated with soil tillage and land preparation for planting the stakes. The annual rainfall in these regions is very low, usually about 600 mm. In highly mechanized cassava cultivation, the number of tractor passes per year can be up to six, and this has resulted in the development of a subsurface hard layer which affects water and solute salt movement. Top soil and subsoil compaction by tractor traffic influences many soil properties which control crop production and quality of the environment.

Of late, root rot infection caused by *Phytophthora palmivora* has been observed in very serious proportions in cassava in these regions, and crop loss to the tune of 60–80% is reported from many farms. This has resulted in significant yield losses to the poor cassava farmers, affecting their livelihood security, and employment opportunities are at stake. Detailed surveys conducted indicated that the soils are highly degraded and the farmers apply fertilizers in a highly imbalanced way resulting in various soil fertility problems and yield losses. The Central Tuber Crops Research Institute (CTCRI), India, conducted field studies to reclaim the degraded Vertisols under cassava and to recommend remedial measures for the soil-related problems in these regions.

20.2 Materials and Methods

Three different on-farm experiments were conducted in degraded Vertisols at Salem, Tamil Nadu, India, during 2003–2009 (11.39° N latitude; 78.12° E longitude; 180 m above mean sea level). The fields had been under continuous cassava cultivation for the past 10 years. The climate of the region is described as semiarid tropics. Initial soil samples were collected before the start of the experiments and were analysed for important soil physico-chemical characteristics. On-farm experiments were conducted in farmers' fields where root rot infection was found to be very serious resulting in yield loss of about 75%.

20.2.1 Effect of Tillage and Land Preparation on Cassava Root Rot in Vertisols

The on-farm experiment was laid out in randomized complete block design (RCBD) with five treatments and four replicates per treatment. The experiments included the following treatments: chisel ploughing and flat bed method of planting, chisel ploughing and ridge and furrow method of planting, disc ploughing and flat bed method of planting, disc ploughing and ridge and furrow method of planting and farmer's practice.

After the harvest of each crop, pits were dug to a depth of 60 cm in each plot and representative soil samples were collected from 0- to 20-cm, 20- to 40-cm and 40- to 60-cm layers. The samples collected from different depths were analysed for different physico-chemical parameters. Every year, the crop was harvested manually, and leaf, stem and tuberous root samples were collected separately from each plot for estimation of nutrient removal.

Analysis of variance was performed on different parameters studied to determine the effects of different treatments using SYSTAT software (Systat 1992). Least significant difference (LSD) test was used at 0.05 level of probability to test differences between treatment means. To compare the three different soil depths, continuous measures analysis of variance was done since the data are not independent but related.

20.2.2 Biofertilizers and Biocontrol Agents for Managing Degraded Vertisols Under Cassava

On-farm experiment was conducted in Tamil Nadu, India, to study the effect of three biofertilizers (N fixer, P-solubilizing bacteria and AM fungi) and two biocontrol agents (*Trichoderma* and *Pseudomonas*) on the incidence of root rot, cassava root yield and soil quality (Byju et al. 2008a). The split plot layout of the experiment included two levels of NPK fertilizers in main plots and nine treatments of biofertilizers/biocontrol agents. Soil samples were analysed for various parameters to study soil quality. Plant samples were also analysed to estimate nutrient removal.

20.2.3 Balanced Fertilization by Site-Specific Nutrient Management

In order to develop more knowledge-intensive balanced fertilization strategy for cassava using the model QUEFTS (Janssen et al. 1990), on-farm experiments were conducted in degraded Vertisols of Tamil Nadu. The experiment included five treatments and four replications and was laid out in randomized complete block design (RCBD). The treatments included absolute control (0 kg N, P and K), nitrogen omission plot, phosphorus omission plot, potassium omission plot and farmers' fertilizer practice (FFP) plot. Tuberous root yields were obtained at harvestable maturity, and yields are reported. Plant N, P and K accumulation in kg ha^{-1} were then estimated using the concentrations of the respective nutrient as determined on a subsample taken at harvestable maturity.

The following five steps were involved in modifying the model in order to adapt and test the QUEFTS model for cassava. The steps 3 and 4 of the QUEFTS model dealing with the relationship between tuberous root yield and nutrient accumulation in total plant dry matter were modified:

(a) Suitable data that fulfil the boundary conditions of the model were selected.
(b) The borderlines describing the maximum and minimum accumulation of N, P and K were fixed, and their sensitivity to different criteria of data selection was studied.
(c) The intercepts that define the minimum amount of nutrient removal that is needed to produce any measurable root yield, needed or not, were studied.
(d) The curves that simulate the optimum uptake requirements of N, P and K at different Y_{max} (YN, YP, YK) were developed.
(e) The simulated optimal internal efficiencies of NPK were compared in farmers' fields.

A fixed effects model was used to analyse the on-farm data because the sampling locations were not selected truly randomly. All effects, except village, were tested against the residual. Village effect was tested against farm within village as error term.

20.3 Results and Discussion

20.3.1 Effect of Tillage and Land Preparation on Soil Properties and Cassava Root Rot in Vertisols

The soils are slightly alkaline in reaction with a pH of 7.8 in 0–20-cm surface layer, which increased with depth up to 8.5 (strongly alkaline) at 100–120-cm depth. The organic carbon content of the surface soil (0–20 cm) was 0.62%, which decreased to 0.54 and 0.51% in 20–40-cm and 40–60-cm layers, respectively. In 60–80-cm and 80–100-cm layers, the organic carbon contents were 0.44 and 0.38%, respectively. At 100–120-cm depth, the organic carbon content was only 0.28%. The $KMnO_4$–N (available N) content in the surface layer was 54.60 kg ha^{-1}, and the NH_4OAc–K (exchangeable K) content in the surface layer was 247.15 kg ha^{-1}. The available N and exchangeable K contents decreased with depth, but the absolute values of exchangeable K, even in the lower layers, were substantial. Soil textural analysis indicated the predominance of 'clay' fraction, and all the layers had a clay texture according to the USDA classification (Buol et al. 1980). In 80–100-cm and 100–120-cm layers, the clay content was found to be high and was more than 70%, and sand and silt fractions were very low.

The available N content in the surface layer was low and exchangeable K high according to fertility rating followed in India. The substantial amount of available K even in the lower soil layers is due to the illitic (micaceous) clay mineralogy of the soil series (Savithri and Santhy 2001).

Tillage and methods of planting significantly increased soil organic carbon (SOC) concentrations compared to farmer's practice in 0–20-cm soil layer, but the four treatments did not show any significant difference. In 20–40-cm and 40–60-cm layers, chisel ploughing and flat bed method of planting and chisel ploughing and ridge and furrow method of planting significantly increased SOC compared to other three treatments. For all the treatments, the SOC decreased significantly with depth, but the absolute values were high even in the 40–60-cm layers.

The results indicated that mechanical manipulation of the plough layer and breaking the hard plough pan below it resulted in significant increase in the movement of SOC and total nitrogen. Deep ploughing with chisel plough resulted in the redistribution of SOC and total nitrogen to the lower soil layers. Redistribution of SOC is advantageous to cassava cultivation whose nutrient- and water-absorbing roots are reported to go as deep as 140 cm within the soil (Fageria et al. 1991). Since cassava is grown in this region mostly as an irrigated crop, this will definitely improve the drainage conditions since the farmers used to apply good amount of irrigation water especially during the last few months, when there is a dry spell.

There was a significant decrease in bulk density of the 0–20-cm layer when deep ploughing with a chisel plough was done. There was no significant difference in the bulk density of 0–20-cm layer between the treatments, 'farmer's practice' and 'disc ploughing'. Similar results were observed for 20–40-cm layer also, while there was no significant difference in bulk density of 40–60-cm soil layer due to different treatments. In all the treatments, significantly higher bulk density was noted in the 20–40-cm layer compared to upper (0–20-cm) or lower (40–60-cm) layers.

There was significant difference in porosity of different soil layers due to treatments. When chisel ploughing along with ridge and furrow method of planting was practised, the porosity in all the soil layers increased significantly compared to corresponding soil layers in other treatments. The porosity of 0–20-cm layer was significantly lower in farmer's practice compared to all other treatments. At 40–60-cm layer, there was no significant difference in porosity when disc ploughing and farmer's practice were adopted, while it increased significantly when chisel ploughing was done.

Chisel ploughing significantly increased the soil water content in all the soil layers. Lowest value was observed in farmer's practice. In plots where chisel ploughing was done, the water content in 20–40-cm layer was significantly lower compared to the water content in respective layers of other treatments.

Significant reduction in bulk density and increase in soil porosity by chisel ploughing result in energy conservation, soil erosion reduction and increased soil water storage (Barzegar et al. 2003; Yadav and Vyas 2006). Lower bulk density and higher porosity of soils observed in areas where chisel ploughing was done could have been due to pulverization and loosening of the soil (Al-Tahan et al. 1992).

Results of volumetric water content indicated a more uniform distribution of water in different soil layers where chisel ploughing was done, while in all other treatments, significantly higher values were observed in 20–40-cm layer where the plough-pan layer existed. Chisel ploughing resulted in the breakage of the plough-pan layer, thereby the downward movement of water was found to be more. A significant positive correlation between root rot incidence and soil moisture at 20–40-cm layer was reported by CTCRI (2005). Deep ploughing or ripping has been reported as an important practice for eliminating soil compaction, destroying hard pans and ameliorating hard setting soils (Jarvis et al. 1986; Hall et al. 1994; Hamza and Anderson 2005).

The movement of available nitrogen and potassium to the subsoil layers under the influence of different tillage and planting methods is given in Table 20.1. The $KMnO_4$–N in 0–20-cm layer was significantly higher in plots where chisel ploughing was done compared to all other treatments. There was no significant difference in $KMnO_4$–N between the treatments, 'farmer's practice' and 'disc ploughing'. In 20–40 and 40–60-cm layers also, the $KMnO_4$–N was significantly higher when deep ripping was done with chisel plough. The $KMnO_4$–N contents in other treatments were on par.

The NH_4OAc–K in 0–20-cm layer was also significantly higher in plots where chisel ploughing was practised. The K contents in 0–20-cm layer in the treatments, 'farmer's practice' as well as 'chisel ploughing' were found to be on par. The NH_4OAc–K content in 20–40-cm layer was also significantly higher where chisel ploughing was done. Disc ploughing also resulted in significantly higher NH_4OAc–K compared to farmer's practice. In 40–60-cm layer, significantly higher K content was noted in soils where chisel ploughing along with ridge and furrow method of planting was adopted.

The $KMnO_4$–N and NH_4OAc–K in different soil layers indicate that mechanical manipulation of the plough-pan layer by deep ripping resulted in relatively uniform distribution of these available nutrients to the lower soil layers up to 60 cm. Deep ripping redistributed surface accumulation of plant-available nitrogen and potassium. Under farmer's practice and where disc ploughing was done, the $KMnO_4$–N declined with depth, while it showed a slight increase, though insignificant, in 20–40-cm layer when chisel ploughing was done. Deep ploughing could enhance leaching of nitrate through the profile (Randall and Iragavarappa 1995).

The influence of different tillage and planting methods on cassava root yield, root rot infection and uptake of N and K is given in Table 20.2. The root yield was significantly higher for the treatment 'chisel ploughing along with ridge and furrow method of planting' (38.67 t ha^{-1}). The root yield was lowest in plots where 'farmer's practice' was adopted. The root rot infection was significantly higher in farmer's practice as well as in those treatments where disc ploughing was done. In soils where deep ploughing with a chisel plough was done, a significant and substantial reduction in root rot infection could be observed. Whereas 73.54% of the total root yield was infected with root rot in the treatment, 'farmer's practice', it reduced to

Table 20.1 Effect of land management on movement of available nitrogen and potassium to subsoil layers

Treatment	$KMnO_4$–N (μg g^{-1}) 0–20 cm	20–40 cm	40–60 cm	LSD (0.05)	NH_4OAc–K (μg g^{-1}) 0–20 cm	20–40 cm	40–60 cm	LSD (0.05)
CP+FB	110.92	111.55	75.33	1.89	156.65	100.77	31.21	6.17
CP+RFM	111.22	117.79	78.79	2.88	157.40	101.27	37.76	7.81
DP+FB	105.33	86.62	71.90	4.14	103.40	51.17	28.97	5.85
DP+RFM	106.33	86.76	68.36	3.20	104.70	52.08	29.65	10.70
Farmer's practice	105.25	84.74	68.95	3.41	102.85	46.29	26.44	7.33
LSD (0.05)	1.94	2.48	3.03		5.18	3.27	1.27	

CP chisel ploughing, *DP* disc ploughing, *FB* flat bed method of planting, *RFM* ridge and furrow method of planting

Table 20.2 Effect of land management on cassava tuber yield (t ha^{-1}), tuber rot infection and nutrient uptake

Treatment	Yield (t ha^{-1})	Root rot incidence (%)	N uptake (kg ha^{-1})	K uptake (kg ha^{-1})
CP+FB	32.54	7.28	198.21	176.69
CP+RFM	38.67	5.02	213.44	185.33
DP+FB	26.89	67.57	179.62	164.47
DP+RFM	26.70	41.21	184.31	160.28
Farmer's practice	22.48	73.54	168.47	158.61
LSD (0.05)	1.61	4.41	13.04	8.72

CP chisel ploughing, *DP* disc ploughing, *FB* flat bed method of planting, *RFM* ridge and furrow method of planting

5.02% in plots where chisel ploughing along with ridge and furrow method of planting was adopted.

A similar trend was observed in the case of total uptake of nitrogen and potassium by the crop. Both N uptake and K uptake were significantly higher in plots where chisel ploughing along with ridge and furrow method of planting was practised. Significantly lower values of N and K uptake were observed in plots where the treatment 'farmer's practice' was adopted.

Significant reduction in the incidence of root in the treatment, chisel ploughing along with ridge and furrow method of planting is due to the decrease in bulk density, increased porosity and better NK mobility to deeper soil layers. The soil quality is greatly improved in this treatment, in terms of improved water movement to subsoil and increased nutrient mobility.

There was a more uniform distribution of the plant-available forms of N and K in the plots where chisel ploughing along with ridge and furrow method of planting was done which could have resulted in the absorption of more amount of these nutrients by the roots of cassava, more than 50% of which are concentrated in soil layer up to 60 cm (Fageria et al. 1991).

Table 20.3 Effect of different treatments on root yield and root rot incidence

Treatment	Root number (per plant)	Root yield (t ha^{-1})	Root rot (%)
Fertilizer			
Recommended level	8.64	40.50	2.10
50% Recommended level	8.98	39.00	1.85
LSD (0.05)	NS	NS	NS
Biocontrol agents and biofertilizers			
Control	8.16	32.55	18.15
Trichoderma	9.20	38.00	0.00
Pseudomonas	9.52	38.00	1.15
Azospirillum	9.39	43.55	0.95
AM fungi	8.63	42.55	0.18
PSB	8.47	36.05	0.00
All-soil	8.55	43.00	0.00
All-set treatment	8.58	38.55	0.00
LSD (0.05)	NS	2.05	3.14

LSD least significant difference at 5%, *NS* not significant, *PSB* P-solubilizing bacteria

20.3.2 Biofertilizers and Biocontrol Agents for Managing Degraded Vertisols Under Cassava

The soils of the experimental site are classified as clayey, smectitic, hyperthermic, udic and haplusterts according to soil taxonomy of USDA (Soil Survey Staff 2010). The soil is alkaline in reaction. The organic carbon and available nitrogen contents are very low. The available P status is medium and exchangeable K content is very high due to the illitic (micaceous) mineralogy of the clay minerals present in the soil. The contents of calcium and magnesium are found to be high according to the soil critical levels for cassava cultivation. These soils are calcareous because of the presence of high calcium carbonate equivalents increasing at subsurface layers. Among the micronutrient cations, zinc and manganese are found to be present at levels below the critical levels needed for optimum growth of cassava. Table 20.3 shows the effect of different treatments on cassava root yield and root rot incidence.

There was no significant difference in tuber number either due to different fertilizer levels or due to different treatments of biocontrol agents and biofertilizers. There was no significant difference in tuber yield between recommended level of NPK and 50% of the recommended level. At the same time, the treatments of biocontrol agents and biofertilizers significantly increased tuber yield of cassava compared to control where no microbial culture was applied. Application of *Trichoderma viride* along with *Azospirillum* or AM fungi resulted in significantly higher tuber yield compared to all other treatments which was on par with the application of all microbial cultures in soil. The fertilizer levels had no significant influence on tuber

Table 20.4 Soil enzymatic activity and microbial biomass as affected by different treatments at harvest

Treatment	Urease (μg NH_4–N g^{-1} soil 24 h^{-1})	Dehydrogenase (μg TPF g^{-1})	β-Glucosidase (μg PNP g^{-1})	MBC (mg C_{mic} kg^{-1})
Fertilizer				
Recommended level	642.83	71.47	38.82	3,058.20
50% Recommended level	621.15	69.18	36.25	2,982.20
LSD (0.05)	0.99	NS	1.85	NS
Biocontrol agents and biofertilizers				
Control	453.16	46.33	27.47	2,511.1
Trichoderma	672.33	73.15	33.72	2,932.6
Pseudomonas	725.32	76.59	39.79	3,122.8
Azospirillum	797.58	77.84	37.19	3,065.8
AM fungi	585.63	80.90	44.98	3,665.7
PSB	584.37	52.19	45.55	3,136.8
All-soil	695.78	82.86	49.99	3,716.0
All-set treatment	621.75	71.53	40.18	2,615.3
LSD (0.05)	2.57	2.18	2.08	79.45

LSD least significant difference at 5%, *MBC* microbial biomass carbon, *TPF* triphenyl formazan, *PNP* *p*-nitrophenol, *PSB* P-solubilizing bacteria

rot incidence caused by *Phytophthora colocasiae*. All the treatments resulted in significantly reducing tuber rot incidence compared to control where no microbial culture was applied.

The results of soil analysis at harvest indicated that there was no significant difference in soil pH. The organic carbon content was significantly higher when recommended level of NPK was applied compared to 50% level. This was due to significantly higher addition of fallen leaves (4.26 t ha^{-1}) in plots where recommended NPK was given compared to 50% level (3.41 t ha^{-1}). The available nitrogen content was significantly higher in soils treated with *Azospirillum* which was on par with that of application of all cultures in soil. The available phosphorus content was significantly higher in soils which received AM fungi and phosphate-solubilizing bacteria. There was no significant difference on soil-available potassium content due to the application of different cultures. Among the micronutrients, iron was significantly higher in soils which received application of *Pseudomonas fluorescens*, while the zinc availability was significantly more in soils treated with AM fungi.

Table 20.4 gives the influence of different treatments on soil enzyme activities as well as microbial biomass carbon. The biochemical nutrient cycling reactions in soils are mediated by microorganisms, and the level of soil enzyme activity can be used as an indicator of soil fertility, soil health and soil quality. Urease is a key component in the nitrogen cycle in soils. The urease activity was significantly higher in plots treated with recommended NPK compared to 50% level. Among the different microbial cultures used, the urease activity was significantly increased by

Table 20.5 Effect of different treatments on NPK uptake by cassava

Treatment	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})
Fertilizer			
Recommended level	161.03	23.92	146.67
50% recommended level	143.23	22.92	139.83
LSD (0.05)	NS	NS	3.73
Biocontrol agents and biofertilizers			
Control	135.20	18.93	138.56
Trichoderma	149.07	23.26	134.34
Pseudomonas	157.89	23.07	135.43
Azospirillum	182.48	21.77	149.06
AM fungi	163.43	26.76	152.21
PSB	161.99	26.76	146.64
All-soil	185.41	26.48	151.23
All-set treatment	165.27	24.84	152.63
LSD (0.05)	12.13	2.05	NS

AM fungi arbuscular micorrhiza, *PSB* P-solubilizing bacteria

the application of *Azospirillum*. Dehydrogenase activity is a measure of overall microbial activity and respiration in soils and hence is an index of general microbial activity in soil. There was no significant difference in dehydrogenase activity between application of recommended NPK and 50% NPK. Application of all cultures in soil resulted in significantly higher activity of dehydrogenase which was on par with application of *Trichoderma* along with AM fungi. β-Glucosidase plays an important role in degradation of carbohydrates in soil and hence is important in carbon cycle in soils. Application of all cultures in soil resulted in significantly higher activity of β-glucosidase followed by application of phosphate-solubilizing bacteria and AM fungi, which were on par. Microbial biomass, although constitute a small fraction, is recognized for their ability to carry out biochemical transformation of nutrients as well as for their importance as a source sink for the major elements N, P and S as well as for C. The microbial biomass C was significantly higher when all cultures were applied to soil which was on par with application of *Trichoderma* along with AM fungi.

There was no significant difference in the uptake of N and K between the treatments of application of NPK at recommended level and 50% level (Table 20.5). Application of all cultures in soil resulted in significantly higher N uptake which was on par with that of *Azospirillum* application. The P uptake was significantly higher for application of AM fungi and phosphate-solubilizing bacteria (PSB) which was on par with that of application of all cultures in soil. The K uptake was significantly higher at recommended level of NPK application, and there was no significant difference in K uptake among the application of different microbial cultures.

Table 20.6 Effect of site-specific nutrient management (SSNM) on root yield (t ha^{-1}), plant nutrient accumulation (kg ha^{-1}) and fertilizer use

	Treatment			
	SSNM	FFP	Δ	*P*>ITI
Root yield (t ha^{-1})	37.35	28.63	8.72	0.005
Plant N uptake (kg ha^{-1})	204.53	172.71	31.82	0.004
Plant P uptake (kg ha^{-1})	23.79	18.62	5.17	0.002
Plant K uptake (kg ha^{-1})	201.01	208.89	−7.88	0.011
N fertilizer (kg ha^{-1})	105	59	46	0.004
P fertilizer (kg ha^{-1})	91	51	40	0.004
K fertilizer (kg ha^{-1})	105	123	−18	0.006

Δ: SSNM – FFP, *FFP* farmers' fertilizer practice, *SSNM* site-specific nutrient management

P>ITI: probability of a significant mean difference between SSNM and FFP

20.3.3 Balanced Fertilization of Cassava by Site-Specific Nutrient Management

Two linear functions describing the maximum accumulation and dilution of N, P and K in total plant dry matter (DM) of cassava were developed. Two straight lines were drawn by including all the data points, and these lines represent the maximum accumulation (a) and dilution (d) of a nutrient in the plant as done earlier for rice by Witt et al. (1999). Three sets of constants representing the slopes of the boundary lines for maximum accumulation (a) and maximum dilution (d) were used to simulate the optimal relationships between tuberous root yield and uptake of N, P and K.

There was a significant increase in tuberous root yield and NPK uptake in SSNM in all the four crops grown during 2003–2006 compared to FFP (Table 20.6). The average yield difference between SSNM and FFP for the four crops grown was 8.72 t ha^{-1} (23%, $P=0.005$), and the differences in tuberous root yield over the years were not statistically significant ($P=0.247$). In nine farms, the average yield exceeded 40 t ha^{-1} with a maximum of 47.69 t ha^{-1} and, in five farms, yields in the SSNM exceeded 10 t ha^{-1} compared to FFP, clearly indicating the superiority of SSNM approach.

Significant differences were noticed in plant N, P and K uptake in SSNM compared with FFP treatments. On an average, plant N uptake increased by 31.82 kg ha^{-1} (15.56%, $P=0.004$) and P uptake by 5.17 kg ha^{-1} (21.73%, $P=0.002$), while there was a decrease in K uptake by 7.87 kg ha^{-1} (3.91%, $P=0.011$). Similar trends in nutrient uptake were observed over the years ($P>0.05$).

The N and P fertilizer use was relatively low, whereas the K fertilizer use was found to be high compared to SSNM. The average rates of N and P application in FFP plots were 59 kg N ha^{-1} and 51 kg P_2O_5 ha^{-1}, whereas the K rate was 123 kg ha^{-1}, respectively. Detailed survey indicated that most of the farmers applied NPK fertilizers without taking into account the actual soil fertility status. The N rate and INS

Table 20.7 Effect on site-specific nutrient management (SSNM) on fertilizer N use efficiency, fertilizer cost and gross return above fertilizer (GRF) cost

	Treatment				
	SSNM	FFP	Δ	*P*>ITI	*P*>IFI
AE_N (kg root kgN^{-1})	80	47	33	0.000	0.002
RE_N (kg N kgN^{-1})	0.52	0.38	0.14	0.000	0.004
PE_N (kg tuber kgN^{-1})	157	90	67	0.000	0.010
AE_P (kg root kgN^{-1})	87	70	17	0.022	0.003
RE_P (kg N kgN^{-1})	0.11	0.10	0.01	0.003	0.008
PE_P (kg tuber kgN^{-1})	279	187	92	0.003	0.017
AE_K (kg root kgN^{-1})	115	74	41	0.000	0.030
RE_K (kg N kg N^{-1})	0.37	0.24	0.13	0.002	0.040
PE_K (kg tuber kg N^{-1})	69	47	22	0.040	0.025
TFC (US$ ha^{-1})	91	59	32	0.005	0.002
GRF (US$ ha^{-1})	1,285	1,047	238	0.004	0.065

Δ: SSNM – FFP; *FFP* farmers' fertilizer practice, *SSNM* site-specific nutrient management
P>ITI: probability of a significant mean difference between SSNM and FFP

were found to be negatively correlated ($r = -0.29$). The P and K status were not significantly correlated with IPS ($r = 0.31$) and IKS ($r = 0.34$).

On an average, 46 and 40 kg ha^{-1} more fertilizer N and P were used in SSNM treatments compared to FFP (+78%, $P = 0.004$ for both N and P). In the case of fertilizer K, 18 kg ha^{-1} less fertilizer K was used in SSNM treatments than in FFP (−15%, $P = 0.006$). Higher rates of application of fertilizer N and P in SSNM treatments were fixed based on the prediction of the calibrated QUEFTS model that accurately accounted for the low native soil N and P status measured as plant N and P uptake in nutrient omission plots. The modified QUEFTS model predicted a lower rate of fertilizer K in SSNM treatment that accurately accounted for the higher native soil K status measured as plant K uptake in K omission plots.

The N, P and K use efficiency in the SSNM treatment was increased significantly in SSNM treatment where the field- and season-specific N management was practised (Table 20.7). More N and P fertilizers was applied in SSNM plots compared with the FFP, while less K fertilizer was used in SSNM plots, and there was significant increase in agronomic efficiency (AE), recovery efficiency (RE) and physiological efficiency (PE) of all the three major nutrients. Across the four crops grown, the AE_N increased by 35 kg kg^{-1} (70%, $P = 0.000$), RE_N by 0.14 kg kg^{-1} (37%, $P = 0.000$) and PE_N by 67 kg kg^{-1} (74%, $P = 0.000$). Almost similar results observed for P and K fertilizer use efficiency also.

The results of the study provide on-farm evidence that the present NPK management practices in India for cassava are inconsistent with the physiological nutrient requirements of the crop, and that is one of the major reasons that prevents further increase in productivity of cassava. In addition to this, it also results in nutrient imbalance and losses. The K supply in FFP appears to be deficient during early crop growth stage and excessive during later stages, leading to poor tuberous root bulking and starch content. The importance of sufficient N and K supply before 60 days after planting is highlighted in many studies (Byju and Anand 2009a) as against what is observed in FFP.

There was an increase in the average fertilizer cost by US$32 ha^{-1} $year^{-1}$ in SSNM treatment, but still the gross return above fertilizer (GRF) increased by US$238 ha^{-1} $year^{-1}$ (23%, $P=0.004$) compared with FFP. The profit over the years increased continuously, which suggests that there was a gradual improvement of the SSNM strategy. The calculation of ΔGRF and its interpretation is based on the assumption that the only difference in crop management between SSNM and FFP is different quantities of nutrients and different timing of a certain constant number of applications so that all other management practices and quantities of input use are held constant. The results indicated that although SSNM was associated with an additional cost, those expenses were far below the increase in GRF measured for all four crops.

20.4 Conclusions and Recommendations

In India, cassava cultivation is concentrated in the state of Tamil Nadu where significant area is under degraded Vertisols in arid environments. Continuous cassava cultivation in these areas resulted in a number of problems which include tuberous root rot, development of subsurface hard pan and nutrient depletion. The studies conducted by the authors have conclusively developed certain soil management technologies to reclaim these Vertisols under cassava. Deep tillage with a chisel plough, application of neem cake, application of biofertilizers such as N fixer, P-solubilizing bacteria and AM fungi and biocontrol agents like *Trichoderma* and *Pseudomonas* are recommended to reclaim these soils. Balanced fertilization based on site-specific nutrient management (SSNM) technology has also been developed using the model QUEFTS (Quantitative Evaluation of Fertility of Tropical Soils) which prescribes fertilizer recommendation for individual fields based on target yield, indigenous nutrient supply and fertilizer recovery efficiency. Cassava farmers of Tamil Nadu has been widely following the developed technology for management of tuberous root rot, and this has substantially enhanced the yield and income of these farmers. The SSNM technology need to be popularized among cassava farmers in these region to fully utilize these degraded Vertisols.

References

Al-Tahan YH, Hassam HM, Hamadi IM (1992) Agricultural management in Asia, Africa and Latin America. Indian J Agric Sci 23:21–27

Barzegar AR, Asoodar MA, Khadish A, Hashemi AM, Herbert SJ (2003) Soil physical characteristics and chickpea yield responses to tillage treatments. Soil Till Res 71:49–57

Buol SW, Hole FD, McCracken RJ (1980) Soil genesis and classification. Oxford and IBH Publishing Co Ltd, New Delhi

Byju G, Anand MH (2009a) Differential response of short- and long-duration cassava cultivars to applied mineral nitrogen. J Plant Nutr Soil Sci 172(4):572–576

Byju G, Anand MH (2009b) Leaf color chart and chlorophyll meter based leaf nitrogen estimation and their critical values for real time nitrogen management in cassava. Commun Soil Sci Plant Anal 40:2816–2832

Byju G, Ravindran CS, Nedunchezhiyan M (2006) Site specific nutrient management as a precision farming tool for cassava cultivation in Tamil Nadu, India. Abstract of papers: 14th Triennial Symposium of the International Society for Tropical Root Crops, Mascot Hotel, Thiruvananthapuram, Kerala, 20–26 Nov 2006, pp 185–186

Byju G, Misra RS, Nair RR (2008a) Soil health, cassava yield and nutrient uptake as influenced by different biofertilizers and biocontrol agents in a Vertisol in India. Global cassava partnership: first scientific meeting GCP-1. Cassava-meeting the challenges of the new millennium, Ghent, Belgium, 20–25 July 2008

Byju G, Nedunchezhiyan M, Ramanandam G (2008b) Soil fertility research for cassava in India. 8th Asian Cassava Research Workshop, Vientiane, Lao PDR, 20–24 Oct 2008

CTCRI (2005) Annual report 2004–2005. Central Tuber Crops Research Institute, Thiruvananthapuram, p 62

Fageria NK, Baligar VC, Jones CA (1991) Growth and mineral nutrition of field crops. Marcel Dekker, New York

Hall DJM, McKenzie DC, MacLeod DA, Toolt ID (1994) Amelioration of a hard setting Alfisol through deep mould board ploughing, gypsum application and double cropping. II. Soil water relations. Soil Till Res 28:271–285

Hamza MA, Anderson WK (2005) Soil compaction in cropping systems: a review of the nature, causes and possible solutions. Soil Till Res 82:121–145

Haripriya AM, Byju G (2008) Chlorophyll meter and leaf color chart to estimate chlorophyll content, leaf color and yield of cassava. Photosynthetica 46(4):511–516

Janssen BH, Guiking FCT, Van der ED, Smaling EMA, Wolf J, Reuler H (1990) A system for quantitative evaluation of fertility of tropical soils (QUEFTS). Geoderma 46:299–318

Jarvis RJ, Hamblin AP, Delroy ND (1986) Continuous cereal cropping with alternative tillage systems in Western Australia. Technical Bulletin no. 71. Western Australian Department of Agriculture, Perth, p 37

Randall GW, Iragavarappa TK (1995) Impact of long term tillage systems for continuous corn on nitrate leaching to tile drainage. J Environ Qual 24:360–366

Savithri P, Santhy P (2001) Nutrient mining in the agro-climatic zones of Tamil Nadu. Fertil News 46(8):59–68

Soane BD, Ouwerkerk C (1995) Implications of soil compaction in crop production for the quality of the environment. Soil Till Res 35:5–22

Soil Survey Staff (2010) Keys to soil taxonomy, 11th edn. United States Department of Agriculture, Natural Resources Conservation Service, Washington, DC

Systat (1992) Systat software. Systat Inc., Evanston

Witt C, Dobermann A, Abdulrachman S, Gines HC, Guanghuo W, Nagarajan R, Satawatananount S, Son TH, Tan PS, Van Tiem L, Simbahan GC, Olk DC (1999) Internal nutrient efficiencies of irrigated lowland rice in tropical and subtropical Asia. Field Crops Res 63:113–138

Yadav BL, Vyas KK (2006) Influence of subsoil compaction on recovery and use efficiency of nitrogen in wheat crop on highly permeable soils. J Indian Soc Soil Sci 54:158–162

Chapter 21
Sustainable Management of Salt-Affected Soils and Poor-Quality Ground Waters for Enhancing Crop Production

Anand Swarup

Abstract Two major types of salt-affected soils were distinguished in the study area: saline and alkali (sodic) soils. Saline soils have an excess of neutral soluble salts such as chlorides and sulphates of Na^+, Ca^{2+} and Mg^{2+}. Plant growth is adversely affected due to reduced water uptake and ionic imbalance and/or nutrient stresses. Alkali soils, on the other hand, have Na_2SO_4 and $NaHCO_3$ which upon hydrolysis produce alkalinity leading to high pH and exchangeable sodium, nutrients unavailability and low yields. The reclamation technology involves integrated use of amendments like gypsum for rice-based cropping system, balanced and integrated use of chemical fertilisers and organic/green manures improving soil health and input-use efficiency. In saline soils, leaching with good-quality water and sub-surface drainage is essential. Use of poor-quality ground water constitutes about 30–80% of total ground water. The management practices for optimal crop production with saline and sodic water irrigation must aim at preventing the build-up of salinity/sodicity and toxic ions in the root zone, to levels that limit the productivity of soils, control the salt balances in soil-water system as well as minimise the damaging effects on crop growth. Efficient, balanced and integrated nutrient management strategies are extremely important to increase yields to match the potential yields obtained under good-quality irrigation water. Therefore, we focus on the ionic interactions and nutrient dynamics as influenced by salinity/sodicity of irrigation water and discuss how these issues relate to the nutritional problems and suggest long-term remedial measures to utilise poor-quality waters for improving and sustaining crop productivity of salt-affected soils.

Keywords India • Marginal water • Nutrient management • Reclamation • Saline soil

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21.1 Introduction

The population of India is increasing at an alarming rate of around 1.9% per annum and is expected to reach 1.40 billion by 2025. To meet food demand, India needs to produce large quantities of food grain, fodder and fuel. Out of the cultivated area of about 182.2 million hectares (Mha), about 75% is already under food crops. There is a little scope for bringing additional area under food crops to meet the ever-increasing food demand. The diversion of good fertile lands for nonagricultural purposes like urbanisation, roads and industry, the area under food crops is shrinking. There is a need to improve agriculture in good areas, and there is also potential to boost production by bringing marginal soils into agricultural production. In India, about 6.73 Mha is lying barren due to salinity or producing uneconomical yields of various crops. Marginal area is expected to increase due to waterlogging, and salinity due to increase in canal irrigation, and intensive exploitation of poor-quality ground waters for agriculture in non-canal commands. Based on soil pH, exchangeable sodium percentage (ESP), concentration and nature of soluble salts and the reclamation procedure to be adopted, these salt-affected soils have been classified in two major categories, alkali (sodic) soils and saline soils.

In sodic soils, the exchange sodium disperses clay and degrades soil structure and affects soil permeability. Thus, in sodic soils, the available water in the sub-surface layers may remain unavailable due to either its slow movement or inability of the roots to penetrate and trap this water. This situation demands special management practices.

21.1.1 Management of Sodic Soils

About 3.77 Mha area is severely affected by sodicity in the Indo-Gangetic plains of India. The main problems are high pH, ESP and calcium carbonate content. Other problems are, very low amount of organic matter and poor physical conditions limiting nutrient availability and plant growth. Crops grown on these soils invariably suffer nutritional deficiencies (N, Ca and Zn deficiency and Na toxicity) resulting in low yields. Crop production and fertiliser use efficiency can be increased by using integrated reclamation approach using gypsum, balanced fertilisers and organic/green manures. Rice-based cropping systems like rice-wheat, rice-clover and rice-mustard are recommended on these soils.

21.1.2 Calcium

Sodic soils present high exchangeable sodium percentage (ESP>15), thereby adversely affecting physical and nutritional properties of soils. The soils are deficient in both soluble and exchangeable calcium (Table 21.1). Though these soils contain sufficient $CaCO_3$, the availability of Ca is insufficient to offset plant needs due to high pH. The plants grown in sodic soils suffer more to lack of Ca than from the toxicity of Na. Increasing sodicity decreases the absolute Ca concentration and Ca–Na ratio of the plant.

Table 21.1 Physical-chemical characteristics of alkali soil

Soil characteristics	Soil depth (cm) 0–15	15–30	30–45	45–60	60–90	90–120
Sand (%)	55.5	51.1	45.9	44.0	46.9	58.5
Silt (%)	25.0	24.5	28.2	22.5	25.7	25.6
Clay (%)	19.5	24.4	25.9	33.5	27.4	15.9
Sandy loam texture						
pH (1:2)	10.4	10.4	10.3	10.2	10.1	10.0
ESP	89	90	84	80	78	76
$CaCO_3$ (%)	3.4	3.5	3.8	4.5	9.8	10.6
Organic carbon (%)	0.20	0.17	0.14	0.10	0.08	0.06
CEC (meq100 g^{-1})	10.5	10.1	10.0	8.8	8.5	8.2
Water-soluble + exch. Ca + Mg (me/100 g)	0.52	0.41	1.02	1.42	1.60	1.62
Available N (kg ha^{-1})	45	41	36	32	32	30
Available P (kg ha^{-1})	38	34	30	28	25	25
Available K (kg ha^{-1})	478	475	460	450	455	452
DTPA-extractable Fe (mg kg^{-1})	3.5	3.8	3.0	2.8	2.9	2.5
DTPA-extractable Mn (mg kg^{-1})	2.6	2.8	2.0	1.2	1.0	1.0
DTPA-extractable Zn (mg kg^{-1})	0.42	0.40	0.38	0.35	0.30	0.25
Intake rate (cm day^{-1})	0.2	–	–	–	–	–

Experiments showed that gypsum applied at rate of 12–15 Mg ha^{-1} (50% GR of 0–15 cm soil) is sufficient to initiate reclamation processes in rice-based cropping system. Since sodic soils invariably contain $CaCO_3$, use of acids like H_2SO_4 or acid forming materials like pyrites (FeS_2) and elemental S is also helpful in supplying Ca ions through solubilisation of $CaCO_3$ and thus meet the Ca needs of plant and soil. The effectiveness of organic materials like farmyard manure, pressmud, poultry manure, paddy and wheat straw and green manures in reclaiming sodic soils and supplying Ca depends on the amount of CO_2 produced and reduced conditions through drop in redox potential under submerged conditions in rice culture (Swarup 1988). Field studies (1989–1990 to 1991–1992) showed that gypsum rate could be reduced from 50 to 25% GR when FYM at 20 Mg ha^{-1} was applied and improvement in crop yields (Table 21.2), and soil properties were also higher with the use of FYM.

21.1.3 Organic Carbon and Nitrogen

Alkali soils are highly deficient in organic matter and low biological activity. Results have shown that long-term balanced fertiliser use under rice-wheat system helps in maintaining the organic carbon status of the soil as compared to the control plots. Loss of ammonia was higher at the field-moisture range and in non-reclaimed soils. Ammonia volatilisation losses followed the first-order reaction rate kinetics with a half-life ($t_{1/2}$) of 62–65 days at field capacity and 10.5 days for waterlogged conditions in sodic soils and

Table 21.2 Effect of soil amendments on the grain yield of rice and wheat in a sodic soil

	Grain yield Mg ha^{-1}							
	Rice				Wheat			
Treatment	1989	1990	1991	Average 3 years	1989–1990	1990–1991	1991–1992	Average 3 years
Control	2.98	4.55	5.23	4.25	0.20	1.00	1.18	0.79
Gypsum 25% GR	5.10	5.23	5.32	5.22	1.67	2.22	2.33	2.07
Gypsum 50% GR	5.44	5.46	5.34	5.41	1.99	2.31	2.42	2.24
Farmyard manure (FYM) 20 Mg ha^{-1}	4.05	5.20	5.30	4.85	1.42	2.00	2.16	1.86
Gypsum 25% GR + (FYM) 20 Mg ha^{-1}	5.78	5.76	5.83	5.79	2.14	2.78	2.82	2.58
Gypsum 50% GR + (FYM) 20 Mg ha^{-1}	6.13	6.01	5.90	6.01	2.36	2.82	2.91	2.70
LSD (P = 0.05)	0.33	0.41	0.40	0.36	0.35	0.36	0.34	0.35

Table 21.3 Nitrogen (ammonia) losses from integrated nutrient management system in rice field under reclaimed alkali soil

	Percent amount of N lost during application			
Treatment	Basal	1st split	2nd split	Total N lost
Control	1.23	–	–	1.23
N_{120}	8.49	8.21	6.76	23.46
$N_{120}P_{22}$	8.28	7.35	6.70	22.33
$N_{120}P_{22}K_{42}$	8.14	7.24	6.65	21.75
$N_{120}P_{22}K_{42}$ + GM	5.82	5.20	5.06	16.08
$N_{120}P_{22}K_{42}$ + FYM	6.73	5.74	5.28	17.75
$N_{180}P_{39}K_{63}$	12.12	10.60	9.48	32.20
Mean	8.26	7.39	6.66	–
LSD at P = 0.05				
Treatments	0.51	0.91	1.19	
Stage of N application	0.32			

were also influenced by temperature (Kumar et al. 2000). Pre-submergence of the soil (submergence prior to planting and N application) for 1 week decreased the pH of alkali soils and reduced volatilisation losses significantly (Kumar et al. 1995).

Significant increases in grain yield of rice were obtained when one-third of total urea-N was applied before puddling in a partially reclaimed sodic soil under 1 week pre-submerged conditions. Further studies showed that ammonia volatilisation losses decreased significantly when FYM or green manure was combined with urea-N application as compared with urea-N alone. The losses of N through ammonia volatilisation from green manure combined with NPK were lower (13.4%) as compared to without it (18.13%). The use of green manure could save 4.73% fertiliser –N (Table 21.3), possibly because in the former, nitrifying population could adequately oxidise the ammonical –N which is then slowly mineralised to meet the plant needs.

Table 21.4 Effect of gypsum and leaching on pH and inorganic P fractions of sodic soils

Gypsum (GR%)	pH	ESP	Olsen–P	H_2O–P	$NaHCO_3$–P	NaOH–P	HCl–P
Nil	9.7	65.0	41.7	32.3	29.3	72.3	239.0
25	9.1	32.4	35.3	26.2	32.8	78.4	239.3
50	8.4	20.0	38.9	24.3	36.4	81.4	241.8
100	8.2	15.0	40.7	6.0	41.0	86.0	240.0

P in mg kg^{-1} of soil

The highest concentration of NH_4–N in flooded water and NH_3 loss occurred when granular urea was applied wholly as a basal dose. Split application of urea reduced the peak NH_4^+–N levels and NH_3 volatilisation losses, thereby increasing its efficiency. Maximum yields of rice and even wheat were obtained when N was applied in three equal splits, as basal and at 3 and 6 weeks after transplanting or sowing. Yields were higher at 150 kg than at 120 kg of N ha^{-1}.

21.1.4 Phosphorus

Barren sodic soils contain high amounts of available (Olsen's extractable) P (Table 21.1). This is primarily due to the presence of sodium phosphates, which are water-soluble. An increase in the rate of gypsum decreased the water-soluble P greatly, but it had little effect on the more strongly adsorbed P fractions (NaOH–P) or Ca-bound P (HCl–P) (Swarup et al. 1994). The main effect of gypsum was to render the adsorbed P fraction (($NaHCO_3$)–P) more labile (Table 21.4).

21.1.5 Potassium

Sodic soils of Indo-Gangetic plains are generally very high in available K (Swarup and Chhillar 1986), and crops do not respond to applied K even after 20 years of rice-wheat and pearl millet-wheat cropping systems in sodic soils (Swarup and Singh 1994). Lack of crop response is attributed to the presence of K-bearing minerals and large contribution of non-exchangeable K (>90%) towards total K uptake by the crops (Swarup and Chhillar 1986; Swarup and Yaduvanshi 2004).

21.1.6 Micronutrients

Sodic soils are sufficient in total zinc but generally deficient in available Zn. Only 3.3% of the total Zn is attributed to the exchangeable, complexed, organically bound and occluded forms, which are considered to be available during crop growth. Thus, zinc deficiency is very common in rice, and its deficiency symptoms appear in the early growth stages (21–25 days), which delay maturity and reduce yields (Swarup

1984). Therefore, significant response to its application is observed. Application of 9 kg Zn ha^{-1} (40 kg zinc sulphate) eliminated Zn deficiency in rice grown on alkali soils treated with gypsum, pyrites, farmyard manure (FYM) and rice husk and raised the available Zn status of the soil to an adequate level, so as to meet the subsequent requirement of 2–3 crops (Swarup 1986). With the application of FYM and *Sesbania* green manure, it was possible to prevent the occurrence of Zn deficiency in rice grown on alkali soils (Swarup 1991). Organic amendments like pressmud, poultry manure and farmyard manure could effectively supply zinc from the native and applied sources to rice crop in a saline-sodic soil. Adoption of rice-wheat system for more than two decades on gypsum-amended sodic soils resulted in decline of the DTPA-extractable Mn to a level of 2.7 mg kg^{-1}, where wheat responded to manganese sulphate application at a rate of 50–100 kg ha^{-1}. Substantial leaching losses of Mn occur following gypsum application in alkali soils (Soni et al. 1997). Foliar application of Mn is better than soil application. Nutrients such as B and Mo are not likely to be limiting factors for plant nutrition in alkali soils, though at higher concentrations, they could prove toxic. However, once the alkali soils are amended with gypsum/pyrites and leached, concentrations of these elements in solution drop to within safe limits and remain no longer toxic to plants (Swarup 2003).

21.1.7 Organic and Green Manures Vis-a-Vis Integrated Nutrient Management

Nutrient imbalance created by continuous use of plant nutrients particularly N alone or combined with suboptimal rates or omission of other nutrients (especially P and Zn) is the primary cause of non-sustainable yields in alkali soils (Swarup 1993). *Sesbania* green manuring or the use of farmyard manure improves the organic carbon and N status of soil and crop yields especially when combined with gypsum (Swarup 1994). But the use of inorganic N fertiliser showed hardly any residual effect. Long-term field studies conducted on a gypsum-amended alkali soil (Swarup 1991) showed that incorporation of *Sesbania aculeata* at 50 days produced 3.85 Mg ha^{-1} $year^{-1}$ of biomass (dry weight), which in turn contributed 110 kg N and 11 kg P ha^{-1} $year^{-1}$ and increased significantly the grain yield of rice and wheat, the average increase being 1.48 and 0.67 Mg ha^{-1} respectively.

21.1.8 Management Strategies for Using High Sodic and Saline Waters

In many arid and semiarid regions of the world, sodic ground water is the main or only source of irrigation, and its continued use poses a threat to improve crop production. Application of gypsum as soil or water amendment is commonly recommended to offset the deteriorating effects of these types of water. However, organic amendments have also been used to alleviate the adverse effects of soil sodicity on crop growth. Development of site-specific integrated plant nutrient supply (IPNS) and management strategies is therefore a viable option for sustaining the productivity of this system. Nitrogen continues to be the most limiting plant nutrient in soils irrigated with sodic water. The continuous use of fertiliser N alone (120 kg ha^{-1}) significantly improved grain yields of rice and wheat over control (no fertiliser). The mean yields increased by 53.9% in rice and 72.9% in wheat.

Phosphorus applied at the rate of 26 kg P ha^{-1} each to rice and wheat significantly improved the yields, the mean increase being 0.72 and 0.65 t ha^{-1}, respectively. The soils irrigated with sodic water generally test high in available K. Potassium applied at a rate of 42 kg ha^{-1} to both crops had no significant effect on yields. Zinc application improved the yields of rice, but the effects were significant only in 1997 and 1998 rice. The rice-wheat productivity and soil fertility on long-term basis can be sustained by integrated use of gypsum or FYM with recommended NPK dose in areas having sodic ground water. Pressmud is economically cheaper and offers alternate opportunities to the farmers.

At a given salinity level, increasing application of organic materials improved yields of many crops. However, when salinity of the irrigation water was higher, the per cent response was reduced when referenced to yields where no organics were applied. It seems that addition of organic materials temporarily immobilise the NH_4^+ nitrogen and subsequently release the organically bound N to crops during the growth season. Increased responses to N fertilisers in the presence of organic materials suggest its role in reducing the volatilisation losses and enhance the N-use efficiency under saline environment. A combination of organic and inorganic sources saved N 50% in rabi season and 25% in kharif season. On the other hand, increasing the level of phosphorus and potassium over the recommended dose seemed to mitigate the adverse affects of salinity. Type of salinity has also been observed to influence the response of crops to phosphorus and potassium application. Therefore, soil test-based fertiliser recommendations in respect of NPK are extremely important for enhancing and sustaining crop productivity.

21.2 Conclusions

This chapter presents various options of managing salt-affected soils and saline and sodic waters. This is essential in a country like India where population is increasing at an alarming rate and thus requires increase in crop production and increase in agriculture areas through bringing marginal lands into crop production. To deal such marginal resources, it is necessary that these resources are properly investigated, and salinity, sodicity and nutrients levels are diagnosed accurately for proper formulation of reclamation strategies for optimum results of costly investments. Such an integrated approach (physical, chemical, hydrological, fertility) should be designed based on the site conditions.

References

Kumar D, Swarup A, Kumar V (1995) Effect of rates and methods of urea-N application and pre-submergence period on ammonia volatilization losses from rice fields in a sodic soil. J Agric Sci (Cambridge) 125:95–98

Kumar D, Swarup A, Kumar V (2000) Effect of temperature on kinetics of urea hydrolysis and ammonia volatilization in submerged alkali soils. Fertil News 45(11):57–63

Soni ML, Swarup A, Singh M (1997) Influence of rates and methods of manganese application on yield and nutrition of wheat in a reclaimed sodic soil. J Agric Sci (Cambridge) 127:433–439

Swarup A (1984) Effect of micronutrients and farmyard manure on yield and micronutrient content of rice and wheat grown on sodic soil. J Indian Soc Soil Sci 32:397–399

Swarup A (1986) Effect of gypsum, pyrites, farmyard manure and rice husk on the availability of zinc and phosphorus to rice in submerged sodic soil. J Indian Soc Soil Sci 34:844–848

Swarup A (1988) Influence of organic matter and flooding on the chemical and electrochemical properties of sodic soil and rice growth. Plant Soil 106:135–141

Swarup A (1991) Effect of gypsum, green manure, farmyard manure and zinc fertilization on the zinc, iron and manganese nutrition of wetland rice on a sodic soil. J Indian Soc Soil Sci 39:530–536

Swarup A (1993) Integrated nutrient supply and management system for sustained crop production in alkali soils. Fertil News 38:27–34

Swarup A (1994) Chemistry of salt affected soils and fertility management. In: Salinity management for sustainable agriculture. Central Soil Salinity Research Institute, Karnal, pp 18–40

Swarup A (2003) Crop response to secondary and micronutrients in salt affected soils of India. Fertil News 48(4):83–93

Swarup A, Chhillar RK (1986) Build up and depletion of soil phosphorus and potassium and their uptake by rice and wheat in a long term field experiment. Plant Soil 91:161–170

Swarup A, Singh KN (1994) Effect of gypsum, farmyard manure and nitrogen on ameliorating of a sodic soil and on yields of rice and wheat. Int Rice Res Notes 19(3):22–23

Swarup A, Yaduvanshi NPS (2004) Nutrient stress management for sustaining crop production in salt affected soils. Bulletin no. 1/2004. CSSRI, Karnal, pp 1–35

Swarup A, Adhikari M, Biswas AK (1994) Effect of gypsum on the behaviour of phosphorus during reclamation of a sodic soil. J Indian Soc Soil Sci 42:543–547

Chapter 22
Controlling Sodic Soil Erosion by Electrolytes and Polyacrylamide Application

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Abstract The anionic polyacrylamide (PAM) is recently used to rehabilitate saline and sodic soils and control soil erosion. The research on the effectiveness of anionic PAM along with gypsum or lime application on soil erosion is rare and poorly documented. Therefore, an experiment was conducted to study the effects of anionic PAM with or without gypsum on the erosion of soils under saline/sodic conditions. For this purpose, a clay loam soil was prepared to achieve three levels of exchangeable sodium percentage (ESP) 0.5, 9.9, and 25.5 with an appropriate solution of salts. Soil samples were air-dried and packed in the trays. Powdered PAM, gypsum, or a mixture of both was applied to the salt-treated soils. Thereafter, the soils were subjected to simulated rainstorm of 40 mm h^{-1} by a fixed rainfall simulator. Saline waters with different levels of electrical conductivity (EC_w): 0.1, 2, 5, and 8 dS m^{-1} were used for simulated rains during the study. PAM amendment substantially controlled the erosion of the soils. The ESP was directly associated with the soil erosion and runoff. Among the treatments, the resistance to soil erosion was developed in the order of PAM > gypsum ≈ saline water > PAM mixed with gypsum ≈ PAM mixed with saline water. The magnitude of runoff water was reduced both by gypsum and saline water, whereas it was enhanced by

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PAM application. The mixed addition of PAM with gypsum or salts exacerbated water erosion of soils.

Keywords Gypsum • Runoff • Saline water • Simulated rainfall • Polyacrylamide (PAM)

22.1 Introduction

In arid and semiarid areas, sodic condition of soils enhances dispersion of the soil and thus cause low permeable crust formation and clogging soil pores over soil surface. During irrigation and rainfall, such soils tend to have more runoff and thus be vulnerable to water erosion (Shainberg and Levy 1994). Agassi et al. (1981) reported a considerable runoff from dispersive noncalcareous sodic soil induced by rainfall. Soil loss becomes more severe under sprinkler systems with high spraying intensities and longer duration of surface irrigation. Runoff and eroded sediments not only lead to deterioration of land productivity but also contribute substantially toward nonpoint source contamination of surface water bodies (Tang and Rengel 2003).

Gypsum has been used to improve soil physical properties such as soil aggregation and permeability (Shainberg et al. 1989). Polyacrylamide (PAM) was found to improve soil structure (Saybold 1994) by reducing clay dispersion. An anionic PAM having large molecular weight has the ability to stabilize soil structure, reduce runoff, and soil loss (Zhang and Miller 1996) when soil solution cations can bridge negatively charged clay particles with anionic PAM (Theng 1984). For this process, PAM carboxyl groups are attaching with soil particles, sealing soil surface and reducing soil loss.

It was reported that the dissolution of PAM encouraged soil aggregation and structure development (Al-Abed et al. 2003). This phenomenon could ensure reduction of soil loss by runoff. Beside, Yu et al. (2003) reported a decrease in infiltration rate after an anionic PAM application on the soil. This was caused by clogging pores via long chains of gel-structured PAM. Also, small molecular weight PAMs may prevent coagulation of clay particles by cancelling the particle charges by adsorption (Heller and Keren 2002; Shainberg et al. 1989).

Soil sodicity can affect many physical and chemical reactions. Soil pH usually has a strong relationship with ESP (Tan 1993). Treating sodic soil with anionic PAM can improve soil structure; however, variation in soil pH may affect PAM efficiency. The direct relationship between soil structure, pH, and PAM application is not very clear. Moreover, the effect of anionic PAM on aggregate stability was not fully studied. Therefore, the experiment was designed and carried out for following objectives: (1) to evaluate the effects of anionic PAM on aggregate stability at different levels of soil pH and (2) to compare the effects of anionic PAM and gypsum on soil erosion under saline and non-saline rainwater conditions.

22.2 Materials and Methods

22.2.1 Soil Preparation and Analysis

The soil for the experiment was sampled from Tottori Prefecture, Japan. It was a paddy field soil with Skeletal Grayed Lowland Paddy soils (Eutric Gleysols), (NIAES 1996). Smectite is the dominant clay mineral in this soil. Textural class of the soil was determined as clay loam by pipette method (Gee and Bauder 1986). The pH of the soil was measured in 1:2.5 soil-water suspensions. Electrical conductivity of soil saturation extract (EC_e) was measured by electrical conductivity meter. Exchangeable cations were extracted using sodium acetate solution (1 N pH 8.2), and cation exchange capacity (CEC) was determined by quantifying the adsorbed sodium cation following Na replacement by 1 N ammonium acetate solution (pH 7). Quantification of cations was conducted by atomic absorption spectrophotometer. Some selected properties for the studied soil are given in Table 22.1.

Soils were air-dried and passed through 2-mm mesh sieve (fine earth fraction). The soil samples were treated with $CaCl_2$, $MgSO_4$, and Na_2CO_3 to achieve the following three levels of ESP: (1) low—ESP 0.5, (2) medium—ESP 6.7, and (3) high—ESP 25.5 (Table 22.2).

Table 22.1 Some physical and chemical characteristics of the studied soil

Physicochemical properties	Value
Sand 2–0.05 mm	39.6%
Silt 0.05–0.002 mm	36.0%
Clay < 0.002 mm	24.4%
Bulk density	1.12 g cm^{-3}
Hydraulic conductivity	6.92×10^{-5} cm s^{-1}
$pH\text{-}H_2O$ (1:2.5)	5.61
ECe	0.77 dS m^{-1}
CEC	17.2 $cmol^{+}$ kg^{-1}
Clay minerals	
Smectite	46–49%
Chalcedony	37–38%
Analcime	3.0–3.5%
Plagioclase	2.7–5.5%
Calcite	2.1–2.6%
Dolomite	2.0–2.8%
Pyrite	0.5–0.7%
Quartz	0.5–0.7%

Table 22.2 Selected chemical characteristics of the salt-treated soils

ESP level of soil	$pH\text{-}H_2O$ (1:2.5)	ECe (dS m^{-1})	ESP	Exchangeable cations ($cmol^{+}$ kg^{-1}) Na^{+}	Mg^{2+}	Ca^{2+}
Low	5.95	9.29	0.5	0.09	0.44	10.85
Medium	6.37	13.54	6.66	1.14	1.09	10.12
High	8.67	2.24	25.45	4.38	0.98	6.14

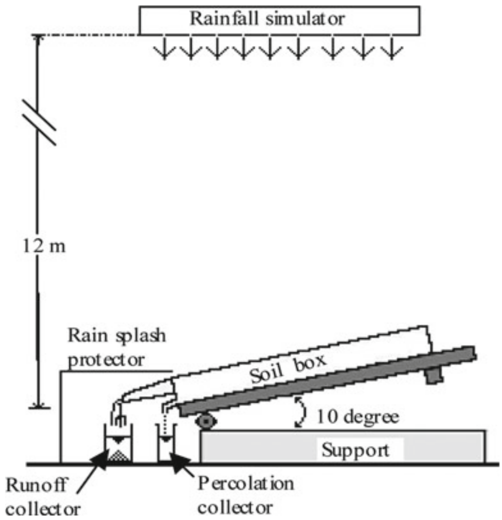

Fig. 22.1 Soil erosion experiment

22.2.2 Soil Erosion Experiment

Paddy field soils are usually affected by water erosion following heavy rainfall. To investigate this phenomenon, steel boxes having a dimension of (100 × 50 × 13 cm) were used for this experiment. All boxes were filled with 7 cm of sand overlain to 3-cm thickness gravel layers. The treated soil was air-dried and uniformly packed to the top of the sand box. The boxes were then placed at 10° slope and 40 mm h^{-1} simulated rainfall was applied for 2 h. Rainwater was prepared by mixing salts of $NaCl_2$ and $CaCl_2$ to attain electrical conductivity levels of 0.13 (original water), 2, 5, and 8 dS m^{-1} with SAR = 5 (mmoles $L^{-1})^{0.5}$. A drip-type rainfall simulator with raindrop fall-height of 12 m was used for the study (Fig. 22.1). Average raindrop size was 2 mm. Runoff was collected by a flume connected at the lower end of the tray at every 5-min intervals. The sediments in the runoff were determined gravimetrically after oven-drying at 105°C for 48 h. Prior to the simulated rainfall, dry gypsum was applied to the soil surface at the rate of 1, 2, and 5 megagrams per hectare (Mg ha^{-1}), whereas the dry PAM was applied at the rate of 20 and 80 kg ha^{-1}. Application rate of the two chemical agents was arranged in a manner that the above two doses of the PAM were mixed with the three doses of gypsum to give a total of six different application conditions. Note that the powdered anionic PAM (AP825, $[–CH_2–CH\ (CONH_2)]_n$) used in the experiment was manufactured by the Dia-Nitrix Co., Ltd. The molecular weight of PAM is 1.1×10^7 g mol-1, and degree of hydrolysis is 17–21%.

22.2.3 Soil Intake Rate Study

Soil of the highest ESP was amended by anionic PAM, gypsum, and mixtures of both. Infiltration rate of the soil was measured using constructed soil column. For this purpose, cylinder of 20 cm diameter and 40 cm height was used. The cylinder was uniformly packed with 3 cm of gravel, followed by 7 cm of sand, and finally with 3 cm of treated soil. The upper part of the cylinder was connected with Marriott bottle in which the water supplies were performed with either saline or non-saline water. The experiment was conducted under constant head and lasted for 2 h. At the end, soil basic intake rate at steady-state condition was calculated (Table 22.3). The study was done following Amoozegar and Warrick (1986) method.

22.2.4 Soil Aggregate Stability

Solutions of different pH values were prepared from NaOH or HCl solutions. Soil was mixed with those solutions to achieve three different levels of pH: 3.49, 5.61, and 9.42. The soil samples were air-dried and then applied with anionic PAM by spraying the 5 ml of dilute PAM (0.1%) solution. The treated soils were air-dried for 48 h before the analysis. Soil aggregate stability was determined by a combination of wet sieving by a set of two aperture mesh of 2,000–1,000 μm and 1,000–75 μm and then by a hydrometer method. Distilled water was used to conduct wet sieving.

22.3 Results and Discussion

22.3.1 Effect of Gypsum or Saline Water on Soil Erosion

Gypsum ($CaSO_4 \cdot 2H_2O$) is known as a dispersion-restricting agent for some sodic soils due to electrolyte concentration and cation exchange effects (Shainberg et al. 1989; Zhang and Miller 1996). Dissolution of gypsum releases electrolytes into the rainwater, the electrolyte effect, and Ca derived from dissolved gypsum displaces Na ions from the exchange complex of the soil, the reclamation effect (Keren and Shainberg 1981). The effects of gypsum and exchangeable sodium percentage (ESP) of the soil on surface runoff and soil loss under rainfall having different electrolyte concentration are shown in Fig. 22.2. Soil with highest ESP showed the highest values for surface runoff. The cumulative runoff for 2 h rainfall did not differ clearly among gypsum levels. The soil loss was not clearly affected by gypsum application rate, but it varied with different soil ESP. However, in all cases, low ESP soil showed the lowest values for soil loss. Those results were partly due to the initial condition that low and medium ESP soils had high initial EC, 9.29 and 13.54 dS m^{-1}, respectively, in which the electrolyte concentration effect exceeded the ion exchange effect.

Both surface runoff and soil loss increased with increasing ESP of the soil (Shainberg and Letey 1984), while gypsum usually helps clay particles to flocculate. Especially during rainfall season, application of gypsum enhances deposition of sediments and reduces uptake of finer particles by the surface runoff (Warrington

Table 22.3 Soil basic intake rate (I_B)

High ESP soil (I_B)	PAM 80 kg ha^{-1}	PAM 20 kg ha^{-1}	Control	PAM 20 kg ha^{-1} + gypsum 2 Mg ha^{-1}	PAM 80 kg ha^{-1} + gypsum 2 Mg ha^{-1}	PAM 20 kg ha^{-1} + gypsum 5 Mg ha^{-1}	PAM 20 kg ha^{-1} + saline water of 2 dS m^{-1}	PAM 20 kg ha^{-1} + saline water of 5 dS m^{-1}	PAM 80 kg ha^{-1} + saline water of 2 dS m^{-1}
mm h^{-1}	0.00	3.24	4.75	5.16	5.50	6.66	7.05	7.08	7.18

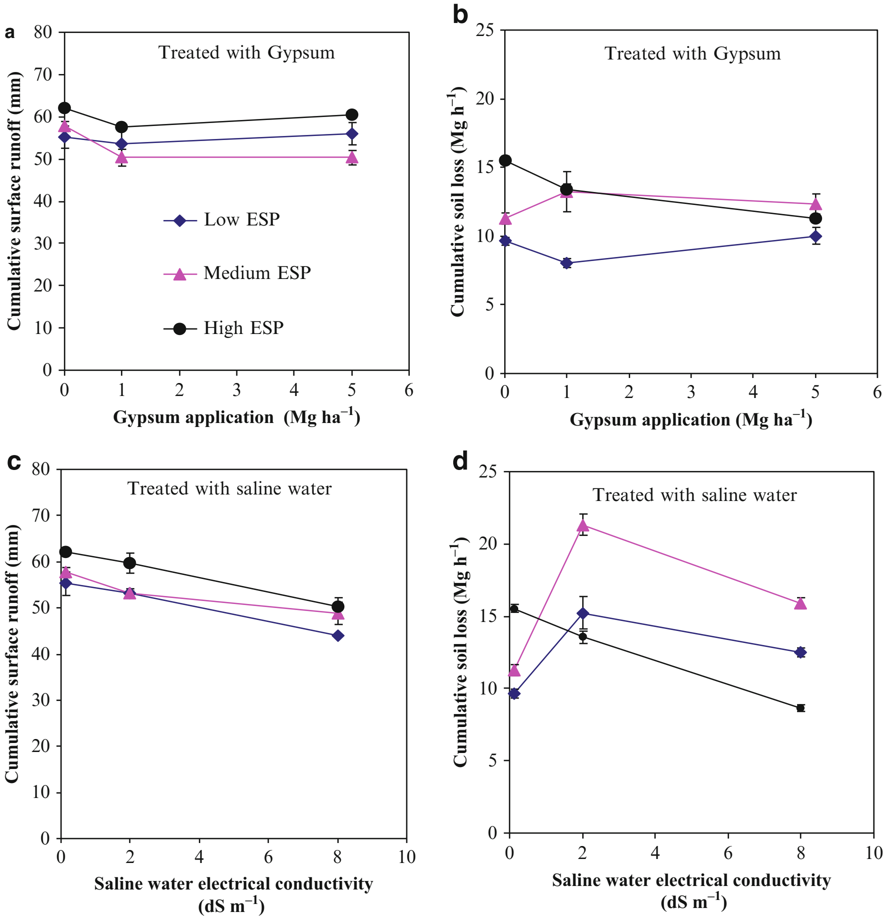

Fig. 22.2 Characteristics of soil erosion at different ESP and treated with gypsum or saline water

et al. 1990; Yu et al. 2003). Surface runoff under saline water rainfall showed the higher value for the higher ESP soil. However, runoff significantly decreased with higher EC of saline water. The saline rainwater with EC = 2 dS m^{-1} enhanced cumulative soil loss as compared to tap water (0.13 dS m^{-1}). This result suggests that some clay dispersed occurred due to saline rainwater of SAR = 5 (mmoles $L^{-1})^{0.5}$.

For both gypsum and saline treatments, soil loss and surface runoff were varied and inconsistent since both were highly affected by initial EC of the soil. Moreover, the interaction effect of EC, ESP, gypsum, and saline water treatment was the main reason for different ranking order of soil loss and surface runoff between all treatments shown in Fig. 22.2.

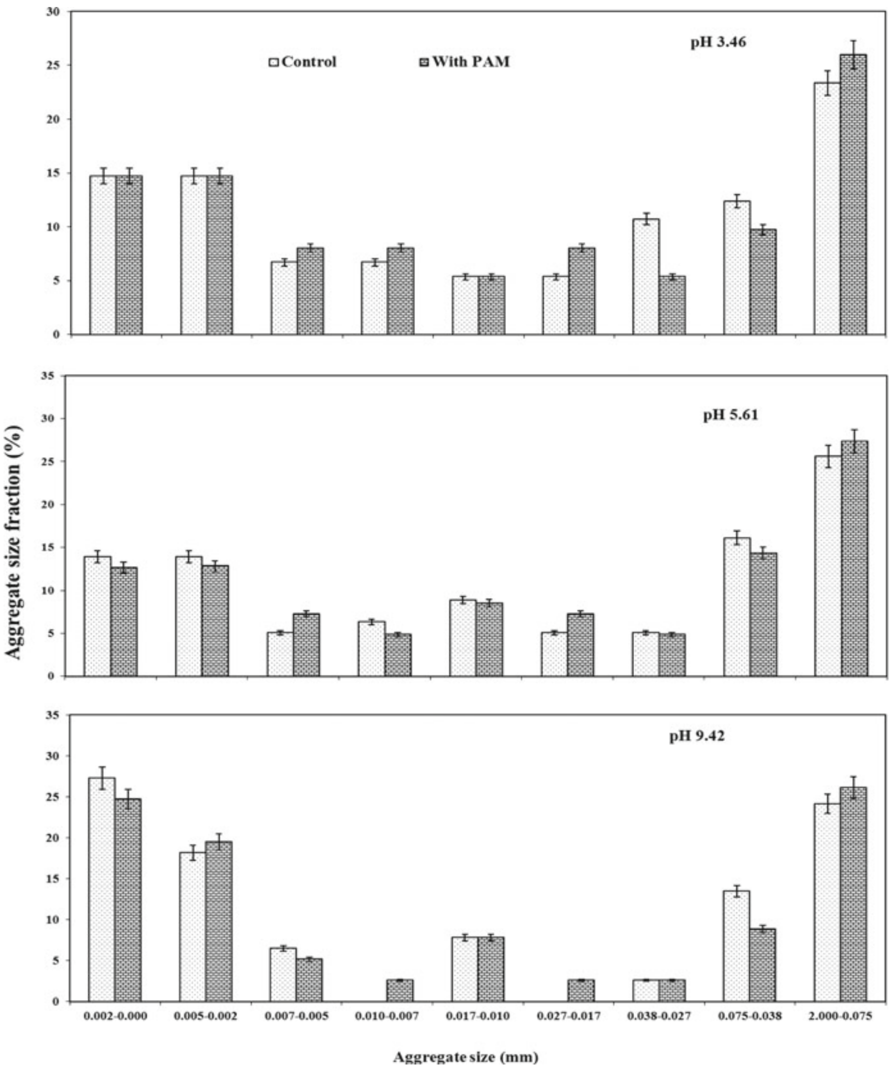

Fig. 22.3 Effect of PAM on soil aggregate stability at three different soil pH conditions

22.3.2 *Effect of PAM on Aggregate Stability at Different Soil pH Conditions*

The effects of PAM on the stability of soil aggregate under different soil pH conditions are given in Fig. 22.3. The soil pH did not interfere with the effectiveness of PAM on soil aggregate stability. Stability of the aggregate having 1–2 mm was considerably enhanced by anionic PAM application for the all pH examined in this study. This is probably due to the anionic PAM incorporation with soil particles and reduction of sediment formation. PAM is an adhesive agent, and it is combining with small particles to form big ones that can resist soil erosion.

The fraction of 2–1 mm was reported as an appropriate range to assess the ability of soils to withstand rain impacts (Rasiah and Kay 1995). Furthermore, as fraction of the largest aggregate is getting larger, formation of small particles becomes less (Berthes and Roose 2002). Generally, aggregate stability increases with an increase in clay content, and therefore, higher wetting rates and impact energy are needed to disintegrate aggregates of clay soils (Shainberg et al. 2003). Physicochemical clay dispersion is enhanced with increase in soil ESP and decrease in soil solution electrolyte concentration (Shainberg and Letey 1984).

22.3.3 Effect of PAM on Temporal Change of Soil Erosion Under Non-saline Rainwater

The temporal changes of runoff and soil loss during 2 h-simulated rainfall were affected by PAM application (Fig. 22.4). Runoff remarkably increased with higher doses of the anionic PAM. This could happen due to the long chain of the PAM which clogged soil pores, prevented infiltration, and enhanced surface runoff. Besides that, soil loss decreased with higher amount of PAM incorporation in the following order: control >20 kg ha^{-1} > 80 kg ha^{-1} PAM.

Yu et al. (2003) and Al-Abed et al. (2003) reported similar results that the anionic PAM effectively reduced soil loss and enhanced surface runoff water. The long chain of the ionic PAM polymer in the soil surface exposed to non-saline rainwater could be a possible reason of reduction in soil loss. As Barvenik (1994) explained that the chain length of the PAM polymer in diluted solutions might reach 0.1 to 0.2 mm. The polymer adsorbed on external surfaces of aggregates and bound soil particles together could develop higher resistance to the impacts of raindrops and reduce soil erosion.

22.3.4 Effect of PAM Mixed with Gypsum on Soil Erosion Under Non-saline Rainwater

As shown in previous section, PAM application enhanced surface runoff. However, mixing PAM with gypsum decreased surface runoff compared to the soil treated with PAM only. More dose of gypsum caused slight decrease in runoff (Fig. 22.5). Cumulative soil loss was increased with increasing gypsum application on PAM-treated soil. This was similar to the results of Yu et al. (2003). He reported that PAM along with gypsum treatments was found less effective than the application of PAM alone in reducing soil loss of silt loam soil. Shrink or broken down of the PAM

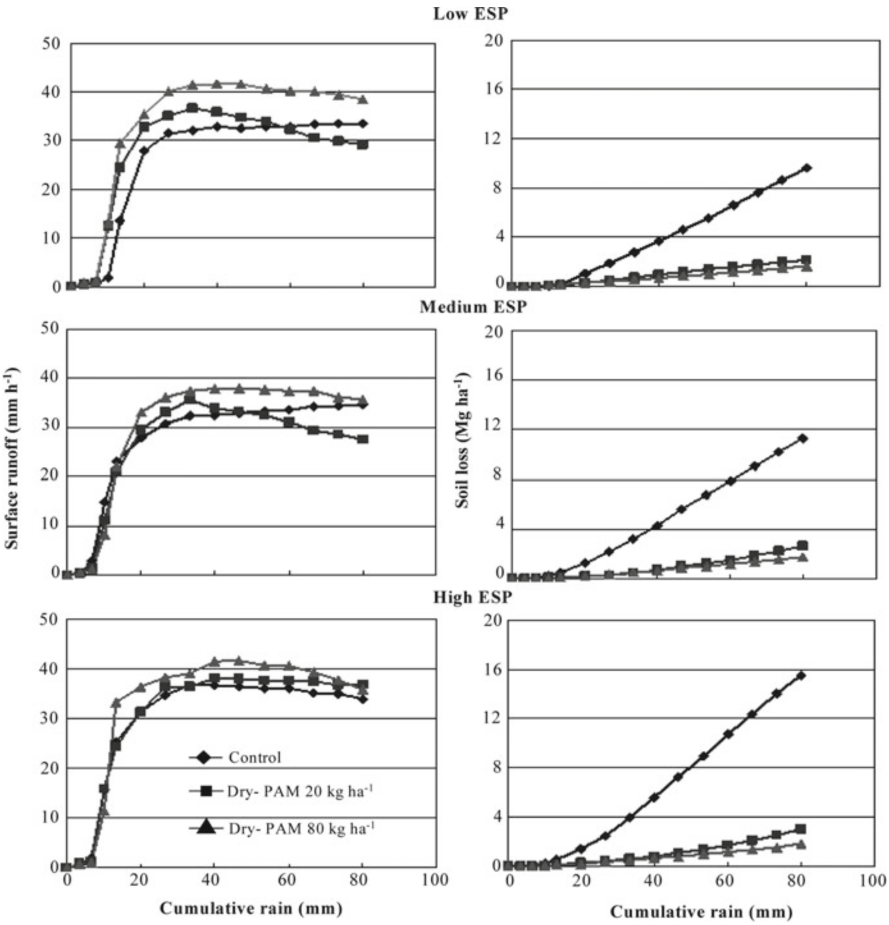

Fig. 22.4 Effect of PAM on surface runoff and soil loss

structure and accompanied decrease in viscosity with the presence of electrolyte, especially gypsum, could be a reason of less effectiveness of PAM with gypsum treatment. However, surface application of dissolved PAM mixed with gypsum was found to be very effective in decreasing seal formation, runoff, and erosion. Moreover, use of PAM mixed with gypsum resulted in higher final infiltration rate and lower runoff and wash erosion levels than gypsum alone in loamy sand and clay soils (Tang et al. 2006). There are several reasons for adding PAM together with a source of electrolytes (e.g., gypsum). PAM efficacy in preventing seal formation is enhanced in the presence of electrolytes (Shainberg et al. 1990). In addition, since amount of PAM to be applied was small (≈20 kg ha^{-1}), mixing the PAM with 2–4 Mg ha^{-1} of a source of electrolytes reduces viscosity of the PAM and can ensure a uniform spreading of the mixture on the soil surface (Tang et al. 2006).

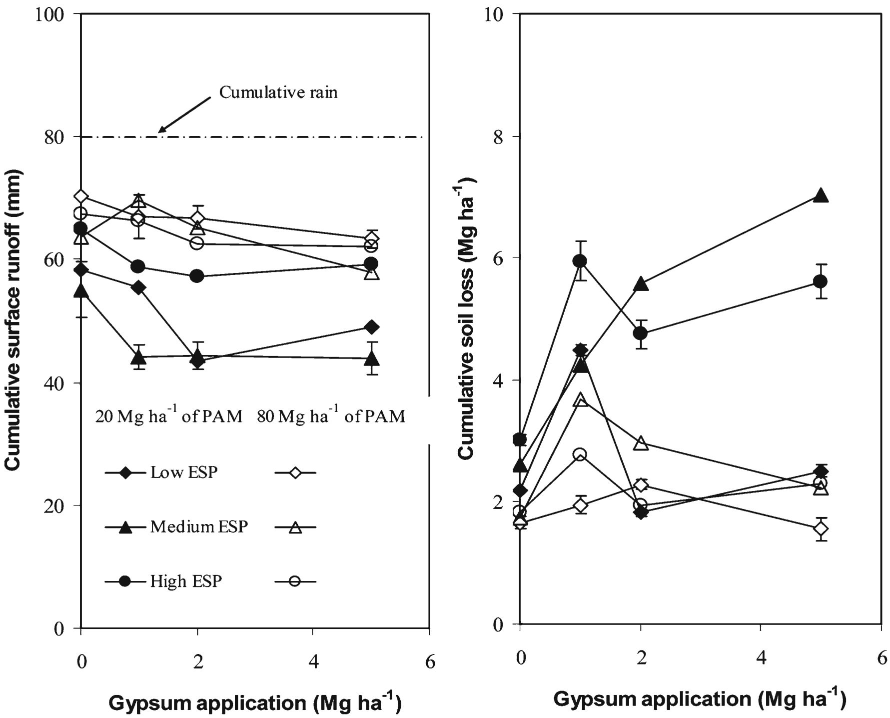

Fig. 22.5 Characteristics of soil erosion at different ESP and treated with PAM mixed with gypsum

22.3.5 Effect of PAM on Soil Loss Under Various Saline Rainwaters

There was a significant decrease in soil loss with increasing PAM application rate. In soil treated with anionic PAM, increasing EC of the saline water rainfall enhanced cumulative soil loss but decreased runoff regardless to ESP status (Fig. 22.6). The combined effects of saline water with PAM treatments were closely resembled to the gypsum mixed with PAM application in terms of soil loss and surface runoff (Fig. 22.5). Originally, the aim of gypsum application is to increase the electrolyte concentration of soil surface prior to rainfall to restrict dispersion of clay particles. However, in this experiment, higher electrolyte concentration could break PAM structure and decrease its efficiency in binding soil particles, clogging soil pores, and sealing soil surface. This could be a reason that PAM together with saline water also induced higher detachments of soil particles and less runoff.

Laboratory and field studies with anionic PAM (e.g., Gardiner and Sun 2002; Bjorneberg et al. 2003; Vacher et al. 2003) have clearly demonstrated that addition of small amounts of PAM (10–20 kg ha^{-1}) to the soil surface was effective in maintaining

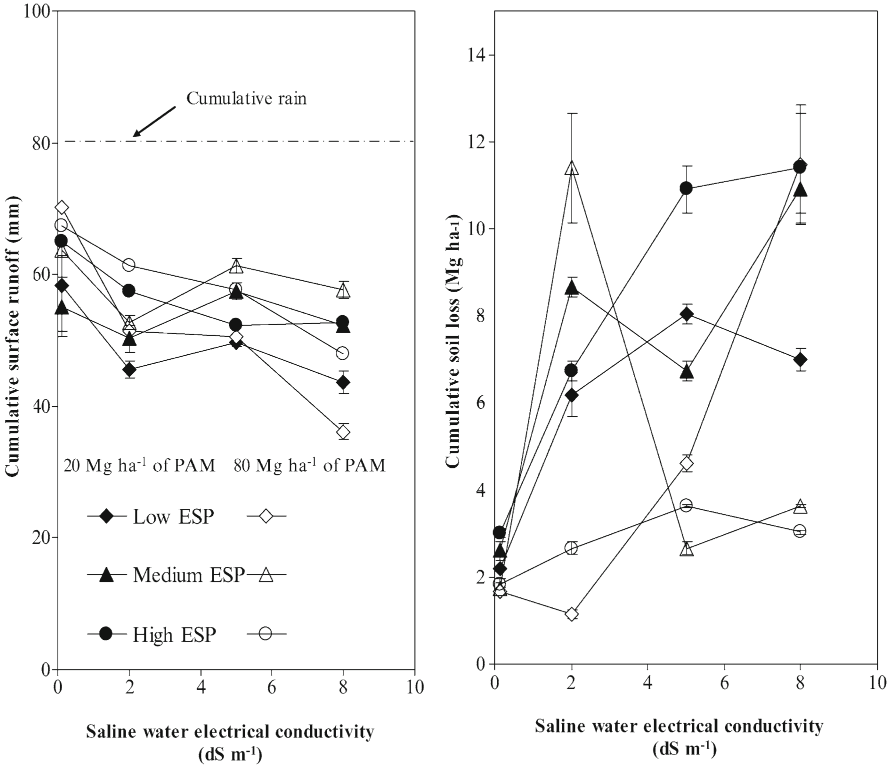

Fig. 22.6 Effect of PAM on soil loss under various saline rainwaters

high permeability and decreasing runoff and soil loss from soils exposed to impact of raindrops, especially when the PAM was applied together with a source of electrolytes (Tang et al. 2006). Concerning sodic conditions, the impact of PAM on infiltration and soil erosion was tested with solutions of different electrolyte concentrations; the results obtained were inconsistent and were not related to the salt concentration in the solutions used. With respect to maintaining high permeability and less runoff, it has been noted that already at ESP-9, PAM was ineffective or less effective compared with non-sodic conditions. Conversely, PAM was very effective in reducing soil erosion even at ESP > 25 (Ben-Hur et a1. 1992; Levy et al. 1995).

The increased PAM application exhibited lower infiltration rate in the studied soil of intake experiment (Fig. 22.7). The final rate of water intake differed among the treatments as follows: PAM 80 kg ha^{-1} < PAM 20 kg ha^{-1} < control < PAM 20 plus gypsum 2 Mg ha^{-1} < PAM 80 plus gypsum 2 Mg ha^{-1} < PAM 20 plus saline water 2 dS m^{-1} < PAM 20 plus saline water 5 dS m^{-1} < PAM 80 plus saline water 2 dS m^{-1}. When PAM was mixed with gypsum or saline water, the accumulated electrolytes on soil surface improved hydraulic conductivity even under high sodic conditions. However, adding PAM with high concentration (80 kg ha^{-1}) could seal soil surface and inhibit infiltration rate.

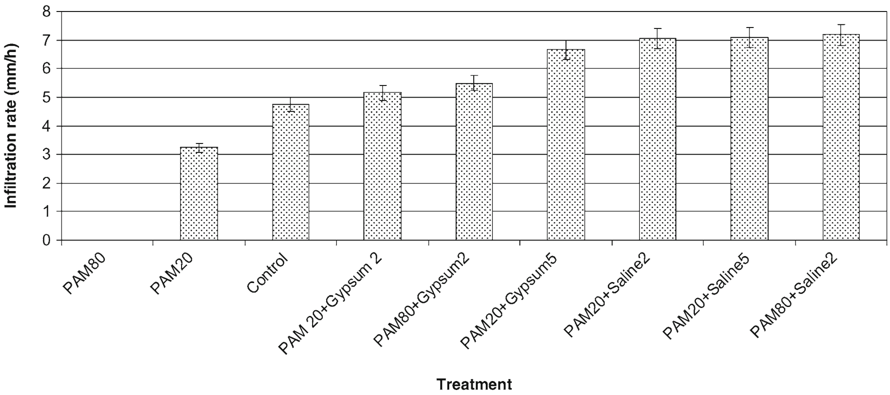

Fig. 22.7 Effect of different treatments on final infiltration rate

In a study conducted by Tang et al. (2006), he found increasing ESP from 5 to 20 in the loamy sand decreased final infiltration rate from 14 to 2 mm h^{-1} and increased runoff and wash erosion in the control. Similar trends but of different magnitude were noted in the other soil types. Spreading PAM mixed with gypsum or gypsum alone was effective in maintaining final infiltration rate >12 mm h^{-1}, low runoff, and wash erosion levels compared with their control.

22.4 Conclusion

This experiment indicated that PAM was more effective than gypsum in controlling soil erosion. As expected, the soil sodicity tremendously enhanced soil losses as well as surface runoff. While the anionic PAM, gypsum, and saline water treatments can sustain or slightly reduced surface runoff, the PAM and PAM-gypsum mixture could significantly reduce soil loss. Effect of PAM on reducing soil loss under saline water rainfall was not clear. This could be due to change in PAM structure in the electrolyte solution. A reduced water intake of soil by PAM was also noted. The application of PAM mixed with other treatments presumably hindered surface seal formation and thus aggravated the detachments of soil particles.

References

Al-Abed N, Amayreh J, Shudifat E, Qaqish L, El-Mehaisin G (2003) Polyacrylamide (PAM) effect on irrigation induced soil erosion and infiltration. Achiev Agron Soil Sci 49:301–308

Amoozegar A, Warrick AW (1986) Hydraulic conductivity of saturated soils: field methods. In: Klute A (ed) Methods of soil analysis. Part I. Soil Science Society of America Book Series No. 5, 2nd edn. Soil Science Society of America and American Society of Agronomics, Madison, pp 383–411

Agassi M, Shainberg I, Morin J (1981) Effect of electrolyte concentration and sodicity on the infiltration rate and crust formation. Soil Sci Soc Am J 45:848–851

Barvenik FW (1994) Polyacrylamide characteristics related to soil applications. Soil Sci 158:235–243
Ben-Hur M, Clark P, Letery J (1992) Exchangeable Na, polymer and water quality effects on water infiltration and soil loss. Arid Soil Res Rehab 6:311–317
Berthes B, Roose E (2002) Aggregate stability as an indicator of soil susceptibility to runoff and erosion; validation at several levels. Catena 47:133–149
Bjorneberg DL, Santos FL, Castanheira NS, Martins OC, Reis JL, Aase JK, Sojka RE (2003) Using polyacrylamide with sprinkler irrigation to improve infiltration. J Soil Water Conserv 58:283–289
Gardiner DT, Sun Q (2002) Infiltration of wastewater and simulated rainwater as affected by polyacrylamide. J Am Water Resour Assoc 38:1061–1067
Gee GW, Bauder JW (1986) Particle-size analysis. In: Klute A (ed) Methods of soil analysis. Part I. Soil Science Society of America Book Series No. 5, 2nd edn. Soil Science Society of America and American Society of Agronomics, Madison, pp 383–411
Heller H, Keren R (2002) Anionic polyacrylamide polymers effect on rheological behavior of Na montmorillonite suspensions. Soil Sci Soc Am J 66:19–25
Keren R, Shainberg I (1981) Effect of dissolution rate on the efficiency of industrial and mined gypsum in improving infiltration of a sodic soil. Soil Sci Soc Am J 45:103–107
Levy GJ, Levin JL, Shainberg I (1995) Polymer effects on runoff and soil erosion from sodic soils. Irrig Sci 16:9–14
National Institute of Agro-Environmental Sciences (NIAES) (1996) Classification of cultivated soils in Japan, Classification Committee of cultivated soils. National Institute of Agro-Environmental Sciences, Tsukuba
Rasiah V, Kay BD (1995) Runoff and soil loss as influenced by selected stability parameters and cropping and tillage practices. Geoderma 68:321–329
Saybold CA (1994) Polyacrylamide review: soil conditioning and environmental fate. Commun Soil Sci Plant Anal 25:2171–2185
Shainberg I, Letey J (1984) Response of soils to sodic and saline conditions. Hilgardia 52:1–51
Shainberg I, Levy GJ (1994) Organic polymers and soil sealing in cultivated soils. Soil Sci 158:267–273
Shainberg I, Sumner ME, Miller WP, Ferina MPW, Pavan MA, Fey MV (1989) Use of gypsum on soils: a review. Adv Soil Sci 9:1–111
Shainberg I, Warrington D, Rengasamy P (1990) Effect of soil conditioner and gypsum application on rain infiltration and erosion. J Soil Sci 149:301–307
Shainberg I, Mamedov AI, Levy GJ (2003) The role of wetting rate and rain energy in seal formation and interrill erosion. Soil Sci 168:54–62
Tan HK (1993) Principle of soil chemistry, 2nd edn, Soil reaction. Marcel Dekker, Inc., New York, pp 255–278
Tang C, Rengel Z (2003) Role of plant cation/anion uptake ratio in soil acidification. In: Rengel Z (ed) Handbook of soil acidity. Marcel Dekker, Inc., New York/Basel, pp 57–81
Tang Z, Lei T, Yu J, Shainberg I, Mamedov AL, Ben-Hur M, Levy GJ (2006) Runoff and interrill erosion in sodic soils treated with dry PAM and phosphogypsum. Soil Sci Soc Am J 70:679–690
Theng BKG (1984) Clay-polymer interactions: summary and perspectives. Clay Clay Miner 30:1–10
Vacher CA, Loch RJ, Raine SR (2003) Effect of polyacrylamide additions on infiltration and erosion of disturbed lands. Aust J Soil Res 41:1509–1520
Warrington D, Shainberg I, Agassi M, Morin J (1990) Slope and phosphogypsum effects on runoff and erosion. Soil Sci Soc Am J 53:1201–1205
Yu J, Lei T, Shainberg I, Mamedov AI, Levy GJ (2003) Infiltration and erosion in soils treated with dry PAM and gypsum. Soil Sci Soc Am J 67:630–636
Zhang XC, Miller WP (1996) Polyacrylamide effect on infiltration and erosion in furrows. Soil Sci Soc Am J 60:866–872

Chapter 23
Practical, Productive, and Environment-Friendly Utilization of Different Categories of Salt-Affected Soils in Arid and Semiarid Regions of Pakistan

Shafqat Farooq, M. Akram, M. Afzal, R. Arshad, and Farooq Azam

Abstract Saline soils in Pakistan are of three types. First type includes porous saline and saline-sodic soils (4.79×10^6 ha) located in irrigated areas. These soils possess electrical conductivity in the range of 10–15 dS m^{-1} and can be cultivated with salt-tolerant wheat. A short-duration and short-stature wheat line (SSt) was developed for such areas which is also resistant to lodging that may occur as a consequence of irrigation. The second types of soils (1.5×10^6 ha) have twin problems of salinity and water deficiency and are located in water-deficit areas of southern Punjab and parts of Sindh. A drought-tolerant wheat line (DTL) was developed for these areas which can be grown with only pre-sowing irrigation and can produce grain yield of about 6,000 kg ha^{-1}. The third types of soils (11×10^6 ha) are located in Cholistan, Thar, Thal, and Kharan areas beset with salinity, high rate of evaporation, and strong winds. Water is most critical and limiting factor that prohibits agriculture production under such areas. Wheat variety "DURUGEN" was developed for these soils which combine tolerance for salt, water deficiency, and high temperature. It can be cultivated in desert areas for production of green biomass which can be used (1) as fodder to raise sheep and goats, (2) to provide green cover to barren lands thereby improving both land and the environment, and (3) to help providing livelihood to the poor natives. This chapter provides details of specific wheat genotypes and successful cultivation of these genotypes on saline soils.

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Keywords Arid region • Cholistan • Pakistan • Salt-affected soils • Wheat

23.1 Introduction

The problem of salinization developed with irrigated agriculture about 6,000 years ago on Tigris-Euphrates River (Jacobsen 1982). With the passage of time, groundwater came above the surface, and salt dissolved in it started accumulating in the root zone which resulted in decline of productivity and loss of powerful agrarian society.

In arid regions, however, cause of soil and/or water salinization is accumulation of water-soluble salts in ground, soils, and water. For example, in Pakistan, it is estimated that about 35–40 million tons of salts are being added regularly to the Indus Basin through the river flows alone (Farooq 2004). The salt concentration in good quality canal water is between 150 and 250 mg L^{-1} (Ghassemi et al. 1995). Application of 500 mm of water with a salinity of 200 mg L^{-1} adds 1 t of salt ha^{-1}, whereas crop requirement of water is about 6,000–10,000 m^3 ha^{-1} of water for one crop which means adding 3–5 t of salt ha^{-1} every crop season. The problem is aggravated when irrigation is applied from saline tube-well water, which adds another 100 million t of salts to soil surface every year (ICID 1991). Leaching of such salts is difficult due to shortage of fresh water and very low annual rainfall (0.99–33 mm). As a result, salinity has developed over 6.30×10^6 ha of land in Pakistan which has collectively and adversely affected chemical, physical, and biological characteristics of soils and crop productivity.

The entire 6.3×10^6 ha of saline soils differed substantially in salt concentration, composition, and climatology and are divided into three general types, i.e., (1) saline soils in irrigated areas, (2) saline soils in water-deficit and/or dry areas, and (3) saline soils in desert areas. The saline soils in irrigated areas possess electrical conductivity in soil saturation extract (ECe) in the range of 10–15 dS m^{-1}, are found as saline-sodic throughout root zone, can be easily drained, and possess good physical qualities. The extent of these soils in Pakistan is 4.79×10^6 ha of which 1×10^6 ha is under wheat cultivation. Cultivation of such soils requires salt-tolerant genotypes which can be specifically tailored to suit the target environment.

Saline soils in water-deficit areas are beset with desertification and are largely located in southern Punjab and some part of Sindh province. The average temperature during wheat season in these areas ranges between 19 and 32°C and average annual rainfall between 0.19 and 32 mm. These soils possess ECe in the range of 6–10 dS m^{-1} and exist as patches. The extent of such soils in Pakistan is 1.5×10^6 ha and can be cultivated with high yielding salt-tolerant germplasm that may also tolerate water deficiency coupled with high temperature.

The saline soils in desert areas are peculiar to semiarid zone comprising Cholistan, Thar, and Kharan. These soils are beset with high rate of evaporation and strong summer winds. Water is most critical and limiting factor that prohibits using such areas for agricultural production. These saline soils require genotypes that can be grown without much water, can sustain strong winds, and can provide green cover to barren land thereby protecting it from the wind erosion.

Cultivating all these soils, however, requires salt-tolerant genotypes which can be specifically tailored, but the problem is that all the saline soils are not similar in nature. There are highly significant differences in salt composition, type, and quantity of predominant salt in a particular area, climatic conditions, availability and type of irrigation water, and coexistence of salinity with desertification. All these conditions warrant selection, tailoring, and/or production of plant specifically suitable to such conditions. In this chapter, efforts made in this direction are being presented. Practical success of these efforts indicated that there exists an approach and strategy for every type of saline soil which can be implemented at will.

23.2 Materials and Methods

Wheat material used in this study comprised short-stature line (SSt), drought-tolerant line (DTL), and "DURUGEN" which combines salt and drought tolerance.

The DTL was produced by crossing one of the salt (Farooq et al. 1992) and water deficiency tolerant (Farooq and Azam 2001) wheat lines WL-1076 with a water deficiency tolerant accession of *Aegilops geniculata*. The F1 hybrid was backcrossed with recurrent wheat parent and selfed six times before DTL was tested in the field for salt tolerance.

Short-stature (SSt) line was produced by crossing another line WL-886 (Farooq et al. 1992) with F2 plants of a cross between (Pasban × W4909) made at USDA-ARS, Forage and Range Research Laboratory, Utah State University, Logan, Utah (Wang et al. 2003a). Dr. Wang transferred independently salt tolerance from *Thinopyrum junceum* (one of the salt-tolerant wild wheat grass) through addition lines synthesized from a partial amphiploid of a cross between *Triticum aestivum* × *Th. junceum*. The disomic addition line (AJDAjs) was crossed with the *Ph1* mutant of Chinese spring. Some of the F2 and F3 derivatives of this cross were screened for salt tolerance and from this screening W4909 was selected.

DURUGEN was produced (Farooq and Azam 2007) by crossing durum wheat (*Triticum durum* L.) as female parent with salt-tolerant accession F of *Ae. geniculata* (Farooq et al. 1989) which is also tolerant to drought and/or water deficiency. It was a fully fertile amphiploid in which doubling of chromosomes occurred automatically. It was produced for dry areas in desert. All these genotypes were tailored made to suit particular stressed environment and were used accordingly

Field trials of all the three genotypes were conducted in government farms (Fig. 23.1). For DTL, the farm selections were made in Khanewal and Mian Channu in the district Multan, and Soil Salinity Research Institute, Pindi Bhattian, a tehsil of Hafizabad District near Faisalabad (the map location is between Faisalabad and Chiniot). Soil Salinity Research Institute is located here because the area possesses large tracts of saline soils which are saline-sodic throughout the root zone with ECe ranging between 10 and 15 dS m^{-1}. For SSt, district Rahim Yar Khan and district Kamalia were selected. Districts Rahim Yar Khan is bounded on the north by Muzaffargarh District, on the east by Bahawalpur District, on the south by Jaisalmer (India) and Ghotki District of Sindh Province, and on the west by Rajanpur District

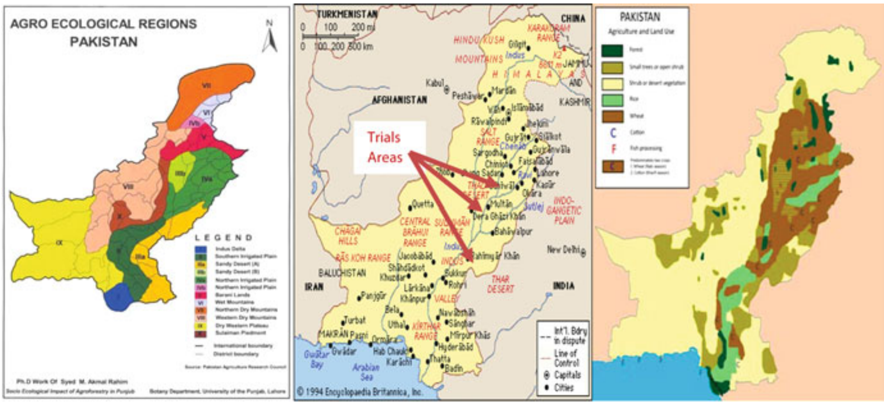

Fig. 23.1 Maps of Pakistan indicating agro-ecological zones (*left*), trial areas (*center*), and agriculture and land use (*right*) describing clearly the ecology of the areas where the trials were conducted

and thus is center of hot and dry area. Water logging and salinity have badly hurt plant life. Because of the increase of salinity at the surface, only salt-resistant plants can survive in most of the areas. The southern half of the district, characterized by sand dunes, is mostly barren. The area thus is largely represented by saline soils in water-deficit area and soils in desert area, while main crops are wheat and cotton as indicated in the maps.

For cultivation of "DURUGEN", artificial desertification was created at the experimental fields of Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad. At every place, five rows each with 5 m of length were sown with the test material in randomized complete block design (RCBD) and three replications. Only two irrigations were applied to SSt and two to DTL (instead of 5–6 given to commercial wheat varieties), while "DURUGEN" was given only pre-sowing irrigation. Fertilizer was applied at half the dose recommended (Rafique et al. 2000) for commercial varieties, i.e., NPK at the rate of 80, 57.5, and 30 kg ha^{-1}. All phosphorus (P) and potassium (K) was applied at the time of sowing, while nitrogen (N) was divided into three doses of 40, 20, and 20 kg ha^{-1}: The first was applied at the time of sowing, and the remaining two at first and second irrigation. At all the locations, wheat cultivar "Inqlab" was used as local check. The yield was recorded at maturity before the crops were harvested in the month of May 2006–2007 crop season.

23.3 Results

SSt was produced for saline areas where wheat-cotton rotation is being practiced especially in the district Rahim Yar Khan in southern part and district Kamalia in central part of the Punjab Province. It was sown at the end of January (instead of

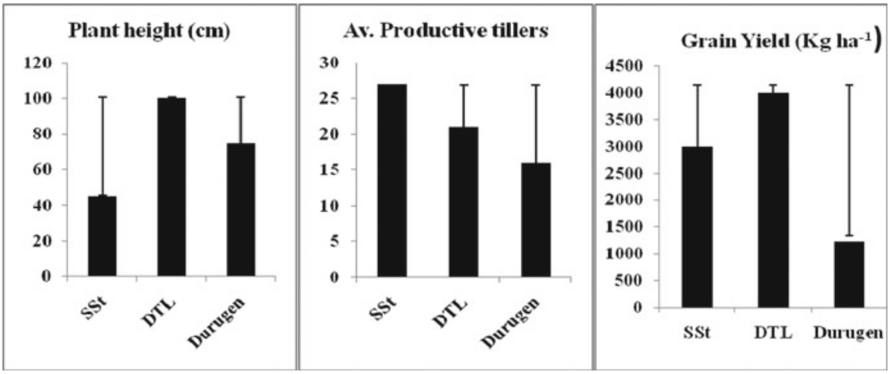

Fig. 23.2 Average plant height (cm), number of productive tillers, and average grain yield in three wheat lines tested on various saline soils in different districts of Pakistan. The plant height of SSt was comparatively less because it is short stature; number of average productive tillers in DURUGEN was comparatively less because within the plant variation for tillers was 6–24; similarly grain yield of DURUGEN was comparatively less because within the plant variation for grain spike^{-1} was 15–23; nevertheless, the grain yield was 23% higher than the other salt-tolerant wheat lines grown under similar conditions

November which is a normal sowing time) after picking last lint of cotton from the cotton field. By the first week of May (90–100 days after sowing), SSt plants on the average attained 45 cm of height, produce 24–30 productive tillers, and average grain yield of about 3,000 kg ha^{-1} compared to 1,000 kg ha^{-1} of commercial cultivar. Getting this much yield in 100 days compared to 155–160 days of commercial cultivars was never possible without SSt (Fig. 23.2). DTL was developed for the saline areas having twin problems of salinity and water deficiency and are largely located in water-deficit areas such as Bahawalpur, and Rahim Yar Khan in the southern Punjab (average temperature during wheat season ranges between 19 and 32°C and average rainfall between 0.91 and 32 mm) and some parts of Sindh province. At Rahim Yar Khan, the genotype on the average possesses 100-cm long plant height, >21 productive tillers plant^{-1}, and grain yield of 4,000 kg ha^{-1} which was 10% higher than the yield obtained from local the check (Fig. 23.2).

DURUGEN was produced to combat salinity that is coupled with high temperature, heat, and water scarcity especially in the areas of Thal, Thar, and Kharan where salinity and desertification coexist. The field trials of first-generation "DURUGEN" plants produced 6–26 tillers, 4–20 spikes, and 60–90-cm plant height, 55–90 g of plant weight, 15–23 grain spike^{-1}, and 2.2–6.3 g grain weight spike^{-1}. The second-generation plant when tested using 50% less irrigation water and salinity of 1/3rd of the seawater (0.88% salt) indicated significantly lower reduction (10–12%) in biomass and grain yield (5–8%) compared to that (37 and 23%, respectively) observed in other salt-tolerant wheat genotypes grown under similar conditions (Fig. 23.1)

23.4 Discussion

The earth surface is undergoing massive land use transformations as a consequence of human-accelerated environmental degradation and global warming (Guy et al. 2006) that may have serious and detrimental effects on human life. These effects are though difficult to predict at the moment, but depleting water resources, increasing temperature, and spread of salinity and of poverty provide some indications of horrible future not too far away from now. The changes are not only a threat to sustained agricultural productivity but have also raised serious environmental concerns in terms of desertification, erosion, and allied problems (Anonymous 2000). It is anticipated that prevalence of such situation around the globe would result in 30% of world arable land loss within next 25 years and 50% by the year 2050 (Wang et al. 2003b). The current world's population is seven billion which is expected to be over nine billion in 2050 of which over seven billion (>current population) would be living in developing countries.

Pakistan's current population is over 180 million, and current frequency of undernourished people is between 35% and 36% which is on the rise (FAO 2008). To meet the Millennium Development Goal, Pakistan needs more food calories to reduce the number of undernourished people which is only possible either by reducing the current calories consumption from 2,340 kcal person^{-1} day^{-1} to the minimum standard of 2,000 kcal person^{-1} day^{-1} (FAO 2008) or increase the food production especially of wheat (which is a major staple cereal) from current production of 4×10^6 t to 26.50×10^6 t. The results obtained in the present study, however, proved the feasibility and applicability of the later approach. For example, short-stature and short-duration wheat line SSt was developed for 1×10^6 ha of saline areas that is canal irrigated and is used for wheat production. This area was specifically focused in the present study. Farmers of this area generally practice wheat-cotton rotation. Being cash crops, farmer wants to pick the last lint of cotton, and hence the fields cannot be vacated in November; for timely wheat sowing instead, the fields are vacated in late January which is too late for wheat sowing. The SSt being short duration is particularly liked by the progressive cotton farmers because it can be cultivated in these fields in late January. Even then, it can be harvested in the first week of May (just in 90–100 days) with a grain yield of about 3000 kg ha^{-1} which is significantly higher than 1,000 kg ha^{-1} grain yield obtained from commercial wheat cultivar planted under similar conditions. The miraculous performance of this line has the potential to revolutionize the wheat production in the cotton belt which is also best with salinity and high temperature. Before production of SSt, farmer used to get only one (cotton) crop, and now they can get two (wheat and cotton). The extent of saline soils in irrigated areas of Pakistan is 4.79×10^6 ha of which 2.89×10^6 ha became saline due to irrigation provided by subsurface saline water. If SSt can be cultivated on only 1×10^6 ha of this area, it would produce approximately 3×10^6 t of extra wheat which in turn can increase consumption of calories by the poor inhabitant of saline/degraded lands. Earlier, production of WLs 1076, 1073, and 41 (Farooq et al. 1992) for these areas exhibited several folds more tolerance (Farooq et al. 1995) and produced significantly higher yield under saline field of ECe of 15–20 dS m^{-1} (Farooq et al. 1998). The WL-1076 being tolerant to multiple stresses (Farooq and Azam 2001) was also used to be cultivated inside standing cotton crop on the beds between two furrows to be used for irrigation. The seepage from the furrow salinized these beds, and WL-1076 being salt and water deficiency tolerant proved excellent for cultivating on these beds. Farmers do not have to vacate the cotton field in November for normal wheat sowing. With the advent of WL-1076, they are getting full cotton crop and a full wheat crop as bonus because they do not provide anything extra like that of irrigation, fertilizer, or spending on land preparation for wheat sowing.

DTL is an improved version of WL-1076 which possesses proven potential to be cultivated on saline soils that are located in water-deficit areas such as Bahawalpur and Rahim Yar Khan where farmers provide only two to three irrigations (instead of at least five given to commercial cultivars) and less than half the recommended dose of fertilizer. In Bahawalpur regions, farmers obtained grain yield of 4,000 kg ha^{-1} which was 10% higher than the commercial wheat cultivar Inqlab that was very popular in that area. Inqlab is an input intensive cultivar, and the resource-deficient farmer cannot afford to cultivate this because they generally do not get access to adequate water supply, which is reducing with every passing day, and they also cannot purchase the expensive fertilizers which are largely imported.

DURUGEN was produced for saline soils that are coupled with desertification. The extent of these soils in Pakistan is 11×10^6 ha and mostly located in Thal, Thar, and Kharan. High temperature, strong winds, heat, and scarcity of water prohibit these areas to be used for agriculture; hence, the inhabitants have largely been migrated to other places in search of livelihood. Potential of DURUGEN has indicated that if cultivated in these areas, the farmer at least can get green cover on the barren land which can prevent land erosion caused by strong winds thereby improving the desert environment. It can also provide some fodder for the animals which is enough attraction for rehabilitating these soils and their owners to their native place. Success achieved by cultivating the newly produced genotypes in the target areas indicated that there exists a practical strategy for productive and environment-friendly utilization of every type of saline soil. However, the magnitude of success varies depending upon the target situation, the cultivar developed for that area (keeping in mind the situation that we kept in mind when we developed these lines), and resource to be invested in a particular target area.

23.5 Conclusion

It can be safely concluded that to support agriculture activities in the changing environment, it is imperative to have continuous development of new genotypes and technologies that can adapt rapidly to any target environment. In the present study, the examples of newly developed genotypes and demonstrated practical, productive, and environment-friendly results indicated that it is indeed possible to use any type of soils at will provided that flow of new genotypes with diversified genetic background remains to continue.

References

Anonymous (2000) Agriculture strategies for the first decade of new millennium. Pakistan Agriculture Research Council (PARC), Ministry of Food, Agriculture and Livestock (MINFAL) and Planning and Development Division, Government of Pakistan, Islamabad

FAO (2008) The state of food insecurity in the world. High food prices and food security-threats and opportunities. Food and Agriculture Organization of the United Nations, Room

Farooq S (2004) Salt tolerance in *Aegilops* species: a success story from research and production to large scale utilization of salt tolerant wheat. In: Taha FK, Ismail S, Jaradat A (eds) Prospects of saline agriculture in Arabian Peninsula. Amherst Scientific Publisher, Amherst, pp 121–134

Farooq S, Azam F (2001) Production of low input and stress tolerant wheat germplasm through the use of biodiversity residing in the wild relatives. Hereditas 135:211–215

Farooq S, Azam F (2007) A new polyploidy wheat for stressed lands and poverty alleviation. Field Crop Res 100:369–373

Farooq S, Niazi MLK, Iqbal N, Shah TM (1989) Salt tolerance potential of wild resources of tribe *Triticeae*-II. Screening of species of the genus *Aegilops*. Plant Soil 119:255–260

Farooq S, Iqbal N, Asghar M, Shah TM (1992) Intergeneric hybridization for wheat improvement-VI. Production of salt tolerant wheat germplasm through crossing wheat (*Triticum aestivum* L.) with *Aegilops cylindrica* and its significance in practical agriculture. J Genet Breed 46:125–132

Farooq S, Asghar M, Iqbal N, Askari E, Arif M, Shah TM (1995) Production and evaluation of salt tolerant wheat germplasm produced through crossing wheat (*Triticum aestivum* L.) with *Aegilops cylindrica*-II. Field evaluation of salt tolerant germplasm. Cer Res Commun 2:275–282

Farooq S, Askari E, Zaidi AA, Shah TM (1998) The wild *Aegilops* and sustainable agriculture: achievements and anticipations at NIAB. In: El Bassam N, Behl RK, Prochnow B (eds) Sustainable agriculture, for food, energy and industry: strategies towards achievement, vol 2. James and James (Science Publisher), London, pp 662–668

Ghassemi F, Jakman AJ, Nix AH (eds) (1995) Pakistan. In: Salinization of land and water resource: human causes, extent management and case studies. University of New South Wales Press Ltd., Sydney Australia, pp 369–395

Guy C, Porat R, Hurry V (2006) Plant cold and abiotic stress gets hot. Physiol Plant 126:1–4

ICID (1991) Asia year. Country report on Irrigation Drainage Development in Pakistan. Published by International Commission on Irrigation and Drainage, New Delhi, India

Jacobsen T (1982) Salinity and irrigation agriculture in antiquity. Deyala Basin archaeological projects: reports on essential results, 1957–58. Undena Publications, Malibu

Rafique MS, Ahmad I, Shah SAH, Shahzad MA (2000) Effect of different rates and N.P. levels on growth and yield of wheat. IAR., 38, 311–317, McGraw-Hill Book, Cologne, pp 172–177

Wang RC, Li XM, Hu ZM, Zhang JY, Larson SR, Zhang SY, Grieve CM, Shannon MSC (2003a) Development of salinity tolerant wheat recombinant lines from a wheat disomic addition line carrying a *Thinopyrum junceum* chromosome. Int J Plant Sci 164:25–33

Wang W, Vinocur B, Altman A (2003b) Plant responses to drought, salinity and extreme temperatures: towards genetic engineering for stress tolerance. Planta 218:1–14

Chapter 24
The Reclamation Effects Should Be Considered for Saline Soil Criteria in Soil Classification System

Zhang Fengrong and Zheng Zhong

Abstract It is well known that most saline soils have salt accumulation at the soil surface and the root zone due to the capillary movement of saline groundwater and subsequent evaporation. The criteria for classifying soil as saline taxa are different in different soil classification systems. In Chinese Soil Taxonomy (CST), soils that have a salic horizon starting within 30 cm from the soil surface are named as Orthic Halosols. In the World Reference Base for the Soil Resources (WRB), soils that have a salic horizon starting within 50 cm from the soil surface are named as Solonchaks. In the US Soil Taxonomy (ST), soils that have a salic horizon starting within 100 cm from the soil surface are named as Salids. In China, a large area of saline soils was reclaimed for crop production. This chapter describes some soil profiles that were classified into saline taxa in CST, WRB, and ST before they are reclaimed, to see if these soils, after a long history of irrigation, are still classified into saline taxa in the three soil classification systems. The results showed that the salts were leached into certain depth, the salic horizons were observed at different depth from the surface, many profiles could not be classified as Orthic Halosols as identified earlier, some of them could not be classified as Solonchaks, and few of them even could not be classified as Salids. With a long irrigation history, the depth of salic horizon is related to the amount of irrigation water and irrigation models. When more water was used for irrigation each time, the salts were found at deeper layers. Relatively the surface irrigation leached the salts deeper than the drip irrigation. According to the present study, we suggest that the criteria of ST should be taken in order to keep the reclaimed saline soils in the saline taxa, i.e., soil classification should not be changed by irrigation. We also suggest that more soil survey should

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be taken for discovering how much water was used in normal irrigation models and how deep the salts were leached under such normal irrigation models. Through analyzing large amount of data, especially those data coming from reclaimed saline soils, the depth and index for salic horizon should be redefined to keep the reclaimed saline soils in the saline taxa of soil classification systems. In this chapter, we examined the criteria of saline soil classification and made some suggestions by citing other scholar's research results published in the scientific literature.

Keywords China • Salic horizon • Saline soils • Soil map • WRB

24.1 The Formation of Saline Soils

Saline soils contain a relatively high concentration of soluble salts, made up largely of chlorides and sulfates of Na, K, Ca, and Mg, which aggravate drought stress because dissolved electrolytes create an osmotic potential that reduces water uptake by plants. The most extensive occurrences of saline soils are in inland areas where evaporation/transpiration is considerably greater than precipitation, at least during a greater part of the year. Salts dissolved in the soil water remain behind after evaporation/transpiration and accumulate at the soil surface (*external saline soils*) or at some depth (*internal saline soils*).

External saline soils form in depression areas with strong capillary rise of saline groundwater and in poorly managed irrigation areas where salts imported with irrigation water are not properly discharged through a drainage system.

Internal saline soils are developed where the water table is deeper and capillary rise cannot fully replenish evaporation losses in the dry season. *Internal saline soils* may also form through leaching of salts from the surface to deeper layers, e.g., by surplus irrigation or by natural flushing of the soil during wet spells.

The most general condition for the formation of saline soils is arid or semiarid climate and depression topography where the groundwater table is high and the water is rich in soluble salts.

24.2 Classification of Saline Soils

As mentioned above, saline soils contain a relatively high concentration of soluble salts, but only those soils that contain certain content of soluble salts and satisfy certain criteria are classified as saline soils. For the most well-known soil classification system, US Soil Taxonomy (ST), World Reference Base for Soil Resources (WRB), and Chinese Soil Taxonomy (CST) as well, all of them identify a *salic horizon* as diagnostic criterion for saline soil classification.

24.2.1 The Criteria of Salic Horizon Are Almost the Same in ST, WRB, and CST

Although there are some differences, the criteria of salic horizon are almost the same in ST (Soil Survey Staff 2010), WRB (FAO 2006), and CST (Cooperative Research Group on Chinese Soil Taxonomy 2001); i.e., the salic horizon is a layer that contains a large content of soluble salts, which aggravate drought stress because dissolved electrolytes create an osmotic potential that reduces water uptake by plants.

The definition of salic horizon in the WRB is as follows:

1. Averaged over its depth, an electrical conductivity of the soil saturation extract (ECe) of 15 dS m^{-1} or more at 25 °C at some time of the year, or an ECe of 8 dS m^{-1} or more at 25 °C if the pH of the saturation extract is 8.5 or more.
2. Averaged over its depth, a product of thickness (in centimeters) and ECe (in dS m^{-1}) of 450 or more.
3. A thickness of 15 cm or more.

The definition of salic horizon in the US Soil Taxonomy (*ST*) *is as follows*:

A salic horizon is a horizon of accumulation of salts that are more soluble than gypsum in cold water.

A salic horizon is 15 cm or more thick and has, for 90 consecutive days or more in normal years:

1. An electrical conductivity (EC) equal to or greater than 30 dS m^{-1} in the water extracted from a saturated paste.
2. A product of the EC, in dS m^{-1}, and thickness, in cm, equal to 900 or more.

The definition of salic horizon in the Chinese Soil Taxonomy (*CST*) *is as follows*:

The salic horizon is a horizon which is rich in salts that are more soluble than gypsum in cold water. It meets the following requirements:

1. Has a thickness of 15 cm or more.
2. Has a salt content of:
   (a) 20 g kg^{-1} or more in Aridosols or Halosols of arid region, or electrical conductivity (EC) in a 1:1 (soil:water) extract is 30 dS m^{-1} or more.
   (b) 10 g kg^{-1} or more in Halosols of other regions, or electrical conductivity (EC) in a 1:1 (soil:water) extract is 15 dS m^{-1} or more.
3. The product of soil content (g kg^{-1}) multiplied by thickness (cm) is 600 or more, or the product of the EC (dS m^{-1}) multiplied by thickness (cm) is 900 or more.

24.2.2 The Depth of Salic Horizon Appearing in Soil Profile for Identifying a Saline Soil Is Different in ST, WRB, and CST

Although all of the three soil classification systems (from soil taxonomic perspectives) need a salic horizon for identifying saline soil, the depth of salic horizon from the soil surface for classifying soil as a saline soil is different.

In the WRB, saline soils are named as Solonchaks. It describes Solonchaks as those kinds of soils that have a salic horizon whose upper boundary starts within 50 cm of the soil surface.

In the ST, saline soils are named as Salids (US soil taxonomy hierarchy) which is a suborder of Aridisols. It describes Salids as those kinds of Aridisols that have a salic horizon whose upper boundary is within 100 cm of the soil surface.

In the CST, saline soils are named as Orthic Halosols which is a suborder of Halosols. It describes Orthic Halosols as those kinds of soils that have a salic horizon whose upper boundary is within 30 cm of the soil surface. Another suborder of Halosols was classified as Alkalic Halosols that have an alkalic horizon which has its upper boundary within 75 cm of the mineral soil surface.

24.3 The Changes of Salt Content and Salic Horizon Distribution in the Soil Profiles After Irrigation and Reclamation

According to the WRB, the total extent of Solonchaks in the world is estimated at about 260×10^6 ha. Solonchaks are most extensive in the Northern Hemisphere, notably in the arid and semiarid parts of northern Africa and the Near East and Central Asia; they are also widespread in Australia and the Americas.

It is also well known that there are some saline soils reclaimed for crops in the world, especially those countries that have a big population and less arable lands for satisfying the food demands; China and Pakistan are good examples. It is estimated that there were about 82×10^6 ha of saline soils (Wang et al. 1993); most of them are distributed in the arid and semiarid area of northwest China and coastal area of eastern China.

In this chapter, the changes of salt content and salic horizon distribution in the soil profiles were studied through investigating the soil profiles in the literatures related to saline soil reclamation in China.

24.3.1 A Case Study in the Luanjing Irrigation Area in Inner Mongolia

The Luanjing irrigation area is located in the west of Inner Mongolia with arid climate (Fig. 24.1). Farmers receive water from the Yellow River to irrigate saline soils

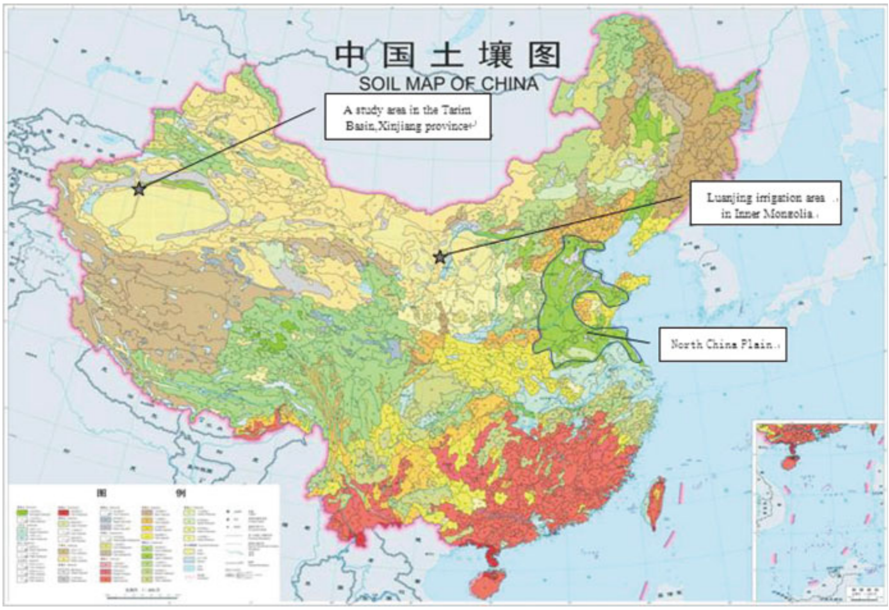

Fig. 24.1 Soil map of China and the studied sites

for cultivation. Wang et al. (2003) studied the changes in salt distribution and salic horizon after irrigation for reclamation. Wang et al. (2003) collected soil samples and analyzed for salt contents in the laboratory. During this study, four soil pits were investigated. The results showed that the salt contents were decreased to a level that was not qualifying the upper 50-cm soil layer to be salic horizon; in-depth investigation of all soil pits revealed that salic horizon moved down to the middle or the lower depths below 50 cm. This has made it clear that after long history of irrigation, the four pits were not classified as Orthic Halosols (CST) nor as Solonchaks (WRB) but still be classified as Salids (Soil Survey Staff 2010).

24.3.2 A Case Study in the Tarim Basin, Xinjiang Province

Xinjiang province is located in the northwest of China and is the driest area in China. Agriculture in this area is not possible without irrigation. Comparing to the vast land, water is limited to irrigate all the land area. It is, therefore, necessary to use the water highly efficiently, and in this regard water saving is very important for cultivation. Zhou and Ma (2006) studied the effects of salt leaching using different irrigation levels and irrigation methods in cotton field, Tarim Basin, Xinjiang province (Fig. 24.1). They reported three scenarios of salt movement: (1) For the reclamation of saline soil, a large amount of irrigation water should be used with a surface irrigation method. (2) Salts are leached from surface to a lower position; the more the water is used for irrigation in one time, the deeper the salts are leached. For example, salts are leached to 40 cm below soil surface with the application of 1,050 m^3 water per hectare in one time and to 70 cm depth with the application of 1,500 m^3 of water per hectare and to below 100 cm when more than 2,025 m^3 ha^{-1} water was used for irrigation. At any applied amount of water, a single irrigation yielded better leaching effects as compared to multiple irrigations during the growing season. (3) Drip irrigation with plastic sheet cover (surface mulching) is a good way of water saving. However, it is important to note that before drip irrigation is used, a prior leaching of salts is necessary to free root zone from salts, and this can be accomplished through surface irrigation to avoid harmful effects to crops. In areas where water table is shallow or it has a potential to raise during irrigation of crops, it has to be lowered down, or a drainage system is to be installed to keep the water table under a permissible depth. The high water table is unfavorable for plant growth and can cause soil salinity through capillary movement and subsequent evaporation.

24.3.3 A Soil Survey Results in the North China Plain

There was large saline area in the North China Plain (also named Huang-Huai-Hai Plain, Fig. 24.1) 50 years ago. In order to increase food supply due to high food demand, the China people implemented the world's largest hydrology engineering project from late 1950s to late 1970s. During the period of project implementation, drainage systems were built up to eliminate the flooding hazard in the region. In order to increase the crop yield, irrigation systems were also established. Because of the monsoon and semiarid climate, the groundwater is commonly used for irrigation purposes. Due to good drainage and prolonged pumping of groundwater for irrigation, the groundwater table fell down to the depth that capillary water rising could not reach the surface, even stopped at certain depth beneath the surface. In that case, salts was leached out of the solum or removed to the lower layer in the soil profile.

In order to study the changes of salt content and salic horizon distribution in the soil profile, a saline soil survey was conducted in the North China Plain (Bai et al. 1999) by using GPS to record coordinates of investigated locations, GIS tool, and kriging method. These results revealed decrease in salinized area in the North China Plain compared to the past, and as a result, presently, the entire plain is free from soil salinization; however, small and isolated areas still remain saline in three lower plains along the Bohai Gulf, northern Hengshui in Hebei province, and Nansihu region in Shandong province. Most of these past saline soils no longer meet the criteria of saline soil whether in the CST standard or in the WRB standard; certainly, they do not meet the criteria of saline soil in the ST standard.

24.4 Discussion

With increasing food demands, people have been cultivating arable land, including some saline land. It is obvious that the salt content and salic horizon distribution in the profiles will be changed after reclamation. It is essential in the reclamation process to remove the excess salts from the root zone, which usually is from the surface to 50 cm beneath the surface for most grain crops. Good drainage is necessary for the reclamation of saline soils; certainly, the application of sufficient water is needed for leaching the salts out of the root zone. So the salts will be leached out of the 50-cm solum beneath the surface, and there will be no salic horizon in 50 cm from the surface for the most reclaimed saline soils. According to present study, the criteria of ST could keep almost of reclaimed saline soils in the saline taxa, i.e., soil classification would not be changed by irrigation and reclamation. Clearly the reclaimed saline soils could be removed from the saline taxa of CST, because the depth of salic horizon occurring is only 30 cm beneath the surface. Some of reclaimed saline soils could not be classified as Solonchaks as well. We suggested that both of WRB and CST should change the depth standard of salic horizon for identifying saline soils following the criteria of ST.

24.5 Conclusions

We suggest that more soil surveys should be taken to discover how much water is used in normal irrigation models and how deep the salts were leached under such normal irrigation models in the world, because the background of saline soil formation and the reclamation method, especially the irrigation methods, are different in different regions. Through analyzing large amount of data, especially those data coming from reclaimed saline soils, the depth and index for salic horizon should be redefined for keeping the reclaimed saline soils in the saline taxa of soil classification systems.

References

Bai Y, Li B, Shi Y (1999) Research of the soil salt content distribution and management in Huanghuaihai Plain based on GIS. Resour Sci 21(4):66–70

Cooperative Research Group on Chinese Soil Taxonomy (2001) Chinese soil taxonomy. Science Press, Beijing/New York, p 203

FAO (2006) World reference base for soil resources. World Soil Resources Reports 103. FAO, Roma

Soil Survey Staff (2010) Keys to soil taxonomy, 11th edn. USDA-NRCS, Washington, DC

Wang Z, Zhu S, Yu R (1993) Saline soils in China. Science Press, Beijing

Wang B, Liu G, Qiu H (2003) The salt leaching effect of irrigation using Yellow River water in the Luanjing irrigation area, Inner Mongolia. Geotech Investig Surv 31(3):19–23

Zhou H, Ma J (2006) Studies on water-salt dynamics and balance of cotton crops land in Tarim irrigation tegion, Xinjiang. J Irrig Drain 6:10–14

Part III
Use of Marginal Quality Water for Crop Production

Chapter 25
Use of Marginal-Quality Waters for Sustainable Crop Production

Donald L. Suarez

Abstract Existing high-quality water supplies are not sufficient to sustain irrigated agricultural production in arid and semiarid regions. Use of marginal-quality waters and reuse of agricultural drainage waters and treated municipal wastewaters are currently the only economic options for maintaining production in these regions. Marginal-quality waters are characterized by one or more of the following: elevated salinity, sodicity, pH, alkalinity, dissolved organic matter, and toxic elements such as boron and selenium. These water characteristics have a potentially adverse impact on crop productivity as well as soil physical properties. However, these waters can generally be used with proper management considerations. Model simulations of irrigation with saline waters confirm field data indicating that existing leaching guidelines overestimate water quantities needed for salinity control in the root zone. Leaching recommendations must also consider efficient water use, costs of water, nutrients, and disposal of drainage water as well as crop production. The sodicity hazard associated with application of saline water has been generally overlooked, due primarily to lack of consideration of the adverse impact of even small quantities of rain on physical properties of the soil surface. Recent long-term studies on infiltration of degraded waters indicate that the sodicity hazard to soil physical properties is greater than currently considered and that surface addition of gypsum may need to be more generally utilized. The utility of computer modeling as an aid to irrigation management is further demonstrated by the simulation of intermittent use of high-boron waters currently deemed unsuitable for irrigation. Future salinity research is critical to meet food demands of arid and semiarid regions of the world, especially for development of new varieties improving the salt and boron tolerance of sensitive species and improved prediction of plant production under multiple stress conditions (salinity water nutrient and toxic element).

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Keywords Crop production • Economic aspects Marginal water • Sodic soil • Wastewater

25.1 Food Production and Irrigated Land

The dramatic increase in total global food production over the last 50 years is well known. The increase is attributed to both an increase in cultivated land and an increase in production on a per-acre basis. This productivity increase is generally attributed to the development of improved crop varieties and management practices (green revolution); however, an important part of this increase is related to an increase in irrigated acreage. Irrigated lands have much higher productivity and economic return per acre as compared to nonirrigated lands. It is estimated that globally, irrigated lands represent 15% of the cultivated land, yet they produce over 30–40% of the world's food (Ghassemi et al. 1995; Postal 1999). In arid regions, the impact of irrigation is much greater than for the world in general, both because dry land production is low in these regions and because arid lands located in high-temperature environments can be almost continually cropped, with multiple harvests. The 35% increase in irrigated land from 1970 to the late 1980s thus provided a significant part of the increase in world's food production and was a major factor in avoiding large-scale famine.

Since the 1980s, there has been a decline in the rate of growth in the world's irrigated land. By the start of the twenty-first century, total irrigated acreage reached a constant value. The stabilization in total irrigated acreage is due primarily to the lack of new developable water supplies in most of the arid and semiarid regions that can most benefit from irrigation.

The situation with respect to sustainability of irrigation in arid regions is grave. Supplemental irrigation in more humid regions has increased, masking the actual decline in irrigated acreage in arid regions. Globally, irrigated agriculture uses approximately 65% of the total freshwater used, with industrial and municipal use making up the balance. California in the USA has experienced significant declines in irrigated acreage. For example, during the 2009 irrigation season, over 180,000 ha have been taken out of irrigation in the Central Valley, with the likelihood that there will not be sufficient water in the future to bring this land back into production. "Land banking" is occurring in other irrigation districts, such as Palo Verde and Imperial where long-term contracts have been signed transferring former irrigation water to municipal water entities. Additional declines in irrigated acreage are occurring due to partial restoration of natural water flows for environmental considerations. Future declines are anticipated due to declining groundwater supplies as well as increasing urban and environmental water demands. Currently the percentage of freshwater used by agriculture in California has declined from 75% as recently as 20 years ago to below 50%, with a corresponding increase by the municipal sector and a decrease in overall use.

Unfortunately, most arid regions do not have new developable surface waters, and the current large freshwater extractions of groundwater required for irrigated agriculture cannot be increased. Of greater concern is the consideration that irrigation is not sustainable at current freshwater utilization rates. This overutilization of freshwater utilizing what is often called fossil water is particularly severe in drier regions of the world, where population density, poverty, and food demands are greatest. Overdrafting of groundwater has resulted in declining water tables, loss of shallow freshwater for municipal use, and sea water intrusion in coastal regions. In the early 1990s, approximately one fifth of the USA's irrigated lands were extracting groundwater in excess of the natural recharge (Postal 1997). The data are not completely known, but the situation appears more severe in many less developed nations in arid and semiarid regions.

Increasing population results in increasing total demand for freshwater for municipal and industrial use as well as for increased food production. Increased freshwater needs are also related to increase per-capita water usage associated with improved economic conditions in a region. Increases in living standards are not only related to increased domestic-per-capita water consumption, but they also result in an increase in water consumption related to food production on a per-capita basis. This increased demand with improved living standards is related to the increased water requirement for meat production versus grain production (expressed as gallons of water per kcal). It will be a major challenge just to maintain the existing level of irrigation and associated food production in the arid and semiarid regions of the world. An increase in living standards will require yet more water.

25.2 Salinity

25.2.1 Salinization of Water Resources

In addition to the unsustainable extraction of freshwater, there is a related decline in water quality of existing supplies; thus, these factors are not unrelated. There are two general factors contributing to the decline in water quality. Extraction of freshwater from a system reduces the extent of dilution of other natural or man-induced salt loads. Secondly, as irrigation brings more salts into a valley, it adds a new source of more saline drainage water to the receiving body of water. These concentrated drainage waters contain both the initial salts present in the irrigation water and salts already in the soil that are displaced by the water leaving the root zone. Thus, in arid regions, irrigation or even changes in cropping patterns that impact recharge often mobilize salts that have accumulated over geologic time either in the unsaturated zone, salinizing groundwater (Australia), or displacing saline groundwater into rivers (Grand Valley CO and the Colorado River). Again due to the long flow paths, this additional salt load can continue for in excess of 150 years, consistent with hydrologic model predictions.

Salinity increases in drainage water relative to irrigation water are inevitable. Plants extract water preferentially, thus concentrating these salts in the remaining soil water. Typically, plants extract only 5–10% of the salt associated with the volume of water that they extract. Hence, more efficient irrigation (generally resulting in less water applied more uniformly), while desirable, results in smaller volumes of drainage water, but of greater salinity. The salinity increase is approximately inversely proportional to the change in volume (inverse to volume of irrigation water/volume of drainage water). Increased water utilization also increases downstream salinity by reducing the volume of freshwater available for dilution of natural flows and drainage waters.

25.3 Marginal Waters

25.3.1 Water Reuse

Reuse of drainage water, where feasible, provides the opportunity for alternative water resources in water-short regions, as well as water table control and a reduction in secondary salinization caused by overirrigation and insufficient drainage. A significant concern regarding reuse of drainage water is its impact on the soil and potential salinization from applying more saline irrigation water on an already saline soil. However, Corwin et al. (2008) observed a decrease in soil salinity and partial reclamation of sodic soil conditions where drainage water more saline than presently used irrigation water was applied. The benefits may be from several factors including a drop in the perched water table below the field, allowing for better drainage, as well as improved infiltration related to application of more saline water and application of greater volumes of water.

Maintaining irrigation in arid regions will require maximum utilization of sustainable water supplies. Water reuse is a necessary aspect of this system, but it should be looked at as complimentary rather than as an alternative strategy for water management or alternative to reduction in drainage volumes. The ideal water use is still to extract the maximum benefit from the initial freshwater application, minimizing the volume of drainage water generated. This minimizes the need for drainage and avoids the mixing and either degradation of freshwater, if the drainage returns to a water supply such as a river, or else degradation of the drainage water by mixing with a saline groundwater. This concept has been often dismissed as impractical. It is argued that as crops vary in salt tolerance, application of water quantities at or near ET is feasible only for salt-tolerant crops if the irrigation water has any appreciable salinity.

25.3.2 Reduction in Quantities of Leaching Water

The possibilities to use saline waters at low leaching fractions have been significantly overlooked due to use of current guidelines, such as Ayers and Westcot (1985).

The major justification for application of water in excess of crop requirements has been the need to leach salts out of the root zone and thus control root zone salinity. The leaching requirement concept provides for calculation of a crop-specific quantity of leaching water in addition to that consumed by the crop, which must be applied to avoid yield loss to salinity.

The use of the static leaching requirement calculation is being questioned on several grounds. Most importantly as demonstrated in an example below, the concept does not consider the decrease in water uptake and thus increase in leaching that occurs when plant yield decreases. The leaching fraction is thus not a fixed input variable but rather a result of water applications, potential ET, and plant response.

Secondly, the method used to calculate plant yield as related to salinity of irrigation water usually involves a simplified calculation of root zone salinity, and the root zone average value is used (Ayers and Westcot 1985) rather than a water uptake calculated value. Since the salinity in the deeper portions of the profile is greater than that near the surface where the roots are concentrated and where most of the water is taken up by the plants, this calculation of average root zone salinity overestimates the salinity experienced by the plant.

Most salt tolerance data was, and is still, collected either in sand culture where the soil water salinity is essentially equal to the irrigation water salinity or else at high leaching fractions where plant-uptake-weighted salinity is at most 50% greater than the irrigation water salinity. Also the simplified calculations utilized neither account for the precipitation of calcite and possibly gypsum that occurs during the concentration of salts in the root zone nor the nonlinearity between concentration increases and increases in osmotic pressure. The combination of the assumption of fixed crop ET with the salt tolerance calculation from average root zone salinity estimates or measurements results in overestimation of the quantity of water needed for leaching. The lower the leaching fraction, the greater the discrepancy between average root zone salinity and plant-uptake-weighted salinity. This also explains why drip irrigation systems operated at or near the crop water requirement do not experience measurable yield losses, contrary to predictions based on application of the leaching requirement concept.

Irrigation recommendations can best be made using computer simulations of the dynamic processes, considering crop salt tolerance and crop ET and root zone salinity based on predicted rather than potential water uptake. Letey and Feng (2007), comparing the results of a transient state model to those of a steady-state model, concluded that the transient model, consistent with field data, indicated that a much lower water application was required to avoid yield loss. Suarez (2012), compared the leaching requirements and prediction of yield loss between UNSATCHEM (Suarez and Simunek 1997) and the Ayers and Westcot (1985) guideline recommendation for leaching and yield loss due to salinity. An analysis of predicted ET, predicted leaching, and crop yield as related to irrigation water salinity is presented below.

The user-friendly SWS version (Suarez and Vaughan 2001; Suarez et al. 2010) of the UNSATCHEM model (Suarez and Simunek 1997) predicts plant response to water and salt stress under dynamic conditions. The model also predicts soil solution composition as related to variably saturated water and solute transport and chemical processes of adsorption, mineral precipitation-dissolution, and cation exchange. The model uses the predicted decreases in plant water uptake to predict the decrease in biomass production. This calculation assumes that yield is directly proportional to water consumption (constant WUE, or water use efficiency).

$$\frac{Y}{Y_M} = 1 - \beta_0 \left(1 - \frac{ET_a}{ET_p}\right) \tag{25.1}$$

where Y is actual yield, Y_M is maximum yield, ET_a is predicted ET, and ET_p is potential ET. The parameter β_0 is a crop adjustable parameter which is typically set to 1.0 but varies between 1.0 and 1.3 (Stewart et al. 1977).

Prediction of the yield of individual plant parts (such as seed or fruit) can be obtained by consideration of the relation of reduction in plant water uptake and yield response of the plant part of interest. The model predicted root zone salinity, and relative yield can be contrasted to predictions based on salt stress from guideline predictions.

Suarez (2012) used the SWS model (Suarez et al. 2010) to predict plant yield reduction from salt stress. A perennial crop with a 100-cm root zone depth on a loam soil ($k_s = 25$ cm day^{-1}) was irrigated for 200 days. The first irrigation of 11 cm was applied after 10 days. After another 10 days, 22 cm of water was applied over 2 days followed by irrigations of 22 cm every 20 days thereafter for a total of 209 cm of applied irrigation water. The potential ET of the crop for full yield was 200 cm, and we assumed a constant potential crop ET (ET_p) value of 1 cm day^{-1}. The initial soil water and irrigation water composition was that of a predominately NaCl system with lesser quantities of Ca, Mg, $SO_{4,}$ and bicarbonate. The $h_{\varphi_{50}}$ for osmotic stress was set at −50 m, using the equation:

$$\alpha_\varphi(h_\varphi) = \frac{1}{1 + \left(h_\varphi / h_{\varphi_{50}}\right)^p} \tag{25.2}$$

where α_ϕ is the osmotic stress response function (scaled from 0 to 1.0 where 1.0 equals no stress), h is the calculated osmotic stress, and h_{50} is the model input osmotic stress at which there is a 50% reduction in water use and relative yield.

The same scenario was also evaluated using the Ayers and Westcot (1985) procedure. In this calculation, we consider the crop requirement of 200 cm of water and the applied water quantity of 209 cm. The average root zone salinity was calculated from the average salinity of the root zone, using the irrigation water salinity and the salinity at the bottom of each of the four quarters of the root zone. Salinity in each quarter was based on the assumption that water uptake is 40% in the first quarter, 30% in the second quarter, 20% in the third quarter, and 10% in the fourth quarter. The average root zone salinity was thus calculated and converted to osmotic pressure using the conversion factor O.P. (MPa) = −0.4 EC (dS m^{-1}), and using Eq. 25.2, the stress factor and relative yield was obtained.

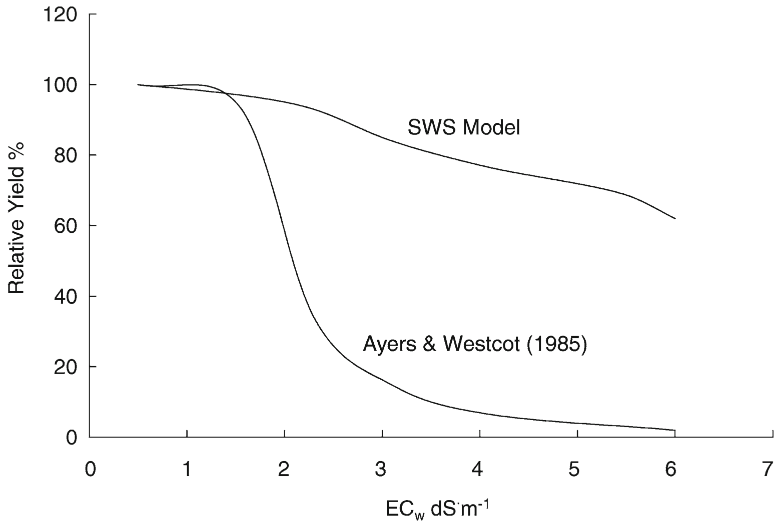

Fig. 25.1 Comparison of SWS model and Ayers and Westcot (1985) predicted crop relative yield as related to irrigation water EC, for a crop with an $h_{50}=-50$ m (−0.5 MPa), $ET_p=200$ and 209 cm applied water (Suarez 2012)

The SWS model predicted relative yield as related to irrigation water salinity is shown in Fig. 25.1. The model predicts a gradual decline in relative yield with increasing irrigation water salinity. With an irrigation water EC of 4.0 dS m^{-1}, the relative yield is still at 81%, despite the application of only a small amount of water above the crop potential ET. In contrast, as shown in Fig. 25.1, the Ayers and Westcot (1985) calculated yield decreases rapidly above EC 1.5 dS m^{-1}. We conclude from the guideline calculations that for this salt tolerance data ($h_{50}=-05$ MPa), irrigation with water above EC = 1.8 dS m^{-1} is not feasible for efficient irrigation practices at a leaching fraction of 0.05. As seen in Fig. 25.1, at higher irrigation water salinities, there is a dramatic difference between the model and the guideline prediction. A similar result to that obtained by calculation from the FAO guidelines (Ayers and Westcot 1985) would also be obtained using the steady-state WATSUIT (Rhoades and Merrill 1976) calculation.

As shown in Fig. 25.2, the guideline assumes constant water consumption even as yield approaches zero. The model predictions show the decrease in plant water uptake associated with salt stress thus increased leaching with increased salinity of irrigation water. The reduction in water uptake moderates the increase in root zone salinity. Consideration of the actual water budget is essential for calculation of the actual salinity in the root zone. The increased leaching and decreased water uptake were due entirely to salt (osmotic stress).

The major discrepancy between these calculations and the SWS predictions is the failure of these calculations to predict the reduction in water consumption by the crop and thus the root zone salinity and leaching fraction. The leaching fraction was assumed to be 0.043 based on applied water and crop water demands (ET); however,

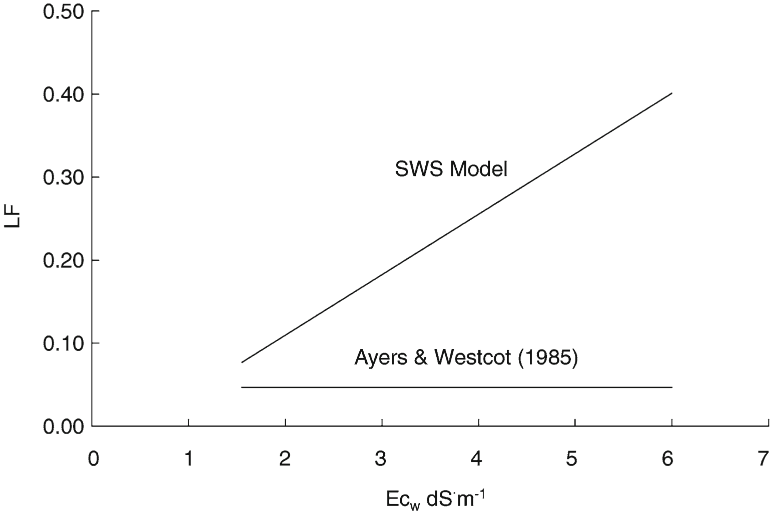

Fig. 25.2 Comparison of SWS model and Ayers and Westcot (1985) predicted leaching fraction as related to irrigation water EC, for a crop with an $h_{50}=-50$ m (−0.5 MPa) salt tolerance value, $ET_p=200$ and 209 cm applied water (Suarez 2012)

the SWS model predicted reduced water uptake and a LF=0.42. The differences between the model predictions (less stress) and the simple calculation method are even greater when we consider waters that precipitate gypsum in the soil, thus reducing the salt concentrations in the soil.

While the above example is somewhat extreme in terms of the close correspondence between water application and crop water demand (209 cm versus 200 cm), such irrigation efficiency is not unusual for new irrigation technologies, such as drip irrigation. It appears that dynamic modeling is necessary for irrigation management when low-target leaching fractions are the objective under conditions of potential yield loss due to salinity.

If model simulations are not available, then what was earlier deemed the high-frequency irrigation leaching requirement (Rhoades 1982) and shown in Fig. 25.3 could be utilized in preference to the recommended leaching requirement figure and discussion from Ayers and Westcot (1985). In contrast to the current recommendation for all irrigation systems, however, Rhoades (1982), Ayers and Westcot (1985), and others recommended that leaching requirement be based on average root zone salinity for conventional irrigation. The current Fig. 25.3 can be used by selecting the salt tolerance of a crop from salt tolerance tables, ensuring that you input the corresponding salinity of the soil solution, and then entering the irrigation water salinity and reading across the needed leaching fraction. When using this method for less than optimum yield, the user needs to be aware that the crop ET will be lower than calculated from the ET_0 and crop coefficients due to salt stress; the volume of water to be applied can be reduced.

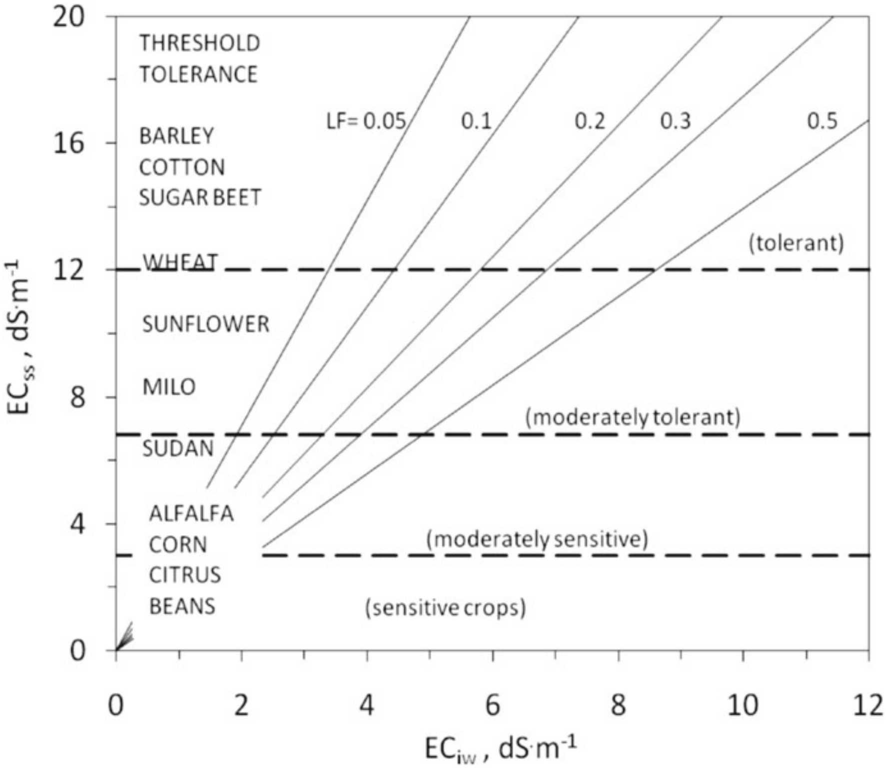

Fig. 25.3 Relationship between water-uptake-weighted root zone salinity (EC_{ss}), electrical conductivity of irrigation water, and leaching fraction required to avoid yield loss (modified from Rhoades 1982)

As observed by data collected from drip irrigation systems, water applications can be greatly reduced and still maintain close to 100% yield in most environments, consistent with the above computer predictions. This in turn suggests that less drainage water of higher salinity will be generated; thus, disposal for maintaining groundwater levels will be reduced.

25.3.3 Crop Quality and Economic Considerations

The classification and consideration of the suitability of saline and brackish waters for irrigation have focused on the threshold salt tolerance levels and leaching necessary for full maximum production. As indicated earlier, the leaching needs of current guidelines are excessive. Equally important, such calculations do not consider the farmer's objective to optimum profit and the societal need for optimum use of resources. Profitability and societal needs for local food production may make even large decreases in relative yield still feasible, especially when alternative water supplies do not exist. These economic considerations should be inputs to the decisions regarding water use, crop selection, and acceptable yields. Selecting more salt-tolerant crops that do not have projected yield losses may also not be optimal. For example, tall wheat grass is more salt tolerant than alfalfa; however, alfalfa outyielded tall wheat grass in controlled studies at EC soil water of 15 dS m^{-1} (Grattan et al. 2004).

In some instances, the adverse impacts of reduced yields may be compounded by reduced crop quality such as smaller fruit size, thus decreasing marketability. However, in some instances, crop quality may improve under saline conditions, at least partially offsetting yield reductions. Recently, Grieve (2011) examined the characteristics or composition variables that were improved by salinity for a variety of crops. These benefits include increased sugar content of many crops, including tomato, carrots, onions, and melons, among others. Salt stress may also increase antioxidants and improve fruit flavor and firmness (Grieve 2011).

25.3.4 Water Quality Considerations Related to Soil Properties

Waters of increased salinity inevitably contain greater proportions of Na and to a lesser extent Mg relative to Ca, due to solubility considerations. The adverse effect of sodium on soil structure, clay dispersion, and water infiltration is well documented. This adverse sodium effect is a major concern when using lower-quality waters for irrigation. The SAR (sodium adsorption ratio, defined as $Na^+/(Ca^{2+}+Mg^{2+})^{0.5}$ where concentrations are in millimoles$_c$ L^{-1}) increases with increasing salinity due to both the change in the relative proportions of ions and the square root term for divalent ions in the SAR expression. The SAR is directly related to the exchangeable sodium percentage in the soil; thus, irrigation with more saline waters almost always results in increased exchangeable sodium.

It is generally considered that the elevated SAR associated with saline waters is not of concern since the infiltration of these waters is not adversely impacted according to guidelines for sodium hazard (Ayers and Westcot 1985). However, this analysis does not consider the impact of rain, which results in a rapid decrease in soil salinity at the surface, with a much slower reduction in the exchangeable Na. Computer simulations of changes in exchangeable sodium upon rain on a sodic soil (Suarez et al. 2006) confirm the observed decrease in infiltration that is observed in studies with cyclic rain and irrigation events over an irrigation season (Suarez et al. 2006, 2008). Shown in Fig. 25.4 is the time-averaged infiltration data for the 1-year experiment for Glendive sandy loam soil as related to irrigation water SAR (Suarez et al. 2008). As shown in Fig. 25.4, there is no evidence of a threshold SAR below which the soil is stable and infiltration is maintained. It appears that any increase in SAR results in a decreased infiltration rate (increase in the time required for infiltration). Thus, even in regions where rainfall is an insignificant contribution to

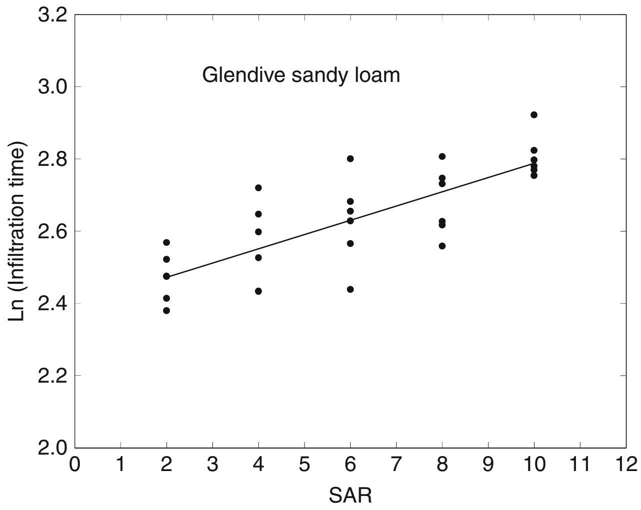

Fig. 25.4 Relationship between SAR and ln infiltration time for loam soil; data is averaged across sampling periods (Suarez et al. 2008)

the water budget, the dispersive effect of sodium is a significant concern and generally indicates the need to apply a surface soil amendment (such as gypsum) when using waters above SAR = 2.

25.3.5 Management of Waters Containing Elevated Boron Concentrations

Current water quality criteria classify waters above boron concentrations of 1 mg L^{-1} to be potentially toxic to plants. Only a few agronomic crops can tolerate soil water concentrations in excess of 10 mg L^{-1}. Elevated B concentrations are often associated with elevated salinity and are one of the major limitations to drainage water reuse in the western USA. As mentioned above for salinity, standards were earlier developed in an era of abundant water where it was easy to dismiss marginal-quality waters for irrigation. The below example (Suarez 2002) demonstrates that waters considered unsuitable can in fact be safely used under some circumstances with proper management. The example considered involves use of UNSATCHEM model (Suarez and Simunek 1997) that considers adsorption and desorption of boron.

In these simulations, we selected a B concentration of 0.8 mmol L^{-1} (8.6 mg L^{-1}). We assume that limited high-quality water is available (either irrigation water or rain); thus, this high-quality water must be supplemented or replaced with marginal-quality water. Marginal-quality water is often not usable for sustained agricultural production, but either it can be utilized in a cyclic fashion with higher-quality water, or the water can be used on separate fields on crops of varying tolerance. A uniform root distribution and uniform water uptake in a 50-cm root zone were utilized. The soil profile was initially free of B, and the ET was input as 1 cm day^{-1} with irrigation applications corresponding to an average input of 2 cm day^{-1}. This corresponding leaching fraction was 0.5 (where leaching fraction is the fraction of water applied that is not used by evapotranspiration and is drained from the root zone). A total of 200 cm of water was applied during the 100-day growing season. The simulation was done for both a sandy and a high-clay-containing soil (surface areas of 100 and 1,000 m^2 g^{-1} corresponding to a soil with relatively low and high B absorption capacity, respectively).

The high leaching and low adsorption capacity of the sandy soil causes a rapid advance of the B front into the soil. A quasi-steady-state profile is established in the root zone after 80 days, with a maximum soil B concentration of 1.6 mmol L^{-1}. The high adsorption capacity of soil results in more adsorption, a steeper B front, and less rapid movement of B into the soil profile. This profile is still very far from steady state after 100 days of irrigation, and the B concentrations are significantly lower than those observed for the sandy soil. Additional simulations were done at a leaching fraction of 0.1. The daily ET is still 1.0 cm day^{-1}; however, the water applications were reduced to 1.11 cm day^{-1}. In this instance, the sandy soil profile is still not at steady state, and the B front is just reaching the 100 cm depth. The maximum soil B concentration will eventually reach 8.0 mmol L^{-1}. For the clay soil profile at leaching fraction of 0.1, the B concentration front extends only to 25 cm and the maximum concentration is only 0.80 mmol L^{-1}, after 100 days, much lower than the steady-state value of 8.0 mmol L^{-1}, and just slightly greater than the irrigation water B concentration.

The mean root zone B concentrations as a function of time are presented in Fig. 25.5 for each of the four simulations (Suarez 2002). The simulations indicate that for a soil with high B adsorption, there is little B hazard during the initial cropping season. The highly leached high-surface-area soil had a higher root zone B concentration throughout the growing season than did the other options. At steady state, the lower leaching management would eventually result in considerably higher B concentrations than the more leached soil. However, the system can be managed in a continuous transitional state. Under this scenario, the recommended management practice (in the absence of salinity considerations) would be minimal water applications. This is contrary to common recommendations based on the steady-state analysis. The mean B concentration in the root zone is sufficiently low that many crops could be grown without yield loss. Sustained management would require winter rains or leaching with higher-quality water or cyclic use of the high B water with a lower B water (alternate years).

The sandy soils rapidly increase in B concentration in the root zone, at both high and low leaching, as shown in Fig. 25.5. During the early portions of the season, the low leaching management results in lower root zone B, as steady-state values are not yet achieved. Around day 70, there is a crossover with the low leaching fraction management resulting in higher root zone B concentrations. In this scenario, it would appear preferable to utilize a low leaching approach at least early in the

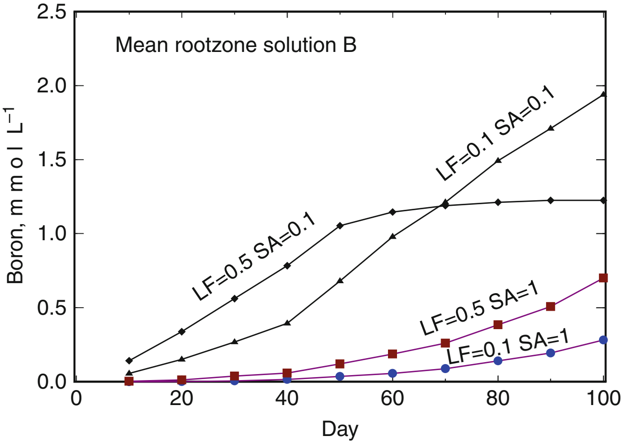

Fig. 25.5 Mean root zone soil solution B concentration with time as related to leaching fraction (LF) and soil surface area (SA), expressed in $10^3 \times m^2\ g^{-1}$ (Suarez 2002). The low-surface-area soil corresponds to a sandy soil with low B adsorption capacity, and the high-surface-area soil corresponds to a clay soil with high B adsorption capacity

irrigation season and especially if B sensitivity is greater during early stages of growth. For low-surface-area soils, most crops would have significant yield reduction due to B toxicity. At the point in which the curves cross, at day 70, it would be beneficial to switch from low to high leaching. Many vegetable crops with high B sensitivity also have a short growing season. In addition, B damage is not instantaneous but rather cumulative, so crops with sensitivity at 0.5 mmol L^{-1} B could likely be grown under this scenario within a 70–90-day growing season.

25.3.6 Potential for Increased Salt Tolerance

Biotechnology in combination with conventional breeding practices holds great promise to improve salt tolerance, especially of crops that are sensitive or moderately sensitive to salinity. It is generally assumed that the adverse response of plants to elevated concentrations of salt is due to the increased osmotic pressure of the soil water. The plant is considered to divert energy into extracting low-salinity water from the more saline soil water, thus impacting plant growth. However, there is a very wide range in salt tolerance, starting at very low-salinity levels such as less than 1.0 dS m^{-1} for strawberry. There is strong evidence that specific ion toxicity is the major impact on salt-sensitive species.

Munns and Tester (2008) considered that plant response to salinity could be represented by a two-part process, with the initial adverse response being related to increase osmotic pressure and a later response related to specific ion toxicity. They consider that the toxic ion effect dominates for salt-sensitive species that lack the ability to control Na^+ transport and that for all other plant species, the ionic effect is important only at high salinity. Development of salt-tolerant varieties of sensitive species can thus be accomplished by focus on development of improved Na^+ (and to a lesser extent Cl^-) exclusion by the roots and restriction of translocation to the leaves. Additionally tissue tolerance to salinity by plants is achieved by compartmentalization of Na^+ and Cl^- at the cellular and intracellular level.

25.4 Conclusions

There is very limited potential for using freshwater for increased development of irrigation in arid regions. More realistically, there will be a significant decrease in freshwater use, due to current unsustainable extractions of freshwater. More efficient use of available resources includes use of new irrigation technologies, reuse of drainage water, use of treated municipal wastewater, use of brackish water, and reduced leaching for salinity control. Replacement of current simplified guidelines for salinity and B leaching with application of more realistic computer model simulations, generating site-specific information, will enable better salinity management and use of resources. Use of marginal-quality waters will in most instances require application of surface calcium amendments to maintain favorable soil physical properties. Opportunities also exist for development of improved salt tolerance for varieties of salt-sensitive plant species.

References

Ayers RS, Westcot DW (1985) Water quality for agriculture. FAO Irrigation and Drainage Paper 29, Rev 1 FAO, UN Rome, p 174

Corwin DL, Lesch SM, Oster JD, Kaffka SR (2008) Short-term sustainability of drainage water reuse: spatio-temporal impacts on soil chemical properties. J Environ Qual 37:S-8–S-24

Ghassemi I, Jakeman AJ, Nix HA (1995) Salinization of land and water resources. University of New South Wales Press LTD, Sydney, p 526

Grattan SR, Grieve CM, Poss JA, Robinson PH, Suarez DL, Benes SE (2004) Evaluation of salt-tolerant forages for sequential water reuse systems. I. Biomass production. Agric Water Manage 70:109–120

Grieve CM (2011) Salinity-induced enhancement of horticultural crop quality, Chapter 47. In: Pessarakli M (ed) Handbook of plant and crop stress, 3rd edn. CRC Press/Taylor & Francis Group, Boca Raton, pp 1173–1194

Letey J, Feng GL (2007) Dynamic versus steady-state approaches to evaluate irrigation management of saline waters. Agric Water Manage 91:1–10

Munns R, Tester M (2008) Mechanisms of salinity tolerance. Annu Rev Plant Biol 59:651–681

Postal S (1997) Last oasis: facing water scarcity. Norton WW & Co., New York

Postal S (1999) Pillar of sand: can the irrigation miracle last? Norton WW & Co., London

Rhoades JD (1982) Reclamation and management of salt-affected soils after drainage. In: Proceedings of the First Annual Western Provincial Conference Rationalization of Water and Soil Research and Management. Lethbridge, Alberta, Canada, 27 Nov–2 Dec, pp 123–197

Rhoades JD, Merrill SD (1976) Assessing the suitability of water for irrigation: theoretical and empirical approaches in prognosis of salinity and alkalinity. FAO Soils Bull 31:69–109

Stewart JI, Danielson RE, Hanks RJ, Jackson EB, Hagan RM, Pruitt WO, Franklin WT, Riley JP (1977) Optimizing crop production through control of water and salinity levels in the soil. Utah Water Res Lab Publication 151–1. Logan, p 191

Suarez DL (2002) Evaluation of management practices for use of low quality waters for irrigation: model simulations. In: Proceedings of the annual meeting of the International Union of Soil Sciences, Bangkok, Thailand, August 14–21, 2002. Symp 34, 1096:1–8

Suarez DL (2012) Modeling transient root zone salinity (SWS Model). In: Wallendar, W.W. and Tanji, K.K. (eds) Agricultural Salinity Assessment and Management 2nd Edition. Am. Soc. Civil Eng. Reston, VA. pp: 855-897.

Suarez DL, Simunek J (1997) UNSATCHEM: unsaturated water and solute transport model with equilibrium and kinetic chemistry. Soil Sci Soc Am J 61:1633–1646

Suarez DL, Vaughan PJ (2001) FAO SWS manual. George E Brown Jr Salinity Laboratory Research No 147, Riverside, p 113

Suarez DL, Wood JD, Lesch SM (2006) Effect of SAR on water infiltration under a sequential rain-irrigation management system. Agric Water Manage 86:150–164

Suarez DL, Wood JD, Lesch SM (2008) Infiltration into cropped soils: effect of rain and sodium adsorption ratio – impacted irrigation water. J Environ Qual 37:S169–S179

Suarez DL, Vaughan PJ, Taber P (2010) SWS model. US Salinity Laboratory, Riverside

Chapter 26
Distichlis Spicata – A Salt- and Drought-Tolerant Plant Species with Minimum Water Requirements for Sustainable Agriculture in Desert Regions and Biological Reclamation of Desert Saline Soils

Mohammad Pessarakli and Kenneth B. Marcum

Abstract Desertification of arable lands due to urbanization, global warming, and low rainfall mandates water conservation and using low-quality/saline waters for irrigation. Use of low-quality irrigation water imposes more stress on plants which are already under stress in these regions. Thus, there is an urgent need for finding salt/drought-tolerant plants to survive under stresses. Since the native plants are growing under such conditions and are adapted to these stresses, they are the most suitable candidates for use under arid regions. If stress-tolerant native species are identified, there would be a substantial savings in inputs in using them under stressful conditions. Present studies on saltgrass (*Distichlis spicata* L.), a euhalophyte, have shown it to have excellent drought/salinity tolerance, making it well adapted to harsh desert conditions, with great potential for use in urban landscape and agricultural settings to combat desertification and reclaim arid saline soils. The objectives of this study were to find the most drought-tolerant saltgrass genotypes for use in arid regions, where limited water supplies coupled with saline soils result in drought/salinity stresses, for use in sustainable desert agriculture, urban landscapes, and in biologically reclaiming desert saline soils. Various saltgrass genotypes were studied to evaluate their growth responses under progressive drought stress. Though all the grasses showed a high level of drought tolerance, there was a wide range of variations observed in their stress tolerance levels. Superior stress-tolerant genotypes were identified which could be recommended for sustainable production under arid regions and combating desertification.

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Keywords Arid regions • Combating desertification • Drought • Salinity stress • Saltgrass

26.1 Introduction

Desert saltgrass (*Distichlis spicata* (L.) Greene var. stricta (Gray) Beetle (Gould 1993)) is an indigenous species of arid and semiarid regions. The species grows in very poor to fair condition soils (Fig. 26.1), in both salt-affected soils and soils under poor fertility as well as drought and harsh environmental conditions (Gould 1993; O'Leary and Glenn 1994). Its dominant and most common habitats are arid and semiarid regions (Marcum et al. 2005).

The plant is abundantly found in areas of the western parts of the United States as well as on the seashores of the United Arab Emirates and several other Middle Eastern countries, Africa, and South and Central American countries (Pessarakli et al. 2005). The species has multipurpose usages. The plant can be used as a potential animal feed, for biological reclamation of salt-affected soils (saline soil reclamation) or soil conservation, establishment and erosion control for covering road sides and soil surfaces in lands with high risks of erosion, and a turfgrass species for use in urban landscape and agricultural settings for lawns and recreation areas to combat desertification. The species can be manipulated to modify its performance and increase its yield and productivity.

Recently, the United States Golf Association (USGA) and the US Bureau of Land Management (BLM) have shown a great deal of interest in funding research

Fig. 26.1 *Distichlis spicata* spp. *stricta* – "saltgrass" endemic to SWUSA. A chloridoid subfamily grass. Saltgrass grown in Wilcox Playa, Arizona, Southwest USA, on salt-affected (saline and sodic) soils. *Distichlis spicata* – desert xerophyte/halophyte

work on this plant species to use it as a turfgrass or for soil erosion control and reclamation of saline soils. Most of these research works have been conducted at the University of Arizona and Colorado State University. Consequently, the USGA and the BLM funds for the investigations on this grass species have been allocated to these institutions. Positive and promising results have already been obtained from these studies (Gessler and Pessarakli 2009; Kopec et al. 2000, 2001a, b, 2006; Marcum 1999; Marcum et al. 2005, 2007; Pessarakli 2005a, b, 2007, 2008; Pessarakli and Kopec 2005, 2006, 2008a, b, 2010; Pessarakli and Marcum 2000; Pessarakli et al. 2001a, b, c, 2003, 2005, 2008, 2011).

Most of the published reports on saltgrass, including those of Sigua and Hudnall (1991), Sowa and Towill (1991), Enberg and Wu (1995), Miyamoto et al. (1996), Rossi et al. (1996), and Miller et al. (1998) are concern only with the growth of this species, usually concentrated only on one grass genotype or the species of a specific location. The present study examined saltgrass accessions from several locations in Southwest states of the United States of America.

The objectives of this study were to find the most drought tolerant of various saltgrass accessions and to recommend them as the potential species for use in arid and semiarid regions, where limited water supplies coupled with saline soils result in drought/salinity stresses, for use in sustainable desert agriculture, urban landscapes, and in biologically reclaiming desert saline soils and combating desertification.

26.2 Materials and Methods

26.2.1 Plant Materials and Establishment

Fourteen (14) Arizona accessions and 7 Colorado accessions of saltgrass (*Distichlis spicata* L.), collected from Arizona and Colorado, and 1 Bermudagrass (*Cynodon dactylon* L.), cultivar Midiron (check), were studied in a greenhouse to evaluate their growth responses in terms of shoot dry matter (DM) weights and percentage of visual green cover (%VGC) maintenance under prolonged drought stress conditions. Plants were grown as vegetative propagules in PVC tubes (6.35 cm diameter, 10.16 cm length) placed in galvanized cans (45.72 cm diameter, 55.88 cm height) filled with 150 kg fritted clay as plant anchor medium (Fig. 26.2). Four replications (4 cans) of each plant were used in this investigation, in a randomized complete block (RCB) design trial.

Plants were allowed to grow under normal condition (daily watering and weekly fertilization) for 1 year for complete establishment. During this period, plants were clipped weekly (clippings were discarded) at 5 cm height in order to reach full maturity and develop uniform and equal size plants. At the end of this phase of the experiment, the plants were uniform, fully established, and ready for the drought stress phase of the experiment.

Fig. 26.2 Drought tolerance of *Distichlis* accessions. Stainless steel galvanized can (*front row*, 1 replication; *rear row*, all 4 replications of the plants) containing 150 kg fritted clay and the PVC tubes planted with saltgrass

26.2.2 Drought Stress Period

A dry-down fritted clay system which mimics progressive drought (White et al. 1992) was used in this investigation. This procedure has been used successfully in our previous drought stress studies (Pessarakli et al. 2001a, b, 2011; Pessarakli and Kopec 2008b). The system imposes a gradually prolonged drought stress to plants (i.e., various saltgrass accessions) planted in separate PCV tubes (experimental units).

The drought stress started by completely saturating the galvanized cans containing 150 kg fritted clay and the PVC tubes containing the grasses, then depriving the grasses from water and fertilizer for a period of 4 months. During the stress period, shoots were clipped weekly at 5 cm height for the evaluation of growth and dry matter (DM) production. The harvested plant materials were oven dried at 65°C, and DM weights were measured and considered the weekly plant DM production. At each harvest, percentage of the visual green cover (%VGC) was also estimated and recorded.

Two months after the initiation of the drought period, the first sign of stress (leaf curling) was shown. Plants gradually showed more signs of wilting (finally, permanent wilting, and eventually death or dormancy). At the end of the 4-month drought stress period, the majority of the plants were either dead or gone to dormancy stage. After the last harvest, plants were daily rewatered to assess and compare their percent of recovery.

26.2.3 Statistical Analysis

Data were subjected to analysis of variance, using SAS statistical package (SAS Institute, Inc. 1991). The means were separated using Duncan's multiple range test.

26.3 Results and Discussion

The results of both shoot weekly dry weights (Table 26.1) and the weekly evaluations of the percentage of the visual green cover (Table 26.2) and the corresponding results for the average of these values over the 14 weeks drought stress data collections and drought tolerance ranking of the various accessions of saltgrass (Tables 26.3 and 26.4) showed substantial variations in drought stress tolerance among the tested accessions. The weekly harvests dry matter data (Table 26.1) show that the greatest range between the clipping weights was 0.237, (0.081–0.318) for harvest 4, and the narrowest one was 0.009, (0.000–0.009) for harvest 14. The low stress-tolerant grasses (i.e., C10 and C66, Tables 26.3 and 26.4) showed a marked reduction (about 50%) in clipping dry weights after 7 weeks (harvest 7) exposure to drought stress (Fig. 26.3). However, a tolerant accession (i.e., A138, Tables 26.3 and 26.4) showed a similar (about 50%) reduction in clipping dry weight after 10 weeks exposure to drought stress (Fig. 26.3). This clearly indicates that some accessions were less tolerant to drought than the others. Both the clipping dry weights and the percent of the visual green cover decreased as the drought period progressed (Tables 26.1 and 26.2). At the end of the drought period, some accessions were in full dormancy, while some showed about 20% visual green cover. However, there was no measurable growth by any plant after 14 weeks growth under drought stress condition.

Table 26.1 Means of clipping dry weights (g/pot) under drought stress, sorted by grass and by ascending values, for the 14 consecutive weekly harvests

Grass	Harvest 1	Grass	Harvest 2	Grass	Harvest 3	Grass	Harvest 4
C66	0.032	C66	0.044	C10	0.049	C10	0.081
A41	0.033	A138	0.045	C66	0.050	C66	0.094
A48	0.033	C56	0.049	C56	0.050	Bermuda	0.105
A137	0.036	A137	0.049	Bermuda	0.070	C56	0.110
C56	0.036	C10	0.051	A138	0.073	A138	0.127
C10	0.037	A41	0.052	C11	0.080	A55	0.142
A138	0.037	A119	0.059	C12	0.088	A40	0.150
A55	0.038	A48	0.059	A48	0.090	C11	0.154
A61	0.039	A55	0.063	A61	0.093	C12	0.159
A119	0.041	A40	0.065	A40	0.093	A48	0.171
A51	0.046	A61	0.067	A137	0.098	A61	0.182
A40	0.047	A86	0.070	A119	0.104	A137	0.186
A86	0.050	C12	0.074	A55	0.107	A119	0.193
A65	0.053	C8	0.076	C8	0.108	C92	0.198
A77	0.056	C11	0.078	A41	0.118	A86	0.219
C12	0.059	Bermuda	0.088	C92	0.119	A41	0.221
A53	0.060	C92	0.090	A77	0.124	A77	0.241
C11	0.064	A53	0.094	A86	0.126	A53	0.248
C8	0.068	A77	0.096	A65	0.150	C8	0.253
72	0.069	A51	0.101	A53	0.153	A65	0.283
Bermuda	0.069	A65	0.105	A51	0.162	72	0.304
C92	0.078	72	0.109	72	0.169	A51	0.318
Mean	0.049		0.072		0.103		0.188
Grass	Harvest 5	Grass	Harvest 6	Grass	Harvest 7	Grass	Harvest 8
C10	0.082	C66	0.053	C66	0.034	C66	0.034
C66	0.084	C10	0.083	C10	0.047	C10	0.041
Bermuda	0.113	C56	0.090	C56	0.059	A61	0.051
C56	0.127	C12	0.116	A53	0.061	A41	0.052
A55	0.135	A40	0.120	A55	0.064	A55	0.057
A40	0.147	A55	0.131	A61	0.065	C56	0.058
C11	0.153	A41	0.134	A119	0.066	A40	0.061
C12	0.158	C92	0.135	A41	0.071	A53	0.061
A61	0.162	A61	0.137	A65	0.072	C11	0.062
A138	0.168	A77	0.148	A51	0.078	A119	0.062
A41	0.174	C11	0.151	A40	0.080	A77	0.065
A119	0.175	Bermuda	0.158	C8	0.080	A65	0.070
A77	0.178	A86	0.167	A77	0.081	C8	0.070
A86	0.182	A137	0.167	A48	0.082	A48	0.077
C92	0.187	A48	0.190	C92	0.083	A51	0.079
A53	0.193	A53	0.193	C11	0.088	A86	0.079
A137	0.197	A51	0.201	A86	0.090	C92	0.081
A48	0.201	A65	0.209	A137	0.103	A137	0.090
A65	0.232	A119	0.217	C12	0.108	C12	0.092
C8	0.240	72	0.257	Bermuda	0.119	Bermuda	0.110
A51	0.241	C8	0.260	72	0.150	72	0.148
72	0.260	A138	0.280	A138	0.267	A138	0.256
Mean	0.172		0.164		0.089		0.080

Table 26.1 (continued)

Grass	Harvest 9	Grass	Harvest 10	Grass	Harvest 11	Grass	Harvest 12
C66	0.034	C66	0.030	C66	0.016	C66	0.009
C10	0.042	A61	0.036	A41	0.017	C56	0.013
A61	0.043	C56	0.038	C56	0.021	A41	0.013
A41	0.049	A41	0.040	C10	0.022	C11	0.013
A40	0.054	C11	0.043	C11	0.022	C10	0.014
C56	0.054	C10	0.043	A61	0.022	A61	0.016
A55	0.055	A55	0.045	A53	0.023	A55	0.017
A119	0.056	A40	0.046	A51	0.024	A53	0.018
A65	0.057	A53	0.046	A55	0.024	A65	0.020
A77	0.060	A119	0.047	A119	0.025	A51	0.020
A53	0.061	A51	0.049	A40	0.027	C12	0.020
C11	0.061	A77	0.053	A77	0.027	A119	0.020
A51	0.066	A65	0.054	A65	0.028	C92	0.021
A86	0.069	C12	0.058	A48	0.030	A77	0.021
C92	0.076	A48	0.059	C12	0.030	C8	0.022
C8	0.076	C92	0.062	A86	0.031	A40	0.022
C12	0.079	A86	0.062	C92	0.031	A48	0.024
A48	0.081	C8	0.068	C8	0.032	Bermuda	0.027
A137	0.086	A137	0.071	Bermuda	0.040	72	0.029
Bermuda	0.096	72	0.079	72	0.041	A137	0.032
72	0.106	Bermuda	0.088	A137	0.041	A138	0.050
A138	0.179	A138	0.135	A138	0.064	A86	0.057
Mean	0.070		0.057		0.029		0.023

Grass	Harvest 13	Grass	Harvest 14
C66	0.001	C10	0.000
A41	0.003	C11	0.000
C56	0.003	C56	0.000
C11	0.003	C66	0.000
C10	0.004	C92	0.000
A53	0.004	A41	0.000
A61	0.005	A51	0.000
C12	0.007	A53	0.000
A55	0.007	A61	0.000
A51	0.007	A119	0.001
C92	0.008	A40	0.001
A65	0.008	A55	0.001
A40	0.008	A48	0.001
A119	0.008	A65	0.002
A86	0.008	C12	0.002
C8	0.008	A86	0.002
A48	0.009	C8	0.002
A77	0.010	A77	0.002
Bermuda	0.012	Bermuda	0.003
72	0.014	72	0.005
A137	0.019	A137	0.007
A138	0.027	A138	0.009
Mean	0.008		0.002

The values are means of 4 replications for each weekly clipping harvest

Table 26.2 Means of the percentage of visual green cover, sorted by grass and by ascending values, for the last 8 consecutive weekly ratings

Grass	Harvest 1*	Grass	Harvest 2*	Grass	Harvest 3*	Grass	Harvest 4*
A55	84	C11	51	C66	38	C66	34
A41	90	C10	53	C10	48	C10	43
C66	90	A77	55	C11	48	C92	43
C11	90	C66	58	C92	48	C11	44
C92	91	A53	58	A53	50	Bermuda	45
C56	91	C92	59	A77	53	A53	46
A77	93	A41	60	C56	54	A77	49
C10	93	C8	63	A41	54	C56	50
A65	94	C56	63	C8	56	A41	50
A61	94	A119	65	Bermuda	58	C8	51
A53	94	A55	66	A55	60	A119	55
A51	94	C12	69	A119	60	A55	56
A48	94	A51	69	C12	64	C12	60
Bermuda	95	A61	69	A51	65	A51	60
A119	95	A86	69	A61	65	A61	60
A86	95	A40	71	A86	66	A86	61
72	95	A65	71	A65	69	A65	64
A40	95	72	71	72	70	A48	66
C12	95	A48	73	A40	71	A40	68
C8	95	Bermuda	73	A48	71	72	68
A137	96	A137	76	A137	76	A137	74
A138	100	A138	95	A138	90	A138	90
Mean	93		66		61		56

Grass	Harvest 5*	Grass	Harvest 6*	Grass	Harvest 7*	Grass	Harvest 8*
C66	30	C66	23	A41	1	A41	1
C92	38	Bermuda	25	A51	3	A51	1
C10	39	A41	26	C66	4	A53	3
A53	39	A51	26	72	4	Bermuda	3
Bermuda	40	A53	26	A53	5	C66	4
C11	41	C92	30	A61	5	A61	4
A51	41	A65	31	Bermuda	5	72	4
A55	41	A77	31	A119	6	A119	5
A41	44	A55	35	A65	8	A65	6
A77	44	A61	35	A77	8	A86	6
C56	46	A119	35	A86	8	A77	8
C8	48	C10	36	C92	10	A48	9
A61	49	C11	36	A55	11	A55	9
A119	49	72	38	A40	13	C92	10
A65	51	C56	40	A48	13	C10	11
A86	53	A86	40	A138	13	A138	11
C12	55	C8	43	C10	14	C56	13
72	55	A48	46	C56	14	A40	14
A48	58	C12	50	A137	16	A137	14
A40	59	A40	50	C8	19	C8	18
A137	68	A137	53	C11	20	C11	18
A138	75	A138	54	C12	31	C12	31
Mean	48		37		11		9

*The harvest values for harvests 1–8 in harvest columns are means of 4 replications for each weekly rating

Table 26.3 Means of saltgrass clipping dry weights (g/pot) and percentage of visual green cover (%VGC) evaluations under drought stress

Grass ID	Shoot DM (g)*	VGC (%)*
72	1.089b**	51b**
A40	0.921bc	55ab
A41	0.977bc	41bc
A48	1.107b	54b
A51	1.392ab	45bc
A53	1.215ab	40bc
A55	0.886bc	45bc
A61	0.918bc	48b
A65	1.343ab	49b
A77	1.162ab	43bc
A86	1.212ab	50b
A119	1.074b	46bc
A137	1.182ab	60ab
A138	1.717a	66a
C8	1.363ab	49b
C10	0.596c	42bc
C11	0.972bc	44bc
C12	1.050b	57ab
C56	0.708bc	47bc
C66	0.521c	35c
C92	1.169ab	41bc
Bermuda	1.098b	43bc

*The values are means of 4 replications of 14 weekly clipping harvests or percent visual green color evaluations

**The values followed by the same letters in each column are not statistically significant at the 0.05% probability level

Overall, the results (both clipping dry weights and the percent of the visual green cover) showed that the A138 and A137 (Arizona accessions) were the best and the most drought-tolerant accessions, and the C10 and C66 (Colorado accession) were the worst and the least tolerant ones (Tables 26.3 and 26.4). This is supported by Kopec et al. (2000) findings that when these accessions of saltgrass were tested, mowed at 1.27 cm in 1.83 m × 1.22 m plots in the field for 2 years, the Arizona accessions showed superiority over the Colorado ones in most of the parameters evaluated. These include percentage of visual green cover, density, uniformity, turf quality, and plant establishment. Marcum (1999) tested these accessions under salinity stress and found essentially similar results. In the present study, most of the saltgrass accessions were more tolerant to drought stress than the bermudagrass (Tables 26.3 and 26.4). Bermudagrass reached full dormancy and/or necrosis stage before most of the saltgrass accessions (Table 26.2). Nevertheless, bermudagrass recovered faster than most of the saltgrass accessions after the plants were rewatered. This may have been due to the more aggressive growth and massive root production of bermudagrass than saltgrass during the experimental period.

Table 26.4 Drought tolerance ranking of saltgrass based on shoot (clipping) DM weight, percentage of visual green cover (%VGC), and overall ranking

Tolerance ranking	Drought shoot DM Wt.*	Tolerance %VGC*	Based on overall
High	A138a (1.717a)**	A138 (66a)**	A138a**
↓	A51ab (1.392ab)	A137 (60ab)	A137a
	C8ab (1.363ab)	C12 (57ab)	A65ab
	A65ab (1.343ab)	A40 (55ab)	A86ab
	A53ab (1.215ab)	A48 (54b)	C8ab
	A86ab (1.212ab)	72b (51b)	C12ab
	A137ab (1.182ab)	A86 (50b)	72b
	C92ab (1.169ab)	A65 (49b)	A40b
	A77ab (1.162ab)	C8 (49b)	A48b
	A48b (1.107b)	A61 (48b)	A51b
	Bermuda b(1.098b)	C56 (47bc)	A53b
	72b (1.089b)	A119 (46bc)	A77b
	A119b (1.074b)	A51 (45bc)	C92b
	C12b (1.050b)	A55 (45bc)	A61bc
	A41bc (0.977bc)	C11 (44bc)	A119bc
	C11bc (0.972bc)	A77 (43bc)	Bermuda bc
	A40bc (0.921bc)	Bermuda (43bc)	A41bc
	A61bc (0.918bc)	C10 (42bc)	A55bc
	A55bc (0.886bc)	A41 (41bc)	C11bc
	C56bc (0.708bc)	C92 (41bc)	C56bc
	C10c (0.596c)	A53 (40bc)	C10c
Low	C66c (0.521c)	C66 (35c)	C66c

*The values are means of 4 replications for 14 weekly clipping harvests or percent visual green color evaluations

**The values followed by the same letters in each column are not statistically significant at the 0.05 probability level

Although all the tested accessions of saltgrass exhibited a high degree of drought tolerance, considering the study parameters (shoot DM weight and percentage of the visual green cover) together, there was a substantial difference found among the various accessions regarding drought stress tolerance (Tables 26.3 and 26.4). Although there were some differences in drought tolerance ranking of the accessions when compared based on shoot DM weight or percentage of the visual green cover, the overall ranking was the best representation of the drought tolerance of the various tested accessions of saltgrass. According to the presented data in Table 26.4, the grasses were ranked in several distinct groups in regard to degree of drought tolerance. The A138 and A137 were the most drought-tolerant accessions, followed by A65, A86, C8, and C12 accessions. These were closely followed by 72, A40, A48, A51, A53, A77, and C92 accessions in drought tolerance. The A41, A55, A61, A119, C11, and C66 saltgrass accessions as well as bermudagrass laid between this and the last group in regard to drought tolerance. The C10 and C66 were among the lowest drought-tolerant grass accessions which the C66 was the least tolerant one (Table 26.4).

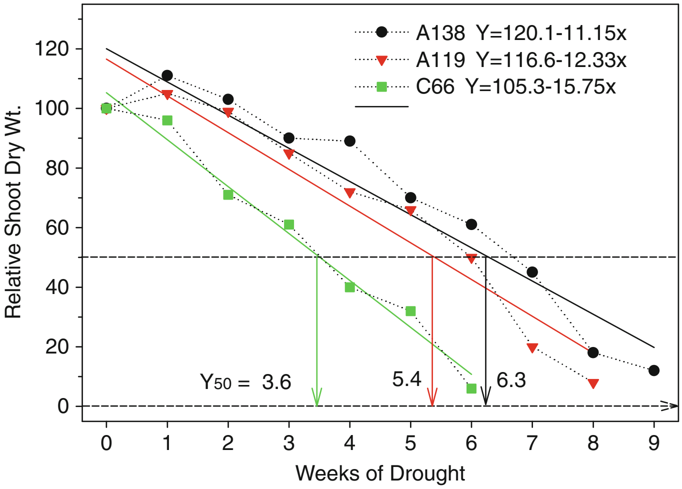

Fig. 26.3 Competitive soil moisture dry-down fritted clay media having known water potential release. Representative saltgrass accessions of high, medium, and low drought tolerance

26.4 Conclusions

Saltgrass shoot dry matter (DM) weight and percentage of visual green cover decreased linearly as drought period progressed. However, at each harvest, there were substantial variations among the tested accessions in regard to both dry matter production and the percentage of the visual green cover. Both the clippings dry weights and the percent of the visual green cover decreased as the drought period progressed. Among the studied accessions of saltgrass, the A138 and A137 (Arizona accessions) were superior and the most tolerant to drought stress, and the C10 and C66 (Colorado accessions) were the worst and the least tolerant accessions. Several accessions, including A65, A86, C8, and C12, were statistically the same as the above superior group (group 1), but numerically with lower values. These were closely followed by accessions 72, A40, A48, A51, A53, A77, and C92, but statistically significantly lower than the superior group (A138 and A137 accessions) in regard to drought tolerance. These results suggest that the A138 and A137 accessions as well as A65, A86, C8, and C12 which were statistically the same as the above superior group and showing superiority over the other ones under drought stress conditions may be recommended for use as plant species under low inputs or harsh desert environmental conditions. Bermudagrass reached full dormancy before most of the saltgrass accessions. Therefore, bermudagrass is less tolerant to drought compared to saltgrass.

Overall, considering the results of this study and the results of our previous drought and salinity stress tolerance studies of this grass species, the following general conclusions can be drawn: Saltgrass is a true halophytic plant species, very high tolerant to both drought and salinity stresses. Growing even under poor soil conditions (salt-affected desert soils) and drought (characteristics of the arid regions), saltgrass is a suitable and beneficial plant species for cultivation under arid and semiarid regions, areas with water shortage or low-quality saline water resources. The grass can still show a favorable growth and development with satisfactory soil surface coverage and proper yields under harsh desert environmental conditions. Consequently, saltgrass can be one of the most suitable plant species to be used for cultivation under arid, semiarid, and areas with saline soils and limited water supplies or drought conditions. Therefore, this species can be successfully used for restoration of the arid lands and for sustainable agriculture in arid regions and combating desertification.

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References

Enberg A, Wu L (1995) Selenium assimilation and differential response to elevated sulfate and chloride salt concentrations in two saltgrass ecotypes. Ecotoxicol Environ Saf 32(2):71–178

Gessler N, Pessarakli M (2009) Growth responses and nitrogen uptake of saltgrass under salinity stress. Turfgrass landscape and urban IPM research summary 2009, cooperative extension, agricultural experiment station, The University of Arizona, Tucson, AZ, United States Department of Agriculture (USDA), Publication AZ1487, Series P-155, pp 32–38

Gould FW (1993) Grasses of the Southwestern United States, 6th edn. The University of Arizona Press, Tucson

Kopec DM, Marcum K, Pessarakli M (2000) Collection and evaluation of diverse geographical accessions of *Distichlis* for turf-type growth habit, salinity and drought tolerance. Report #2, Cooperative Extension Agriculture Experiment Station Service, The University of Arizona, Tucson, AZ, p 11

Kopec DM, Adams A, Bourn C, Gilbert JJ, Marcum K, Pessarakli M (2001a) Field performance of selected mowed *Distichlis* Clones, United States Golf Association (USGA) research report #3. Turfgrass landscape and urban IPM research summary 2001, Cooperative Extension Agriculture Experiment Station, The University of Arizona, Tucson, AZ, United States Department of Agriculture (USDA), Publication AZ1246 Series P-126, pp 295–304

Kopec DM, Adams A, Bourn C, Gilbert JJ, Marcum KB, Pessarakli M (2001b) Field performance of selected mowed *Distichlis* Clones, United States Golf Association (USGA) research report #4. Turfgrass landscape and urban IPM research summary 2001, Cooperative Extension Agriculture Experiment Station, The University of Arizona, Tucson, AZ, United States Department of Agriculture (USDA), Publication AZ1246 Series P-126, pp 305–312

Kopec DM, Stephen N, Brown PW, Pessarakli M (2006) Water and turfgrass in the arid southwest: water use rates of Tifway 419 bermudagrass, sea isle 1, seashore paspalum, and inland saltgrass. United States Golf Association (USGA) Green Section Record, A Publication of Turfgrass Management, November–December 2006 Issue (6):12–14

Marcum KB (1999) Salinity tolerance mechanisms of grasses in the subfamily Chloridoideae. Crop Sci 39:1153–1160

Marcum KB, Pessarakli M, Kopec DM (2005) Relative salinity tolerance of 21 turf-type desert saltgrasses compared to bermudagrass. Hort Sci 40(3):827–829, www.ashs.org

Marcum KB, Yensen NP, Leake JE (2007) Genotypic variation in salinity tolerance of *Distichlis spicata* turf ecotypes. Aust J Exp Agric 47(12):1506–1511

Miller DL, Smeins FE, Webb JW (1998) Response of a Texas *Distichlis spicata* coastal marsh following lesser snow goose herbivory. Aquat Bot 61(4):301–307

Miyamoto S, Glenn EP, Olsen MW (1996) Growth, water use and salt uptake of four halophytes irrigated with highly saline water. J Arid Environ 32(2):141–159

O'Leary JW, Glenn EP (1994) Global distribution and potential for halophytes. In: Squires VR, Ayoub AT (eds) Halophytes as a resource for livestock and for rehabilitation of degraded lands. Kluwer Acad Publ, Dordrecht, pp 7–19

Pessarakli M (2005a) Supergrass: drought-tolerant turf might be adaptable for golf course use. Golfweek's SuperNews Magazine, 16 Nov 2005, p 21 and cover page. http://www.supernewsmag.com/news/golfweek/supernews/20051116/p21.asp?st=p21_s1.htm

Pessarakli M (2005b) Gardener's delight: low-maintenance grass. Tucson Citizen, Arizona, Newspaper Article, 15 Sept 2005, Tucson, AZ. Gardener's delight: low-maintenance grass. http://www.tucsoncitizen.com/

Pessarakli M (2007) Saltgrass (*Distichlis spicata*), a potential future turfgrass species with minimum maintenance/management cultural practices. In: Pessarakli M (ed) Handbook of turfgrass management and physiology. CRC Press/Taylor & Francis Group, Boca Raton, pp 603–615

Pessarakli M (2008) Nitrogen nutrition of *Distichlis* (Saltgrass) under normal and salinity stress conditions using ^{15}N. Turfgrass and Environment, United States Golf Association (USGA), Bernards, p 70

Pessarakli M, Kopec DM (2005) Responses of twelve inland saltgrass accessions to salt stress. USGA Turfgrass Environ Res Online 4(20):1–5. http://turf.lib.msu.edu/tero/v02/n14.pdf

Pessarakli M, Kopec DM (2006) Interactive effects of salinity and mowing heights on the growth of various inland saltgrass clones. Turfgrass and Environment, United States Golf Association (USGA), Bernards, pp 83–84

Pessarakli M, Kopec DM (2008a) Establishment of three warm-season grasses under salinity stress. Acta HortScience, Int Soc of Hort Sci (ISHS) 783:29–37

Pessarakli M, Kopec DM (2008b) Growth response of various saltgrass (*Distichlis spicata*) clones to combined effects of drought and mowing heights. USGA Turfgrass Environ Res Online, 1 Jan 2008, 7(1):1–4. http://turf.lib.msu.edu/tero/v02/n14.pdf

Pessarakli M, Kopec DM (2010) Growth responses and nitrogen uptake of saltgrass (*Distichlis Spicata* L.), a true halophyte, under salinity stress conditions using ^{15}N technique. In: International conference on management of soil and groundwater salinization in arid regions, Sultan Qaboos University, Muscat, Sultanate of Oman, 11–14 Jan 2010

Pessarakli M, Marcum KB (2000) Growth responses and nitrogen-15 absorption of *Distichlis* under sodium chloride stress. Am Soc Agron-Crop Sci Soc Am-Soil Sci Soc Am (ASA-CSSA-SSSA) annual meetings, Minneapolis, MN, 5–9 Nov 2000

Pessarakli M, Marcum KB, Kopec DM (2001a) Drought tolerance of twenty one saltgrass (*Distichlis*) accessions compared to bermudagrass. Turfgrass landscape and urban IPM research summary 2001, cooperative extension, agricultural experiment station, The University of Arizona, Tucson, AZ, United States Department of Agriculture (USDA), Publication AZ1246 Series p-126, pp 65–69

Pessarakli M, Marcum KB, Kopec DM (2001b) Drought tolerance of turf-type inland saltgrasses and bermudagrass. American Society of Agronomy-Crop Science Society of America-Soil Science Society of America (ASA-CSSA-SSSA) annual meetings, Charlotte, NC, Agronomy Abstract, C05-pessarakli130005-P, 27 Oct–2 Nov 2001

Pessarakli M, Marcum KB, Kopec DM (2001c) Growth responses of desert saltgrass under salt stress. Turfgrass landscape and urban IPM research summary 2001, Cooperative Extension, Agricultural Experiment Station, The University of Arizona, Tucson, AZ, United States Department of Agriculture (USDA), Publication AZ1246 Series P-126, pp 70–73

Pessarakli M, Kopec DM, Koski AJ (2003) Establishment of warm-season grasses under salinity stress. Am Soc Agron-Crop Sci Soc Am-Soil Sci Soc Am (ASA-CSSA-SSSA) annual meetings, Denver, CO, 2–6 Nov 2003

Pessarakli M, Marcum KB, Kopec DM (2005) Growth responses and nitrogen-15 absorption of desert saltgrass under salt stress. J Plant Nutr 28(8):1441–1452. www.tandf.co.uk/journals/titles/01904167.asp

Pessarakli M, Gessler N, Kopec DM (2008) Growth responses of saltgrass (*Distichlis spicata*) under sodium chloride (NaCl) salinity stress. USGA Turfgrass Environ Res Online, 15 Oct 2008, 7(20):1–7. http://turf.lib.msu.edu/tero/v02/n14.pdf

Pessarakli M, Marcum KB, Emam Y (2011) Relative drought tolerance of various desert saltgrass (*Distichlis spicata*) genotypes. J Food Agric Environ 9(1):474–478

Rossi AM, Brodbeck BV, Strong DR (1996) Response of xylem-feeding leafhopper to host plant species and plant quality. J Chem Ecol 22(4):653–671

SAS Institute Inc. (1991) SAS/STAT user's guide. SAS Institute Inc., Cary

Sigua GC, Hudnall WH (1991) Gypsum and water management interactions for revegetation and productivity improvement of brackish marsh in Louisiana. Commun Soil Sci Plant Anal 22(15/16):1721–1739

Sowa S, Towill LE (1991) Effects of nitrous oxide on mitochondrial and cell respiration and growth in *Distichlis spicata* suspension cultures. Plant-Cell Tiss Org Cult (Netherlands) 27(2):197–201

White RH, Engelke MC, Morton SJ, Ruemmele BA (1992) Competitive turgor maintenance in tall fescue. Crop Sci J 32:251–256

Chapter 27
Relative Salinity Tolerance of 35 *Lolium* spp. Cultivars for Urban Landscape and Forage Use

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Abstract Increasing population growth, particularly in urban centers, is resulting in critical freshwater shortages for both agriculture and urban use worldwide. To counteract existing water crises, many governments are restricting use of freshwater sources for irrigation. In the urban setting, governments are requiring use of reclaimed wastewater or other secondary saline water sources in lieu of freshwater for landscape irrigation. *Lolium* spp. (ryegrasses) is widely used for forage as well as in urban turf landscapes. Relative salinity tolerance of 35 *Lolium* spp. cultivars was determined in solution culture by measuring changes in shoot weight, root weight, rooting depth, and % green leaf canopy area, relative to control (non-salinized) plants. There was a wide range in salinity tolerance of the tested cultivars, ranging from salt tolerant (e.g., cv. Paragon) to salt sensitive (e.g., cv. Midway). All shoot parameters were highly correlated, being mutually effective predictors of salinity tolerance. Root dry weight, significantly correlated with all shoot quality and growth parameters, was also effective in predicting relative salinity tolerance. However, rooting depth was not correlated with other parameters, and therefore not effective in predicting relative salinity tolerance. Based on these results, it is concluded that salt-tolerant cultivars exist within *Lolium* spp. for agricultural forage and urban landscape use.

Keywords Forage • *Lolium* spp. • Salinity tolerance • Turfgrass • Urban landscape

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27.1 Introduction

Increasing population growth in large urban centers is resulting in critical potable water shortages (Anderson et al. 2005; Kjelgren et al. 2000), a trend progressively worsening due to droughts related to global climate change (Barnett et al. 2005; European Commission 2006; Pearman et al. 2003). Demand on limited potable water resources is resulting in government-mandated water use restrictions which limit use of potable water while requiring use of reclaimed or other secondary saline water sources for irrigation of turfgrass landscapes (Arizona Department of Water Resources 2003; California State Water Resources Control Board 2006; Council of Australian Governments 2004).

Ryegrasses are among the most widely used C3 grasses for forage and turfgrass in temperate regions (Barnes et al. 2003). Ryegrasses used for forage or turfgrass generally consist of three species: perennial (*Lolium perenne* L.), annual or Italian (L. *multiflorum Lam*.), and intermediate (*Lolium xhybridum Hausskn*.), an interspecific hybrid of the two. Though perennial ryegrass provides higher quality forage and is more cold-tolerant and persistent, it is lower yielding and slower to establish than annual ryegrass (Cosgrove et al. 1999). However, in modern turfgrass landscapes, perennial and intermediate ryegrasses are generally used instead of annual ryegrass, due to their higher quality (Turgeon 2005). Perennial ryegrass has been ranked moderate in salinity tolerance, tolerating soil ECe ranging from 4 to 8 dS m^{-1} (Harivandi et al. 1992), with annual and intermediate ryegrasses ranked more salt sensitive, tolerating soil ECe from 3 to 5 dS m^{-1} (Marcum 2006). However, little information is available regarding the difference in salinity tolerance between species, nor regarding the range in salinity tolerance present among turf cultivars or accessions within species. The goal of this study was to determine the degree and range of salinity tolerance present among a broad selection of modern ryegrass cultivars.

27.2 Materials and Methods

To minimize environmental interactions, research was conducted in a controlled environment glasshouse using a solution culture protocol (Marcum et al. 2005). Temperatures were maintained at 28–32°C during day and 20–24°C during night, with maximum photosynthetically active radiation (PAR) levels of 950 μmol m^{-2} s^{-1}. Day lengths ranged from 10 to 12 h, and light levels were supplemented for 2 h during early morning (after sunrise) and late afternoon (before sunset) with high-pressure sodium lamps (1,000 W; Energy Technics, York, PA). Ryegrass cultivars were seeded at a rate of 40 g m^{-2} into 7-cm-diameter × 8-cm-deep pots filled with coarse, acid-washed silica sand. Grasses were established under mist and then transferred to culture tanks containing 32 L 1/2 strength Hoagland's No. 2 solution, modified with Fe-sodium ferric diethylenetriamine pentaacetate (DTPA) chelate to provide 3 mg L^{-1} elemental Fe. Nutrient solutions were changed at 10-day intervals

Table 27.1 Ryegrass (*Lolium* spp.) cultivar names, species, and source

Cultivar	Species	Source
Achiever	*L. perenne*	Scotts Co.
Ascend	*L. perenne*	Scotts Co.
BlackHawk	*L. perenne*	TMI Turf Merchants, Inc.
Caddieshack	*L. perenne*	Jacklin Seed Co.
Calypso II	*L. perenne*	Pickseed West, Inc.
Cutter	*L. perenne*	Pickseed West, Inc.
Divine	*L. perenne*	Scotts Co.
Essence	*L. perenne*	DLF International Seeds
Express	*L. perenne*	Pickseed West, Inc.
Fiesta III	*L. perenne*	Pickseed West, Inc.
Froghair	*L. xhybridum*	TMI Turf Merchants, Inc.
Gator II	*L. perenne*	DLF International Seeds
Jiffie	*L. perenne*	Pickseed West, Inc.
Laredo	*L. perenne*	TMI Turf Merchants, Inc.
Legacy II	*L. perenne*	LESCO, Inc.
LineDrive	*L. perenne*	LESCO, Inc.
Lowgrow II	*L. perenne*	Pickseed West, Inc.
Majesty	*L. perenne*	Scotts Co.
Manhattan III	*L. perenne*	TMI Turf Merchants, Inc.
Midway	*L. xhybridum*	LESCO, Inc.
Monterey	*L. perenne*	Jacklin Seed Co.
Pace	*L. perenne*	Barenbrug USA
Paragon	*L. perenne*	TMI Turf Merchants, Inc.
Peak	*L. perenne*	Barenbrug USA
Pinnacle	*L. perenne*	Barenbrug USA
Platinum	*L. perenne*	DLF International Seeds
Premier II	*L. perenne*	Barenbrug USA
Spyglass	*L. perenne*	Jacklin Seed Co.
Sunshine	*L. perenne*	Pickseed West, Inc.
Superfly	*L. perenne*	Jacklin Seed Co.
Top Gun	*L. perenne*	Jacklin Seed Co.
Top Hat	*L. perenne*	DLF International Seeds
Transist	*L. xhybridum*	Pickseed West, Inc.
Williamsburg	*L. perenne*	LESCO, Inc.
Wilmington	*L. perenne*	LESCO, Inc.

to ensure minimal changes in nutrient ion concentrations. Cultivars, including species and origin, are listed in Table 27.1.

Shoots were clipped 1X per week at 2 cm throughout the experiment. Turfgrasses were established for 2 months under this mowing regime prior to initiation of salinity treatments. Salinity was then gradually raised in treatment tanks (control tanks received no salt) by 1 dS m^{-1} daily using a 3:1 ratio by weight of NaCl to $CaCl_2$ salts, until treatment level of 6 dS m^{-1} was reached.

Data collection began 1 week after reaching final treatment salinity levels, continuing over a 42-day period. Shoot dry weight and % green leaf canopy area were measured weekly. Rate of decline of individual cultivar shoot dry weight (relative to control) with time, indicated as slope, was calculated by linear regression (Der and Everitt 2001). Root dry weight and rooting depth were measured at the end of the experiment.

Experimental design was a randomized complete block (RCB), split plot, with 35 cultivars (subplots) included in each solution culture tank (main plots). There were six replications. All data were statistically analyzed by analysis of variance, utilizing least significant difference (LSD) separation of treatment means, and relative shoot dry weights were also analyzed by regression (Der and Everitt 2001). Relative shoot dry weight and % green leaf canopy area data were transformed by arsin prior to analysis (Steel and Torrie 1980) but are presented as percentages. Pearson product moment correlation coefficients were used to compare variables.

27.3 Results and Discussion

Relative shoot dry weights declined linearly with increasing days of salinity exposure in ryegrass cultivars; therefore, the slope of linear regression was used to describe relative salinity tolerance. Slope of decline in relative shoot dry weight with time ranged from −0.99 in cv. Paragon to −4.89 in cv. Froghair (Table 27.2). From regression analysis, days to 50% relative shoot dry weight ranged from 10 to 30 days in ryegrass cultivars (data not shown). Relative shoot dry weights at experiment termination ranged from 61% in cv. Paragon to 0% in cvs. Manhattan III, Transist, and Froghair. Root weight at experiment termination ranged from 1.5 g in cv. Paragon to 0.1 g in cv. Froghair (Table 27.2). Similarly, rooting depth ranged from 8.1 cm in cv. Paragon to 0.1 cm in cvs. Transist and Froghair.

Shoot parameters were highly correlated, being mutually effective predictors of salinity tolerance. Following 6 weeks of salinity stress, relative leaf dry weight at final harvest was correlated with % green leaf canopy area ($r = 0.89$) and with predicted days to 50% leaf dry weight ($r = 0.84$) (Table 27.3). Root dry weight (RW), though significantly correlated with all shoot quality and growth parameters, was only moderately effective in predicting relative salinity tolerance. Rooting depth (RD) was not correlated with other parameters, and therefore not effective in predicting relative salinity tolerance. Cv. Paragon was most salt tolerant, as indicated by all parameters. Other salt-tolerant cvs. included ‘Divine’ and ‘Williamsburg’. Intermediate ryegrasses *(Lolium* x*hybridum)* were invariably more salt sensitive than perennial ryegrasses *(Lolium perenne)*.

27.4 Conclusions and Recommendations

A large range in salinity tolerance was found among modern ryegrass (*Lolium perenne* and *L.* x*hybridum*) cultivars. Shoot parameters relative leaf dry weight, days to 50% leaf dry weight, and % green leaf canopy area were highly correlated and

Table 27.2 Salinity tolerance parameters of 35 ryegrass (*Lolium* spp.) turf cultivars following 6 weeks exposure to 6 dS m^{-1} root media salinity

Cultivar	SW_{SLOPE}	SW_{REL} (%)	GL (%)	RW (g)	RD (cm)
Paragon	–0.99	61.4	67	1.50	8.1
Divine	–1.53	39.9	33	1.10	6.6
Express	–1.72	32.3	17	0.91	6.2
Jiffie	–1.79	28.5	23	0.91	0.7
Caddieshack	–1.79	28.5	17	0.96	5.5
Cutter	–1.80	23.3	17	1.07	3.7
Essence	–1.84	25.8	17	1.01	0.5
Spyglass	–1.93	16.7	20	1.37	3.7
Majesty	–1.96	21.8	17	1.26	1.3
Fiesta III	–2.01	19.7	10	0.99	0.8
Legacy II	–2.02	13.2	13	1.03	5.6
Wilmington	–2.08	14.7	17	1.14	4.2
Premier III	–2.13	10.6	10	1.14	3.0
Laredo	–2.16	17.5	10	0.92	5.5
Superfly	–2.18	10.2	10	1.29	3.3
Gator II	–2.19	19.7	13	0.96	4.0
Sunshine	–2.19	7.1	7	1.29	0.5
Achiever	–2.21	9.6	17	0.91	3.2
BlackHawk	–2.24	5.8	13	0.61	4.6
Peak	–2.29	6.3	7	1.07	5.8
Top Hat	–2.30	12.3	10	0.91	3.3
Ascend	–2.32	15.0	10	1.26	3.3
Calypso II	–2.33	8.0	7	0.92	6.6
Top Gun	–2.36	5.0	7	1.36	4.4
Platinum	–2.38	5.2	7	1.06	7.8
Pace	–2.39	3.9	3	0.90	1.5
Lowgrow II	–2.46	9.0	3	0.79	0.3
Monterey	–2.62	2.8	3	0.89	2.4
Midway	–2.84	0.7	0	0.22	1.4
LineDrive	–3.13	2.0	0	1.01	6.0
Manhattan III	–3.91	0	0	0.80	0.2
Transist	–4.63	0	0	0.26	0.1
Froghair	–4.89	0	0	0.10	0.1
$LSD_{0.05}$		7.4	8	0.21	1.8

Shoot parameters include slope of decline of relative shoot dry weight over the 6 weeks exposure to salinity (SW_{SLOPE}), relative (as % of control) shoot dry weight (SW_{REL}) at final harvest, and % green leaf canopy area (*GL*) at final harvest. Rooting parameters are root dry weight (*RW*) and rooting depth (*RD*)

equally effective in predicting salinity tolerance. Salinity-tolerant cultivars included ‘Paragon’, ‘Divine’ and ‘Williamsburg’. *Lolium* x*hybridum* cultivars were invariably most salt sensitive. In situations where saline irrigation water is used, it is recommended that *Lolium perenne* cultivars are used, particularly ‘Paragon’. There is broad genetic diversity for salinity tolerance within the *Lolium* genus, indicating that good progress may be made in breeding improved salt-tolerant cultivars.

Table 27.3 Pearson correlation coefficients and probability levels for relative leaf dry weight at final harvest (*LWREL*), predicted days to 50% leaf dry weight (*LW50*), % green leaf canopy area at final harvest (*GL*), root dry weight (*RW*), and rooting depth (*RD*)

Variable	GL	LW_{REL}	LW_{50}	RW
LW_{REL}	0.89			
	0.0001<			
LW_{50}	0.84	0.77		
	0.0001<	0.0001<		
RW	0.53	0.45	0.56	
	0.001	0.006	0.0005	
RD	0.35	0.30	0.32	0.18
	0.04	N.S.	N.S.	N.S.

N.S. = not significant at 5% level of probability

References

Anderson RF, Rosenberg B, Sheahan J (2005) The U.S. Conference of Mayors urban water council national city water survey, 2005, p 31, Washington, DC http://www.usmayors.org/74thWinterMeeting/NationalCityWaterSurvey2005.pdf

Arizona Department of Water Resources (2003) Third management plan: 2000–2010. Arizona Department of Water Resources, Phoenix. http://www.azwater.gov/dwr/Content/Publications/files/ThirdMgmtPlan/tmp_final/

Barnes RF, Nelsen CJ, Collins M (2003) Forages, an introduction to grassland agriculture. Wiley-Blackwell, New York, p 556

Barnett TP, Adam JC, Lettenmaier DP (2005) Potential impacts of a warming climate on water availability in snow-dominated regions. Nature 438:303–309

California State Water Resources Control Board (2006) Porter-Cologne water quality control act, California Water Code, Section 13552–13577. California State Water Resources Control Board, Sacramento, http://www.swrcb.ca.gov/water_laws/docs/portercologne.pdf

Cosgrove D, Casler M, Undersander D (1999) Ryegrass types for pasture and hay. Agronomy Advice FC 14.12.2, University of Wisconsin Cooperative Extension. http://www.uwex.edu/CES/forage/pubs/ryegrass.htm

Council of Australian Governments (2004). National water initiative. Council of Australian Governments meeting, 25 June, Canberra, ACT. http://www.coag.gov.au/meetings/250604/index.htm#water_initiative

Der G, Everitt BS (2001) A handbook of statistical analyses using SAS, 2nd edn. CRC Press, New York

European Commission (2006) Water scarcity and drought: in-depth assessment. First interim report – Nov 2006, p 68, Brussels, Belgium, http://ec.europa.eu/environment/water/pdf/1st_report.pdf

Harivandi MA, Butler JD, Wu L (1992) Salinity and turfgrass culture. In: Waddington DV, Carrow RN, Shearman RC (eds) Turfgrass – Agronomy Monograph 32. American Society of Agronomics, Madison, pp 207–229

Kjelgren R, Rupp L, Kilgren D (2000) Water conservation in urban landscapes. Hort Sci 35:1037–1040

Marcum KB (2006) Use of saline and non-potable water in the turfgrass industry: constraints and developments. Agric Water Manage 80:132–146

Marcum KB, Pessarakli M, Kopec DM (2005) Relative salinity tolerance of 21 turf-type desert saltgrasses compared to bermudagrass. Hort Sci 40(3):827–829

Pearman GI, Hennessy K, Jones R, Maheepala S (2003) Climate change and its predicted effects on water resources. In: Water, the Australian dilemma. Proceedings of the annual symposium of the Academy of Technological Sciences and Engineering. The Academy of Technological Sciences and Engineering, Melbourne, pp 174–191

Steel RGD, Torrie JH (1980) Principles and procedures of statistics, a biometrical approach, 2nd edn. McGraw-Hill, New York

Turgeon AJ (2005) Turfgrass management, 7th edn. Prentice Hall, Englwood Cliffs

Chapter 28
Enhancing The Quality of Turfgrasses with Saline Groundwater

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Abstract Australia is listed under group II which represents countries that face economic water scarcity in 2025. Groundwater resources are the main source of water supplies for 30% of the world's population. We have studied the use of saline groundwater to grow four turfgrass species (*Paspalum vaginatum*, *Sporobolus virginicus*, *Distichlis spicata* – three halophytes; and *Pennisetum clandestinum* – a non-halophyte) over two years under saline irrigation (13 dS m^{-1}) groundwater or with freshwater, both at approximately 60% replacement of net evaporation. Soil salinity was assessed with the EM38, and by soil sampling and subsequent analyses for EC, a strong correlation was found between the two methods ($r^2 = 80\%$). Irrigation with saline water reduced turfgrass colour (i.e. 'greenness') in *Pennisetum clandestinum* whereas it was not affected in *Distichlis spicata*, *Paspalum vaginatum* and *Sporobolus virginicus*. Growth, represented by turf height increased by 3, 10 and 3 cm under saline irrigation for *Paspalum vaginatum*, *Sporobolus virginicus* and *Distichlis spicata*, respectively, whereas decreased by 1 cm for *Pennisetum clandestinum*. Na^+ concentration in leaf tissues increased threefold more in *Pennisetum clandestinum* compared with the halophytic grasses. Elucidation of quantitative relationships between growth, root-zone salinity and water content will improve basic knowledge on the functioning of halophytes managed for turfgrass and contribute to the sustainable management of these species under saline irrigation conditions. This chapter illustrates the potential use of the halophytic grasses as high-quality turfgrasses.

Keywords Halophytes • Ion regulations • Leaching fraction • Mechanisms of salt tolerance • Salinity and sodicity

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28.1 Introduction

Worldwide 1 quarter billion hectares (ha) are irrigated using about 70% of the surface water (Stikker 1998). A study in the United States of America (USA) shows that an average of 58% of the freshwater resources are used to irrigate the outdoor landscape, while in Florida, the average is 71% (Baum et al. 2003). In Australia, many rural and coastal towns have saline groundwater and/or saline soils. In Western Australia alone, more than 30 rural towns are adversely affected by dryland salinity, with threats to valuable infrastructure and amenity areas (State Salinity Council 2000); likewise, it is in the Arabian Peninsula (Abdelfattah and Shahid 2007). Salinity impacts on community budgets to maintain, or repair, infrastructure, as well as increasing social costs, due to the resulting poor quality of ovals and turfgrass amenity areas. Salt-tolerant turfgrasses will improve the aesthetics of public open spaces and ovals, with benefits to the community. Moreover, use of saline water, rather than potable water supplies, to irrigate turfgrass areas will help conserve our precious high-quality water resources and reduce net input of water within town sites.

According to International Water Management Institution (IWMI), United Arab Emirates (UAE) was listed under group 1, which represents countries that face physical water scarcity in 2025. These countries have an annual freshwater availability of less than 1,000 m^3 per capita (the index for water scarcity), and also they need to convey and regulate 25% or more of the 1995 levels to meet their 2025 needs. Thus, it is worthwhile to consider the available massive amount of saline water resources (IWMI 2000).

The low recharge of freshwater resources in UAE (only 10%) of the required water in 1990 and the continuity of the withdrawal of freshwater resources will increase the pressure on these precious water resources, similar to the case in the Arabian Peninsula where water scarcity is escalating as predicated for the coming 10 years to be ~32 million m^3 (Jaradat 2005). Given the increase growth rate of the population and the increase in the irrigated agriculture in UAE of up to 158% by the year 2025, the need rises for alternative water resources (IWMI 2000).

Groundwater resources are the main source of water supplies for 30% of the world's population (UNDP 2000). However, many limitations threaten these sources (i.e. salinity and chemical pollution from either industrial residues or agricultural pesticides), and in the agricultural zone of Australia, much of the groundwater is saline (Northey et al. 2005).

The use of saline water without proper management practices could lead to accumulation of salts in both the groundwater and the root zone (Shahid et al. 2009). To date, there is very little information that quantifies the amount of water, irrigation frequency and the depth of application required to maintain salinity in the root zone below the salinity threshold of plant species as one way to secure the freshwater resources to domestic uses.

Through the understanding of the water availability and dynamics in the soil and the atmospheric demand, water can be used as a potent management variable to manipulate the growth and maintenance of turfgrasses (Roy et al. 1999). Over-irrigation, on the other hand, gives poor utilization of water resources, increases surface run off and causes production problems associated with excessively wet soil. It also leads to recharge of underlying aquifers, leaching of nutrients, increased incidence of plant disease and an increase in pumping costs.

The salt concentration will increase constantly and will subsequently cause reductions in plant growth and quality if the leaching fraction is not sufficient (Fu et al. 2005; Stolte et al. 1997). Leaching is an efficient solution to control the salinity in the root zone of irrigated areas (Petersen 1997). To achieve this target, an extra water quantity should be applied along with plant water requirements; this is known as leaching fraction (LF) (Oster 1994). The quantity of LF depends on the initial soil salinity and the accepted salinity level in the root zone for a certain species and also soil type. In sandy soils, it is reported that application of 30% LF achieved sustainability in growing turfgrasses under Mediterranean-type climate (Brown et al. 2001).

Sodicity is another problem associated with salinity where clay is a major component of the soil. Sodium will begin displacing cations such as calcium, magnesium and potassium from the soil exchange complex. These cations will be leached away from the soil. The sodicity causes dispersion of clay particles, effectively clogging the soil and blocking the movement of water and air through the soil (Nelson and Ham 2000).

Using saline water was found to affect soil physical properties due to increasing the sodium-adsorption ratio (SAR) and exchangeable sodium percentage (ESP), particularly when the electrolyte concentration was subsequently reduced due to rainfall or using of low-salinity water (Letey 1993).

Irrigation uniformity is a major factor when using saline water for irrigation (Wichelns and Oster 2006); the spatial variability in soil salinity is well documented (Lobell et al. 2010); therefore, the nonuniform saline irrigation system will add up to the spatial variation within the same field.

Monitoring moisture status of the soil is a tool to improve irrigation scheduling. Control of the soil moisture status reduces through drainage and maintains optimum levels of soil water for maximum plant growth (Makin and Goldsmith 1988). To implement a reliable and accurate irrigation scheduling regime regular, soil moisture readings are essential. There are different tools available for obtaining soil moisture content including neutron probe (NB), time-domain reflectometer (TDR) and tension and capacitance techniques (O'Brien and Oberbauer 2001; Banton et al. 1997; Sudduth et al. 2003).

28.1.1 Salt-Tolerant Turfgrass Species

The review of literature in respect to halophytic turfgrass species identified three highly salt-tolerant species as described below.

28.1.1.1 *Paspalum vaginatum* (Saltwater Couch or Seashore Paspalum)

Seashore paspalum is a halophytic warm-season (C_4) turfgrass species that has been used on golf courses and other recreational sites (Duncan 1999). This salt-tolerant species is widely distributed in Australia, having been used on salt-seepage areas in the wheat belt of Western Australia (WA) and also occurring adjacent to salt lakes, estuaries, beaches and on lower headlands (Loch and Lees 2001). Differences have been observed for tolerance to salinity (Dudeck and Peacock 1985).

Paspalum tolerates irrigation with water of EC 6–22 dS m^{-1} and survives irrigation with 40 dS m^{-1} (Semple et al. 2003). Duncan (1999) conducted a screening trial for approximately 300 ecotypes of this grass with respect to many stresses, particularly salinity, where he found three ecotypes with high tolerance to salinity up to EC of 41 dS m^{-1} in the irrigation water.

The most salt-tolerant genotypes have been identified and developed as turfgrass cultivars (Duncan and Carrow 2000; Lee et al. 2000, 2004). 'Saltene' has long been used as a variety in the WA turfgrass industry, and the finer-textured 'Velvetene' has recently been developed.

28.1.1.2 *Distichlis spicata* (Saltgrass)

This halophytic species occurs in coastal marshes and saline deserts in America. One turf-type ('NyPa Turf'), selected from desert accessions, has been trialled (visual observations) in one small plot on a salt-affected discharge site (i.e. not irrigated) in the Wickepin area, Western Australia. Distichlis is highly salt tolerant (only 50% growth reduction at EC of 35 dS m^{-1}) and can survive irrigation with water of an EC as high as 40 dS m^{-1} but grows best at 20 dS m^{-1} (Leake et al. 2001). Salt tolerance in this species has been attributed partly to the presence of salt-excreting glands on its leaves (AlShammary et al. 2004).

28.1.1.3 *Sporobolus virginicus* (Marine Couch Grass)

This halophytic species is widely distributed in Australia, occurring in saline coastal and inland habitats (Simon and Jacobs 1999). The species shows large morphological variation (Simon and Jacobs 1999), and Loch (Queensland DPIF) has selected a good turf-type that has shown promise for use on saline areas in southern Queensland (Loch, personal communication). Salt tolerance is attributed to tissue-ion regulation, partly due to the presence of salt-excreting glands on its leaves and discrimination between Na^+ and K^+ during transport to shoots (Marcum and Murdoch 1992; Bell and O'Leary 2003). The genotype used in this study is the best turf-type performer from a screening of ~20 accessions (D. Loch, personal communication). Members of this species have been reported to survive irrigation with water of EC 55 dS m^{-1} (Gallagher 1979).

The use of saline water in irrigation will lead to accumulation of ions (Na^+ and Cl^-) in the leaves causing toxicity (Maas et al. 1982).

When soil salinity increases, plant water uptake decreases (Bielorai et al. 1983). Thus, more water is available for leaching of salts from the soil, removing more salt from the root zone (Tekin and Lyman 2006). Sustainable agricultural systems based on saline water irrigation can be established, provided appropriate management techniques are applied (Rhoades et al. 1992).

To improve the water use efficiency of turfgrass, turfgrass areas should be watered according to the soil moisture status and turfgrass needs. It has been shown that by adjusting irrigations according to soil moisture sensing, it is possible to reduce water consumption by 40–50% without reducing turfgrass quality (Shearman 1986).

The quantity, quality and schedule of irrigation water affect the growth and performance of turfgrasses (Carrow 1995; Gaudreau et al. 2002; Richie et al. 2002). Under arid regions, the evapotranspiration (ET) for turfgrasses is almost double that in humid regions (Carrow 1995) while variations in ET between species could be 20–60% ET (Kjelgren et al. 2000).

The landscape coefficient (K_L) of warm-season grass (C_4) is (0.65–0.85) which is lower than K_L of cool-season grass (C_3) when irrigated frequently (two times a week) (Carrow 1995). The minimum daily irrigation required to maintain turf growth and colour ranged from 50 to 60% of net daily evaporation (E_{pan}) in C_4 turfgrasses (Short 2002).

28.1.2 Physiology of Salt Tolerance

The decrease of K:Na in the plant caused by salinity is a limiting factor to plant growth, so halophytes increase their salt tolerance by excluding toxic ions in the root zone by filtering the ion influx at different stages (i.e. endodermis, exodermis); those layers also help in lowering ion content in plant cells by regulating the efflux of Na^+ (Yeo et al. 1999; Chinnusamy et al. 2005) or excluding ions from the xylem in the root.

Despite the ion exclusions, some ions find their way into plant cells and tissues (Sanders et al. 1999). The ions can be accumulated in sheaths or stems to protect leaves which are the most sensitive tissues to salinity (Wei et al. 2003; Netondo et al. 2004). Leigh and Storey (1993) found that Na^+ is compartmentalized within the vacuoles to protect cytosol and organelles.

We hypothesize in this study that: (1) halophytic turfgrasses are maintaining high-quality turf surfaces when irrigating with saline water (EC_w 13.5 dS m^{-1}), (2) K:Na ratio is a key factor for salinity tolerance in grass species, (3) the EM38 is an effective tool to monitor salinity and its measurements and representing the actual soil salinity, (4) proper saline irrigation management leads to no salt accumulation higher than that in the irrigation water and (5) proper irrigation management did not increase the level of watertable.

28.2 Materials and Methods

Turf plots were established under the field conditions of WA; saline groundwater (ECw 13.5 dS m^{-1}) and non-saline water were used to irrigate four replications of each treatment in randomized complete block design (RCBD) trial; plots were 9 m^2 each. Irrigation adjusted fortnightly to compensate 60% evaporation. On-site weather station recorded the maximum and minimum air temperature, relative humidity and rainfall; data are presented in Fig. 28.1.

Chemical fertilizer (Turf Special, a soluble NPK fertilizer with micronutrients, CSBP Limited) broadcasted at 30 kg N ha^{-1} broadcasted every second week. After full coverage of the plots, sampling started by collecting clippings to evaluate the dry-matter (DM) production. The harvested plant materials were freeze dried at −30 °C, and DM weights were recorded to estimate the tissue water content. Dried samples were ground to a fine powder for measuring ions.

Six piezometers (2-m long each) were installed on-site to monitor the watertable; these were sealed with bentonite clay to ensure no leakage from the surface water. Flopper was used every fortnight to measure the height of watertable from the soil surface.

Electromagnetic induction (EMI) technique was used to assess soil salinity by using the EM38 which measures apparent EC (ECa) at its horizontal down to 75 cm and at vertical positions down to 150 cm. As the root system of the turfgrasses is

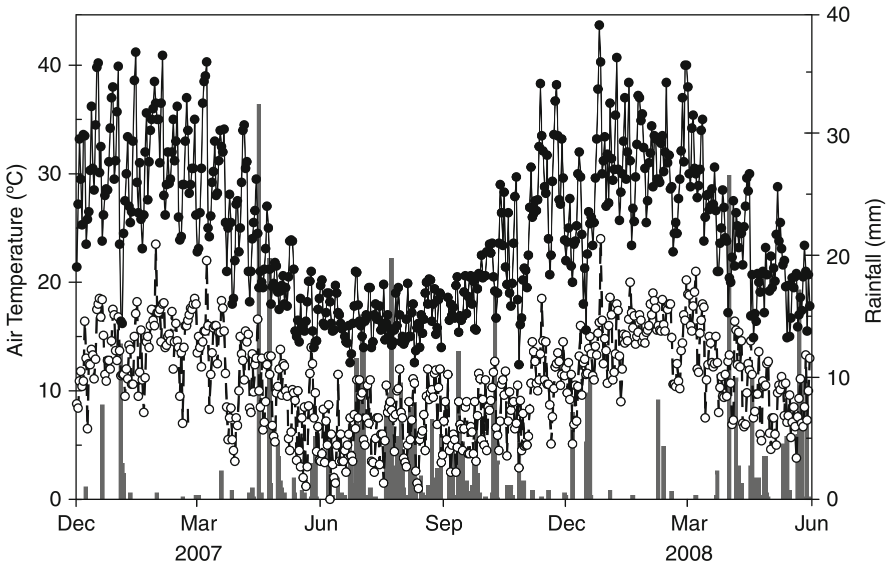

Fig. 28.1 Summary of weather conditions. Average monthly air temperature (- -○- -), average monthly relative humidity (——●——) and total monthly precipitation (*bars*) at Wagin GPS location 33° 18′ 38.54″ S and 117° 20′ 52.99″ E, Western Australia during (December 2006 until May 2008). Each point is the mean of 28–31 values

accommodated in the top soil (Short and Colmer 2007), data here is presented from the horizontal position.

Soil cores were taken using 70-mm diameter auger from the top soil (0–25 cm) and the subsoil (25–50 cm) to validate the EM38 readings and also to measure the cation exchange capacity (CEC) in units of centimoles kilogram (cmoles kg^{-1}) and the exchangeable sodium percentage (ESP). Soil pH was measured prior to conducting the experiment and after terminating the experiment.

Turf height was measured in each plot using the rising disc method (NZSTI, New Zealand) prior to the fortnight mowing schedule; plots were mowed then at 30 mm height using a walk-behind grass mower.

Ions (Na^+, K^+ and Cl^-) were extracted by adding 10 mL of 0.5 M HNO_3 to 0.1 g of ground tissue in 10 mL vials (exact amounts of acid and ground tissue were recorded), samples then were shaken for 48 h in dark at 30°C. Diluted extracts were analysed for Na^+ and K^+ using flame photometer (Jenway PFP7); Cl^- was measured using chloridemeter (Buchler-Cotlove). Ion measurements were validated using a reference plant tissue sample with known concentrations of the three ions.

28.2.1 Statistical Data Analysis

Statistical analysis of the data, which involved data processing and variance analysis (ANOVA), was performed using the statistical programme GenStat 10th Edition. All the acquired data were represented by an average of the four replicate measurements and standard errors (SE). Significance was tested at the 5% level.

28.3 Results and Discussion

Data collected from 6 piezometers revealed that irrigation did not increase significantly the level of watertable over 8 month of monitoring ($P=0.064$); however, there was 1 piezometer that differs significantly from other 5 piezometers (Fig. 28.2).

Data obtained by the EM38 at the horizontal position revealed that the proper irrigation management maintained soil salinity at a level equal to that in the irrigation water. The repeated measurements every fortnight for three random spots within each plot were evident that no spatial or radial distribution of salts in the root zone occurs (Fig. 28.3).

Soil salinity data obtained by soil coring from the top soil (0–25 cm) and subsoil (25–50 cm) (data not shown) confirmed the results obtained by the EM38. A significant correlation was found between both measurements with R^2 of 80% over the course of the study; however, it was as high as 96% during the irrigation season (Fig. 28.4).

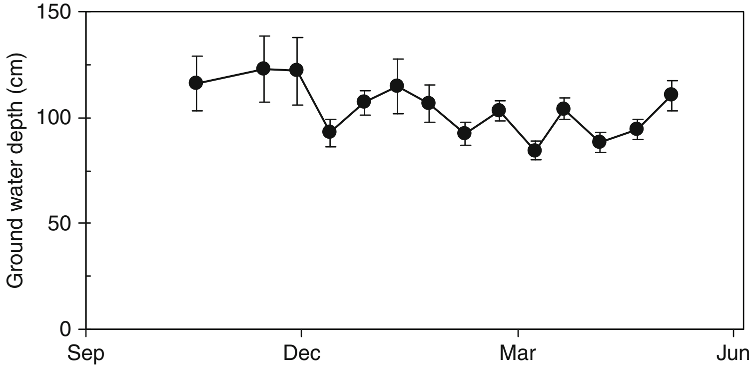

Fig. 28.2 Depth of the watertable measured in 6 piezometers (50-mm diameter) installed on-site; data was collected every 2 weeks and presented on monthly basis. Data are means of 6 measurements ± SEM

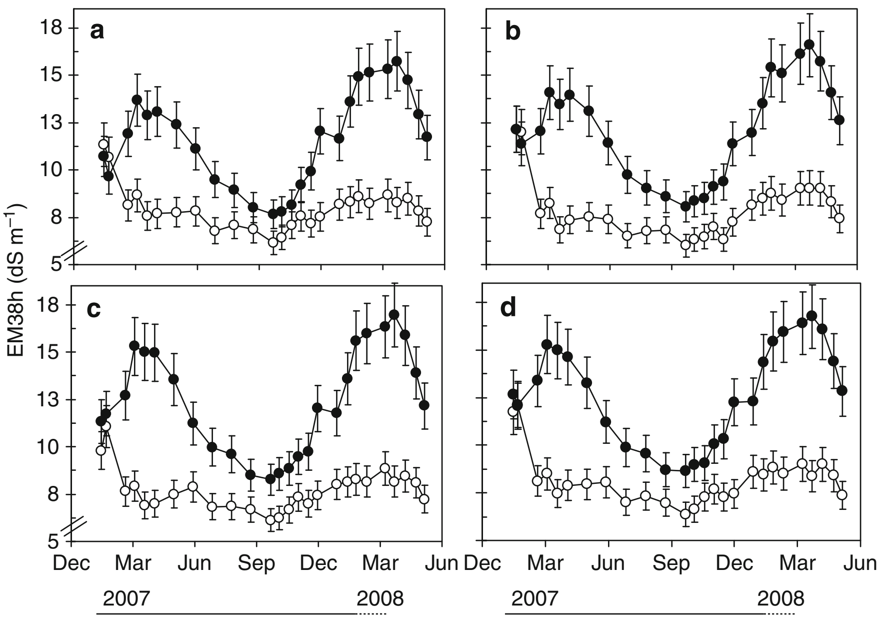

Fig. 28.3 Soil EC (dS m^{-1}) of turf plots irrigated with non-saline water (- -○- -) or saline groundwater (EC$_w$ 13.5 dS m^{-1}) (—●—). Measurements were made of (**a**) *P. clandestinum*, (**b**) *P. vaginatum*, (**c**) *S. virginicus* and (**d**) *D. spicata*. Plants were grown under field conditions in 9 m^2 plots at Wagin, Western Australia. EC was measured every 2 weeks. Values are the mean of three replicates. Error bars denote the SEM. The continuous line indicates the irrigation season; the dotted line indicates the subsequent period without irrigation

There was no significant difference in soil salinity under the studied species; however, it is apparent that the very high salt-tolerant species (*Distichlis spicata* and *Sporobolus virginicus*) are having higher soil salinity when compared to *Paspalum vaginatum* and *Pennisetum clandestinum*.

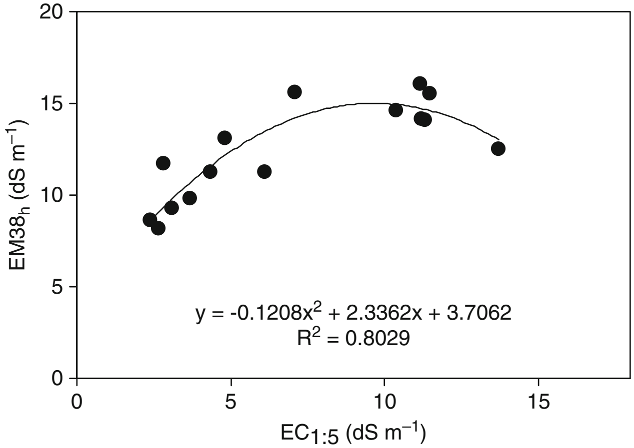

Fig. 28.4 Relationship between soil salinity in dS m^{-1} obtained by soil cores and the EM38 in horizontal position. Soil cores were collected from the top 25-cm layer of five saline plots and five non-saline plots. Data collected every 2 weeks. Values are the mean of five replicates

The chemical analysis of soil exchangeable cations showed that the cation exchangeable capacity (CEC) for the soil samples after the first and second summer is higher than that of the initial samples prior to commencing the saline irrigation (Fig. 28.5). The SAR of the irrigation water is in sodic range, 7.7 throughout the course of the experiment; therefore, the increase in soil sodicity is not significant. Data represent that no significant difference in sodicity between the top soil (0–25 cm) and the subsoil (25–50 cm) was found. The sample from the subsoil (23 samples) has an ESP of 0.298, knowing that sodic soil is defined as one in which more than 10–15% of the clay's negative charge is balanced by sodium ions. The ESP threshold in Australia is 6, whereas it is 15 in the United State due to the high clay content in Australian soils (Northcote and Skene 1972; Richards 1954).

The subsoil was sodic (ESP 7.3) prior to commencing the saline irrigation due to the high watertable while the top soil was not sodic (ESP 4.6). The highest exchangeable capacity observed was (ESP 4.0) while the lowest is (3.1). The proportion of exchangeable cations that has the highest fraction of exchangeable is Ca (74% of total CEC) while Na was 41% of total CEC. The concentration of exchangeable Al ranges from 0.1 to 0.99% of the total CEC. Soil pH values did not show significant difference between the initial and final samples (soil cores), $P=0.12$; pH values ranges between 7.6 and 7.9 throughout the course of the experiment.

28.3.1 Plant Growth (Height)

Average final plant height for all species was 35, 39, 25 and 33 cm for the fresh *Pennisetum clandestinum*, *Paspalum vaginatum*, *Sporobolus virginicus* and *Distichlis spicata*, respectively, under non-saline irrigation while it was 34, 42, 32

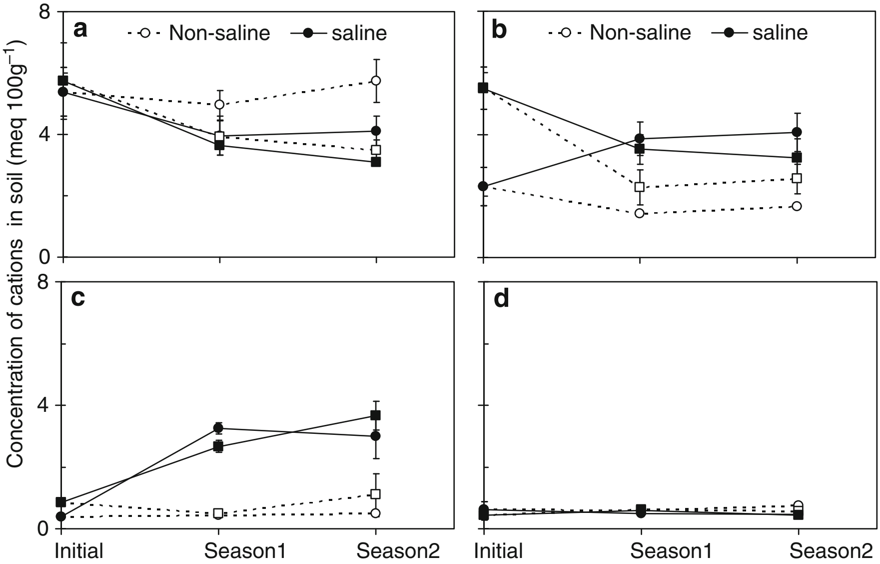

Fig. 28.5 Concentration of cations (**a**) Ca^{2+}, (**b**) Mg^{2+}, (**c**) Na^{+} and (**d**) K^{+} in the soil prior to start the experiment and at the end of each irrigation season. 9 m^2 field plots in Wagin, Western Australia were irrigated with non-saline (*open symbol*) or saline groundwater (EC_w 13.5 dS m^{-1}) (*closed symbol*). Measurements were taken from the top soil (0–25 cm) (—●—) and subsoil (25–50 cm) (—■—). Values are the mean of five replicates (each replicate being a plot mean) ± SEM

and 36 cm under saline irrigation after commencing the saline irrigation by 10 weeks (Fig. 28.6). Height measurements were statistically different (5% level) 10 weeks after commencing the saline irrigation.

28.3.2 Ion Concentration

The K:Na ratio (data not shown) in the *Pennisetum clandestinum* was four-fold more than the average of the other three tested halophytic species; this ratio dropped in the first irrigation season (112 days) to 0.2 of the initial ratio for plots irrigated with control water and 0.03 to saline irrigated plots; for *Paspalum vaginatum*, the same drop in the ratio was for the control irrigated plots but higher for the saline irrigated ones (0.8). The ratio was slightly improved in *Sporobolus virginicus* under control irrigation and declined to 0.2 of the initial ratio under saline irrigation; *Distichlis spicata* had a ratio of 0.9 for control irrigated plots and 0.2 for saline irrigated plots.

The K:Na ratio increased significantly in the next 144 days with no irrigation during the rainy season. The K:Na in the saline irrigated plots was double that of control irrigated ones in *Sporobolus virginicus* and *Distichlis spicata* while it was 2.4 for *Paspalum vaginatum* and *Pennisetum clandestinum*.

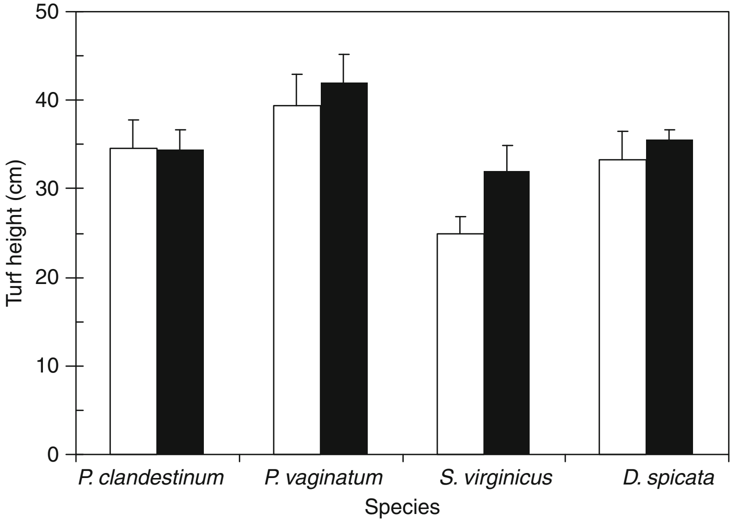

Fig. 28.6 Turf height measured using the rising disc, measurements were taken 10 weeks after commencing the irrigation treatments; non-saline irrigation (*open bar*) or saline groundwater (EC_w 13.5 dS m^{-1}) (*closed bar*). Values are the mean of three replicates ± SEM

The second irrigation season was longer (208 days); however, *Distichlis spicata* and *Paspalum vaginatum* maintained almost the same ratio of the first irrigation treatment season for both saline and control irrigation plots while in *Sporobolus virginicus* the ratio dropped by half. The *Pennisetum clandestinum* irrigated with saline water maintained almost the same ratio for saline irrigated plots and half of it for control irrigated plots.

Over all the study period, *Distichlis spicata* and *Sporobolus virginicus* coordinated to maintain high K:Na ratio for both saline and control irrigated plots when compared to the other three species, and *Paspalum vaginatum* shows quick recovery in regards to having high K:Na (Marcum and Murdoch 1992).

This study demonstrated the potential use of halophytic turfgrasses as high-quality turf surfaces when irrigated with saline water. Various researchers (Marcum 2004; Sharma and Tyagi 2004) reported that proper saline irrigation scheduling lead to sustainable farming. It has been reported earlier that *Distichlis spicata* tolerates up to water EC 35 dS m^{-1} (Leake et al. 2001), but such high tolerance was associated with 50% reduction in growth. The reduction, however, could be an advantage in turf industry as it reduces the maintenance requirements such as mowing, aeration and fertilizer application which are the most expensive costs in turf industry (Pizzo and Associates, 2003).

Soil salinity monitoring is crucial to achieve sustainability (Steppuhn et al. 2005), and technologies such as the EM38 and di-electric salinity sensors are capable of accurately quantifying the real-time soil salinity when pre-calibrated.

The K:Na ratio is known as criteria of assessing species tolerance to salinity during the growing season; however, this study brought to prominence that K:Na is an effective criteria for salinity tolerance even in short time (2 weeks in this study) which is the frequency of mowing, which reflects the ability of *Distichlis spicata* and *Sporobolus virginicus* to maintain high K:Na in the newly formed leaves.

28.4 Conclusion

Freshwater resources are limited. Saline groundwater resources should be taken into consideration. Management practices when using saline water will be different than when irrigating with freshwater resources to sustain plant and soil. Quantifying water requirements of species, as well as understanding of the physiology of those turfgrass species, will aid in substituting the highly water consuming or salt-sensitive turfgrass species in ovals and public areas with halophytes.

Data provided by this field evaluation of salinity tolerance in *Pennisetum clandestinum*, *Paspalum vaginatum*, *Sporobolus virginicus* and *Distichlis spicata* is conclusive that salt stress did not impact the halophytic turfgrass species while caused a decline in growth and quality of the non-halophyte species; the decline was severe during the summer season causing leaf discolouration. *Sporobolus virginicus* and *Distichlis spicata* have demonstrated high salinity tolerance, and they have great potential for use as turfgrasses in salt-affected lands.

References

Abdelfattah MA, Shahid SA (2007) A comparative characterization and classification of soils in Abu Dhabi coastal area in relation to arid and semi-arid conditions using USDA and FAO soil classification systems. Arid Land Res Manage 21(3):245–271

Alshammary SF, Qian SF, Wallner SJ (2004) Growth responses of four turfgrass species to salinity. Agric Water Manage 66:97–111

Banton O, Seguin MK, Cimon MA (1997) Mapping field-scale physical properties of soil with electrical resistivity. Soil Sci Soc Am J l61:1010–1017

Baum MC, Dukes MD, Miller GL (2003) Residential irrigation uniformity and efficiency in Florida. ASAE paper no FL03-100. American Society of Agricultural Engineers, St Joseph

Bell HL, O'Leary JW (2003) Effects of salinity on growth and cation accumulation of *Sporobolus virginicus* (Poaceae). Am J Bot 90:1416–1424

Bielorai H, Shalhevet J, Levy Y (1983) The effect of high sodium irrigation water on soil salinity and yield of mature grapefruit orchard. Irrig Sci 4:255–266

Brown PW, Mancino CF, Young MH, Thompson TL, Wierenga PJ, Kopec DM (2001) Penman Monteith crop coefficients for use with desert turf systems. Crop Sci 41:1197–1206

Carrow RN (1995) Drought resistance aspects of turfgrasses in the Southeast: evapotranspiration and crop coefficients. Crop Sci 35:1685–1690

Chinnusamy V, Jagendorf A, Zhu JK (2005) Understanding and improving salt tolerance in plants. Crop Sci 45:437–448

Dudeck AE, Peacock CH (1985) Salinity effects on perennial ryegrass germination. Hort Sci 20:268–269

Duncan RR (1999) Environmental compatibility of seashore paspalum (saltwater couch) for golf courses and other recreational uses. I. Breeding and genetics. Int Turfgrass Soc Res J 8:1208–1215

Duncan RR, Carrow RN (2000) Seashore paspalum: the environmental turfgrass. Sleeping Bear Press, Chelsea

Fu JM, Koski AJ, Qian YL (2005) Responses of creeping bentgrass to salinity and mowing management: growth and turf quality. Hort Sci 40:463–467

Gallagher JL (1979) Growth and element compositional responses of *Sporobolus virginicus* (L.) Kunth. to substrate salinity and nitrogen. Am Midl Naturaslist 102:68–75

Gaudreau JE, Vietor DM, White RH, Provin TL, Munster CL (2002) Response of turf and quality of water runoff to manure and fertilizer. J Environ Qual 31:1316–1322

International Water Management Institute (IWMI) (2000) World water supply and demand 1995–2025. International Water Management Institute, Colombo. ISBN 92-9090-400-3

Jaradat AA (2005) Saline agriculture in the Arabian Peninsula: management of marginal lands and saline water resources. J Food Agric Environ 3(2):302–206

Kjelgren R, Rupp L, Kilgren D (2000) Water conservation in urban landscapes. Hort Sci 35:1037–1040

Leake J, Barrett-Lennard E, Yensen N, Prefumo J (2001) NyPa Distichlis cultivars: rehabilitation of highly saline areas for forage, turf and grain. Final Report Project RAS98-74. Rural Industries Research and Development Corporation, Kingston

Lee GJ, Duncan RR, Carrow RN (2000) Salinity tolerance of *Paspalum vaginatum* and *Cynodon spp*. genotypes. Aust Turfgrass Manage J 2(3):30–32 (TGIF Record 65750)

Lee GJ, Duncan RR, Carrow RN (2004) Salinity tolerance of seashore paspalum ecotypes: shoot growth responses and criteria. Hort Sci 39:1138–1142

Leigh RA, Storey R (1993) Intercellular compartmentation of ions in barley leaves in relation to potassium nutrition and salinity. J Exp Bot 44:755–62

Letey J (1993) Relationship between salinity and efficient water use. Irrig Sci 14:75–84

Lobell DB, Lesch SM, Corwin DL, Ulmer MG, Anderson KA, Potts DJ, Doolittle JA, Matos MR, Baltes MJ (2010) Regional-scale assessment of soil salinity in the Red River Valley using multi-year MODIS EVI. J Environ Qual 39(1):35–41

Loch DS, Lees TW (2001) Halophytic native grasses for stabilization and rehabilitation of salt-affected sites in northern Australia. In: Proceedings of the fourth Australian workshop on native seed biology for revegetation, Australian Centre for Mining Environmental Research, Mildura, VIC, 3–4 Sept 2001, pp 235–246

Maas EV, Grattan SR, Ogata G (1982) Foliar salt accumulation and injury in crops sprinkled with saline water. Irrig Sci 3:157–168

Makin W, Goldsmith H (1988) Selection of drainage and its phased implementation for salinity control. J Irrig Drain 2:109–121

Marcum KB (2004) Use of saline and non-potable water in the turfgrass industry: constraints and developments. Agric Water Manage 80:132–146

Marcum KB, Murdoch CL (1992) Salt tolerance of the coastal salt marsh grass, *Sporobolus virginicus* (L.) Kunth. New Phytol 120:281–288

Nelson PN, Ham GJ (2000) Exploring the response of sugarcane to sodic and saline conditions through natural variation in the field. Field Crops Res 66:245–255

Netondo GW, Onyango JC, Beck E (2004) Sorghum and salinity: I. response of growth, water relations, and ion accumulation to NaCl salinity. Crop Sci 44:797–805

Northcote KH, Skene JKM (1972) Australian soil with saline and sodic properties. CSIRO Australian Soil Publication 60. CSIRO, Melbourne

Northey J, Christen E, Ayars JE, Jankowski J (2005) Occurrence and measurement of salinity stratification in the shallow ground water in the Murrumbidgee irrigation area, south eastern Australia. Agric Water Manage 81:23–40

O'Brien JJ, Oberbauer SF (2001) An inexpensive portable meter for measuring soil moisture. Soil Sci Soc Am J 65:1081–1083

Oster JD (1994) Irrigation with poor quality water. Agric Water Manage 25:271–297

Petersen FH (1997) Water testing and interpretation. In: Reed DW (ed) Water, media, and nutrition for greenhouse crops. Ball Publishing, Batavia 2:31–49

Pizzo and Associates (2003) Recreation management. Going native, Apr 2003. http://www.recmanagement.com/columns.php?fid=200304GC02

Rhoades JD, Kandiah A, Mashali AM (1992) The use of saline waters for crop production. J Irrig Drain Paper 48. FAO, Rome

Richards LA (ed) (1954) Diagnosis and improvement of saline and alkali soils. USDA handbook no. 60. United States Salinity Staff, Washington, DC

Richie WE, Green RL, Klein GH, Hartin JS (2002) Tall fescue performance influenced by irrigation scheduling, cultivar, and mowing height. Crop Sci 42:2011–2017

Roy JW, Parkin GW, Wagner-Riddle C (1999) Water flow in unsaturated soil below turfgrass: observations and LEACHM (within EXPRES) predictions. Soil Sci Soc Am J 64:86–93

Sanders D, Brownlee C, Harper JF (1999) Communicating with calcium. Plant Cell 11:691–706

Semple WS, Cole IA, Koen TB (2003) Performance of some perennial grasses on severely salinised sites on the inland slopes of New South Wales. Aust J Exp Agric 43:357–371

Shahid SA, Dakheel AJ, Mufti KA, Shabbir G (2009) Automated in-situ soil salinity logging in irrigated agriculture. Eur J Sci Res 26(2):288–297

Sharma DP, Tyagi NK (2004) On-farm management of saline drainage water in arid and semi-arid regions. Irrig Drain 53:87–103

Shearman RC (1986) Kentucky bluegrass cultivar evapotranspiration rates. Hort Sci 21:455–457

Short DC (2002) Irrigation requirement and water-use of turf grasses in a Mediterranean-type environment. PhD thesis. The University of Western Australia, Perth

Short DC, Colmer TD (2007) Development and use of a variable-speed lateral boom irrigation system to define water requirements of 11 turfgrass genotypes under field conditions. Aust J Exp Agric 47:86–95

Simon BK, Jacobs SWL (1999) Revision of the genus *Sporobolus* (Poaceae, Chloridoideae) in Australia. Aust Syst Bot 12:375–448

State Salinity Council (2000) Natural resource management in Western Australia: the salinity strategy. Government of Western Australia, Perth, p 72

Steppuhn H, Van Genuchten MT, Grieve CM (2005) Root-zone salinity: indices for tolerance in agricultural crops. Crop Sci 45:221

Stikker A (1998) Water today and tomorrow, prospects for overcoming scarcity. Futures 30(1):43–62

Stolte WJ, McFarlane DJ, George RJ (1997) Flow systems, tree plantations, and salinisation in a Western Australian catchment. Aust J Soil Res 35:1213–1229

Sudduth KA, Kitchen NR, Bollero GA, Bullock DG, Wiebold WJ (2003) Comparison of electromagnetic induction and direct sensing of soil electrical conductivity. Agron J 95:472–482

Tekin K, Lyman SW (2006) Leaching requirements to prevent soil salinization. J Appl Sci 6(7):1281–1489

United Nation Development Program (UNDP) (2000) Human development report 2000. United Nations Development Program. Oxford University Press, New York. Water J Hydrol 272:238–249

Wei W, Bilsborrow PE, Hooley P, Fincham DA, Lombi E, Forster BP (2003) Salinity induced differences in growth, ion distribution and partitioning in barley between the cultivar Maythorpe and its derived mutant Golden Promise. Plant Soil 250:183–191

Wichelns D, Oster JD (2006) Sustainable irrigation is necessary and achievable, but direct costs and environmental impacts can be substantial. Agric Water Manage 86:114–127

Yeo AR, Flowers SA, Rao G, Welfare K, Senanayake N, Flowers TJ (1999) Silicon reduces sodium uptake in rice (*Oryza sativa* L.) in saline conditions and this is accounted for by a reduction in the transpirational bypass flow. Plant Cell Environ 22:559–565

Chapter 29
Plant Response to Saline-Water Irrigation in a Sicilian Vineyard

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Abstract This chapter presents results of a 3-year field investigation in a vineyard located in Sicily (Mazara del Vallo, Trapani) within the framework of the Project "*Evolution of cropping systems as affected by climate change*" (CLIMESCO). Soil-plant responses to two saline irrigation waters were determined by measuring soil hydrological characteristics, soil salinity, crop transpiration and stomatal conductance in field plots of a Sicilian vineyard. The results proved that crop transpiration (T_r) and stomatal conductance (G_s) were significantly affected by soil salinity conditions, expressed by electrical conductivity of soil saturation extract (EC_e). Significant reductions in T_r and G_s were found in plants irrigated with water of $EC_w = 1.6$ dS m^{-1} (L) compared to T_r and G_s values in plots irrigated with water $EC_w = 0.6$ dS m^{-1} (R). Significantly higher crop water stress index (CWSI) values, indicating stronger stress conditions, were measured in the L treatment, relative to the R treatment. Validity of the linear relationship between relative yield and relative transpiration was confirmed. A value of 0.7 for the yield response factor (Ky) provided accurate prediction of yield reduction in years 2008 and 2009. Reductions due to soil salinity, calculated according to Maas and Hoffman equation, showed that under conditions of water and salinity stress, yield reduction due to salinity represented a percentage of the total yield reduction of up to 11% in the L

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plots and up to 3.5% in the R plots. The investigation also indicated that EC_e (1.5 dS m^{-1}) discriminated a different plant response to salinity, indirectly confirming the Maas threshold value for grapes. Under the irrigation conditions in the Sicilian vineyard, it is suggested to implement management strategies aimed at keeping soil salinity below this threshold value. This can be realized by using low-salinity irrigation water only or by alternating the two irrigation sources.

Keywords Deficit irrigation • Grapes • Salinity tolerance • Stomatal conductance • Transpiration

29.1 Introduction

Many Mediterranean countries, including Egypt, Libya, Tunisia, Algeria, Morocco, Syria, Malta and Lebanon, exhibit water availability below the threshold of 1,000 m^3 $person^{-1}$ $year^{-1}$. In addition, lower availability than the benchmark of water scarcity is also observed in certain regions within countries such as Spain, Greece and Italy, although on average they exceed the 1,000 m^3 $person^{-1}$ $year^{-1}$ threshold (UN Population Division 1994). Pressure on the limited water resources in such areas is steadily increasing due to both increasing population and living standards. Higher temperatures and population growth will increase the demands for water in most Mediterranean countries. Higher rates of evaporation would cause rises in salt concentration in surface waterbodies, while rises in sea level would favour sea intrusion into aquifers to coastal areas. Under these conditions, freshwater resources available for agriculture are declining quantitatively and qualitatively (Crescimanno et al. 2004).

Water demands for irrigation are projected to rise, bringing increased competition between agriculture and other users (Crescimanno and Marcum 2009). Therefore, the use of lower-quality water sources, such as saline waters, will inevitably be practised for irrigation purposes in order to maintain an economically viable agriculture (Crescimanno 2001). In order to overcome water scarcity, many countries have adopted the use of marginal, saline water for irrigation (Crescimanno et al. 2004). This coupled with adverse climatic conditions makes the Mediterranean region more vulnerable to salinization and desertification (Szabolcs 1994; Crescimanno and Garofalo 2006b). Salinity acts on plants through non-specific and specific mechanisms. The non-specific effect is due to decreased osmotic potential of soil solution that impedes transpiration and photosynthesis (Shannon and Grieve 1999). Specific effects relate to ion uptake and altered physiological processes resulting from toxicity, deficiency or changes in mineral balance (Hasegawa et al. 2000). Downton et al. (1990) refuted conceptions assuming direct inhibition of photosynthesis by showing that stomatal behaviour altered by salinity sufficiently explains the photosynthetic response.

Quantitative understanding of crop production under deficit irrigation with saline water is generally based on three assumptions. First, an increase in salinity above the crop tolerance level will decrease yield (Maas and Hoffman 1977; Maas 1990); second, biomass production is linearly related to transpiration (de Wit 1958; Shani and Dudley 2001); and third, the effects of salt and water stress on yields are additive (Nimah and Hanks 1973).

The validity of the first two assumptions is well established. The linear dependence of relative dry-matter production ($Y_{actual}/Y_{potential}$) on relative transpiration ($T_{actual}/T_{potential}$) under conditions of water deficit has been validated for a variety of climates and crops (De Wit 1958; Shani and Dudley 2001). Under conditions of salt stress (Bresler and Hoffman 1986; Bresler 1987) and Na stress (Shani and Dudley 2001), relative yield and relative transpiration are linearly related.

The validity of the third assumption is less certain. Plants respond to drought by attempting to both decrease transpiration and increase water uptake. Because plants respond to drought induced by limited water or elevated salinity by a similar mechanism, the sum of the matric and osmotic components of the water potential has been used to estimate yield (Nimah and Hanks 1973; Cardon and Letey 1994). However, the complex nature of plant response to salt and water stress may result in a response that is not necessarily equal or additive when the two stress factors are imposed simultaneously.

Grapes have been defined as moderately sensitive to salinity (Maas 1990). Maas reported threshold values for grapevines of ECe 1.5 dS m^{-1} and a salinity response of 9.6% yield decrease for every subsequent unit (dS m^{-1}) increase in EC_e. However, conclusions concerning vine response to salinity are largely based on short-term studies in hydroponic growing conditions or in potting media, and there have been few studies on mature grapevines over time (Walker et al. 2002).

Sicily is a typical Mediterranean country in which conditions of water scarcity and drought as well as increasing use of saline water for irrigation are taking place (Crescimanno 2009). In Sicily, wine grape (*Vitis vinifera*) is one of the most important crops, both in terms of crop production and economic value. Management options suitable to prevent salinization, while maintaining acceptable levels of crop productivity and/or wine quality in irrigated vineyards, need to be developed in Sicily (Crescimanno and Garofalo 2005, 2006a).

This chapter reports results of a 3-year field investigation carried out in a vineyard located in Sicily (Mazara del Vallo, Trapani) within the framework of the Project *Evolution of cropping systems as affected by climate change* (CLIMESCO), funded by three Italian Ministries (University, Agriculture and Environment). Research was aimed at investigating soil-plant responses to irrigation with two saline waters having different salinities. Soil hydrological characteristics, soil salinity, crop transpiration and stomatal conductance were measured in experimental plots irrigated by the two different irrigation waters. Effect of water and salinity stress on crop physiology and yield was explored by using the equation proposed by Doorenbos and Kassam (1979) and by the equation proposed by Maas and Hoffman (1977).

29.2 Materials and Methods

29.2.1 Field and Irrigation Description

Investigation was carried out at the Foraci Farm (http://www.cantineforaci.com/), a vineyard located in the Mazzaro basin region of Sicily. Two different irrigation treatments were established (L and R) to monitor soil and plant responses to irrigation water salinity (Fig. 29.1).

Irrigation treatment L used irrigation water from a lake having $EC_w = 1.6$ dS m^{-1}; irrigation treatment R used water from a well having $EC_w = 0.6$ dS m^{-1}.

Two vine rows, designated L row and R row, were selected, one in each of the two treatments. Eleven soil sites, corresponding to plant numbers 1, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100, were selected along each of the two rows for determining the soil hydraulic parameters and plant physiological parameters. Undisturbed soil samples were collected at the selected locations to determine the soil shrinkage curve and the water retention curve.

Irrigation scheduling was established according to a water balance model taking into account climatic data, the amount of soil water available for crops (AW_{max}) and crop parameters.

Table 29.1 reports the irrigation scheduling applied from 7 June 2007 to 30 July 2009. Irrigation in R and L row plots was performed on subsequent days, and measurements were carried out in plots 1 day after irrigation. Irrigation amount was

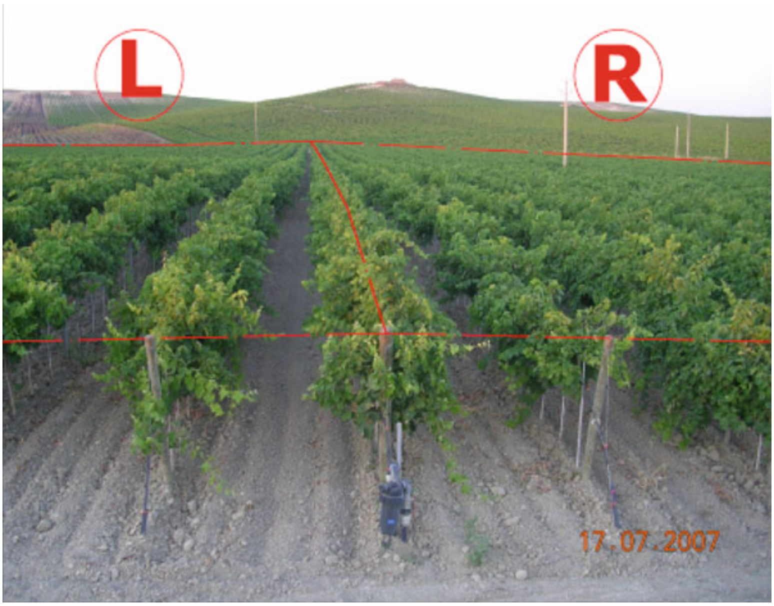

Fig. 29.1 Foraci Farm (Mazzaro basin, Sicily, Italy): location of the two treatments (L and R)

Table 29.1 Irrigation scheduling and measurement dates from 2007 to 2009

Irrigation (L)	Measurements (L)	Irrigation (R)	Measurements (R)
7 June 2007	–	7 June 2007	–
17 July 2007	18 July 2007	18 July 2007	19 July 2007
25 July 2007	26 July 2007	26 July 2007	27 July 2007
25 June 2008	26 June 2008	24 June 2008	25 June 2008
1st July 2008	2 July 2008	30 June 2008	1st July 2008
8 July 2008	9 July 2008	7 July 2008	8 July 2008
16 July 2008	17 July 2008	15 July 2008	16 July 2008
29 July 2008	30 July 2008	28 July 2008	29 July 2008
8 July 2009	9 July 2009	7 July 2009	8 July 2009
22 July 2009	23 July 2009	21 July 2009	22 July 2009
30 July 2009	31 July 2009	29 July 2009	30 July 2009

15 mm deep per event. Reference evapotranspiration (ETo) was calculated by using the Hargreaves equation (Hargreaves and Samani 1982).

29.2.2 Soil Physical and Hydraulic Parameters

Replicated soil cores of different sizes to measure physical and hydraulic characteristics were sampled from different horizons of 11 plot sites selected along each row. The soil shrinkage curve was determined by measuring vertical and horizontal shrinkages (Crescimanno and Provenzano 1999). The water retention curve was determined by the tension method at matric potential at h values between 0 and −150 cm and by the pressure membrane plate apparatus at h values up to −300 cm. Volumetric water content (θ) corresponding to gravimetric water content (U) was determined by using the bulk density (ρ_b) values obtained by the shrinkage curve. The equation proposed by Brutsaert (1966) was fitted to the θ and h values. Parameter estimation was performed by fixing the saturated water content, θ_s, at the measured value and optimizing the residual water content θ_r, together with the Brutsaert α' and n' parameters (Crescimanno and Garofalo 2005).

29.2.3 Soil and Physiological Measurements

Gravimetric water content, U, soil salinity (EC_e) and physiological measurements (transpiration, stomatal conductance) were measured 1 day after each irrigation on a total of 11 plants per row going from plant no. 1 to plant no. 100 corresponding to soil sampling plot locations along the L and R rows. U and ρ_b (U) were used to calculate volumetric water content θ, which therefore accounted for a variable soil volume. Soil saturated extracts were prepared using the soil collected at 60 cm at each soil-plant sampling plot site, and soil electrical conductivity (EC_e) was measured by a conductivity meter (Crison, Micro CM 2002) (Rhoades 1993).

Crop transpiration (T_r) and stomatal conductance (G_s) measurements were made on three recently matured leaves per plant using a CIRAS-2 portable infrared gas analyzer (PP Systems). Crop water stress index (CWSI) was calculated according to Doorenbos and Kassam (1979):

$$\mathrm{CSWI} = 1 - \frac{T_r}{T_m} \tag{29.1}$$

with T_r = actual transpiration (mm) and T_m maximum transpiration (mm). T_m was calculated as a percentage of maximum evapotranspiration (ET_m) ($T_m = 0.9\ ET_m$).

29.2.4 Yield Reduction Due to Water Stress

The effect of water stress on yield can be quantified by relating the relative yield reduction (Y_r) to the relative evapotranspiration deficit ($1 - ET_e/ET_m$) through an empirically derived yield response factor (Ky) (Doorenbos and Kassam 1979):

$$Y_r = 1 - \frac{Y_a}{Y_m} = \mathrm{Ky}\left(1 - \frac{ET_e}{ET_m}\right) = \mathrm{Ky}\left(1 - \frac{T_r}{T_m}\right) \tag{29.2}$$

where Y_a is the actual yield, Y_m is the maximum potential yield and Ky is the yield response factor.

29.2.5 Yield Reduction Due to Salinity

Relative yield (Y'_a/Y_m) under salinity conditions can be predicted by the Maas and Hoffman equation (1977):

$$\frac{Y'_a}{Y_m} = 100 - b\left(EC_e - a\right) \tag{29.3}$$

where Y'_a/Y_m (%) is the relative yield, EC_e (dS m^{-1}) is the electrical conductivity of saturated extract, a (dS m^{-1}) is the salinity threshold value (EC_e where $Y'_a = Y_m$) and b (% per dS m^{-1}) is the slope of the regression line. According to Maas (1990), for grapes a is equal to 1.5 dS m^{-1} and b is equal to 9.6.

Equation 29.3 can be rewritten as follows:

$$Y'_r = 100 - b\left(EC_e - a\right) \tag{29.4}$$

where Y'_r represents the yield reduction due to salinity.

29.3 Results and Discussion

29.3.1 Soil Physical and Hydraulic Parameters

Table 29.2 reports soil classification and physical characteristics (particle-size distribution soil texture) of some profiles (E, F, G and H) located along the L and R rows. Table 29.3 reports the Brutsaert water retention parameters obtained for the 11 soil plot locations corresponding to plants from 1 to 100 along the R and L rows.

Table 29.4 reports the maximum water available for crops (AW_{max}) calculated from field capacity and wilting point (θ_r) for the 11 L and R plot locations.

Statistical analysis (paired *t*-test) proved that differences between the AW_{max} values measured in L and R row plots were nonsignificant ($P=0.01$). The same

Table 29.2 Classification and physical properties of the E, F, G and H profiles

Soil profile	Classification	Horizon[a]	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Textural class[b]
E (R)	Typic Chromoxerert	Akp2	30–60	54	37	9	Clay
F (R)	Typic Chromoxerert	Akp2	30–60	54	36	10	Clay
G (L)	Typic Chromoxerert	Akp2	30–60	52	37	11	Clay
H (L)	Typic Chromoxerert	Akp2	30–60	33	34	33	Clay loam

[a]Horizon designation (*A* master horizon, *k* presence of $CaCO_3$ equivalents, *p* plough layer)
[b]Soil textural class according to Soil Survey Division Staff (1993)

Table 29.3 Parameters of the water retention curves (Brutsaert) determined for the 11 soil-plant locations along the L and R rows

	Left row				Right row			
Plant No.	θ_r (cm^3/cm^3)	θ_s (cm^3/cm^3)	α	n	θ_r (cm^3/cm^3)	θ_s (cm^3/cm^3)	α	n
1	0.276	0.501	0.0325	1.052	0.27	0.42	0.0207	1.005
10	0.282	0.500	0.0238	1.005	0.27	0.43	0.0172	1.005
20	0.281	0.519	0.0275	1.005	0.27	0.47	0.0217	1.005
30	0.312	0.533	0.0254	1.005	0.27	0.47	0.0198	1.005
40	0.297	0.523	0.0335	1.005	0.28	0.49	0.0286	1.005
50	0.304	0.491	0.0252	1.197	0.28	0.44	0.0140	1.005
60	0.293	0.501	0.0242	1.005	0.29	0.47	0.0191	1.005
70	0.294	0.500	0.0262	1.005	0.29	0.48	0.0226	1.005
80	0.281	0.520	0.0221	1.005	0.29	0.46	0.0274	1.005
90	0.272	0.534	0.0082	1.334	0.29	0.45	0.0143	1.005
100	0.315	0.494	0.0217	1.005	0.28	0.50	0.0093	1.005

Table 29.4 Maximum water available for crops (AW_{max}) and wilting point (θ_r)

R row	θ_r	AW_{max}	L row	θ_r	AW_{max}
1	0.26	39.0	1	0.3	42.0
10	0.28	36.0	10	0.28	48.0
20	0.28	42.0	20	0.28	42.0
30	0.28	42.0	30	0.31	48.0
40	0.28	42.0	40	0.31	36.0
50	0.28	42.0	50	0.31	28.8
60	0.28	42.0	60	0.29	42.0
70	0.28	42.0	70	0.30	36.0
80	0.28	36.0	80	0.29	54.0
90	0.28	42.0	90	0.29	60.0
100	0.28	66.0	100	0.28	42.0

result was obtained with reference to θ_r. The two row plots therefore had a similar hydrological behaviour in terms of amount of water retained by the soil and made available to crops. However, the higher θ_r values measured in the L plots might be a consequence of the higher salinity, causing swelling of these soils in the course of the laboratory experiments.

29.3.2 Electrical Conductivity of Saturated Extract (ECe)

Figure 29.2 illustrates EC_e values measured in the course of the 2007, 2008 and 2009 irrigation seasons.

Significantly higher EC_{sat} values were measured in the L row, compared to R row plots across all 3 years, consistent with the higher salinity of water used to irrigate the L row plots.

29.3.3 Transpiration (T_r) and Stomatal Conductance (G_s)

Figure 29.3 illustrates transpiration (T_r) values (mmol m^{-2} s^{-1}) measured 1 day after irrigation events in the 11 plants located along the L and R rows from 2007 to 2009.

Paired *t*-tests proved that significantly higher T_r values were measured in R row plots compared to values measured in L row plots, across all 3 sampling years. Higher T_r values measured in R plots indicate that greater water uptake occurred in the R plot plants in all 3 sampling years.

Figure 29.4 illustrates stomatal conductance (G_s) values measured 1 day after irrigation events from 2007 to 2009 in the 11 plants located along the L and R rows.

Consistent with the higher T_r, statistically significant higher G_s values were measured in the R row plots, compared to values measured in the L row plots, across all 3 sampling years.

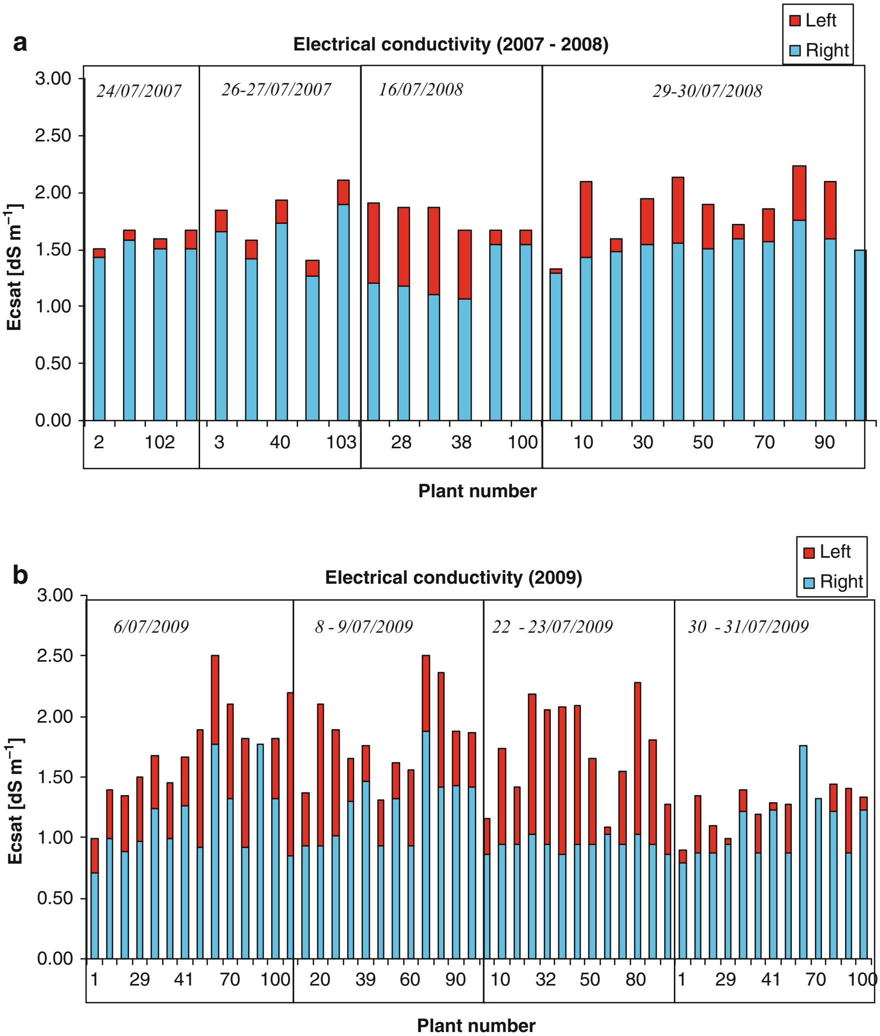

Fig. 29.2 Electrical conductivity (EC_e) measured after irrigation at the depth of 60 cm in the 11 locations along the R and L rows in 2007, 2008 (**a**) and 2009 (**b**)

The results indicated that significantly higher T_r and G_s were measured in the R row plots compared to those measured in the L row plots in all 3 considered years.

Figure 29.5 illustrates the regression relationships between the T_r and G_s values measured 1 day after irrigation events from 2007 to 2009 in R and in L row plots.

As can be seen in Fig. 29.5, both the T_r, and G_s values measured in the R row plots extended over a much wider range than those measured in the L row plots. For example, G_s values reached 1,200 mmol m^{-2} s^{-1} in R row plots; however, values measured in L row plots reached a maximum value of only 600 mmol m^{-2} s^{-1}. This indicates that R row plot plants maintained much higher stomatal conductance and

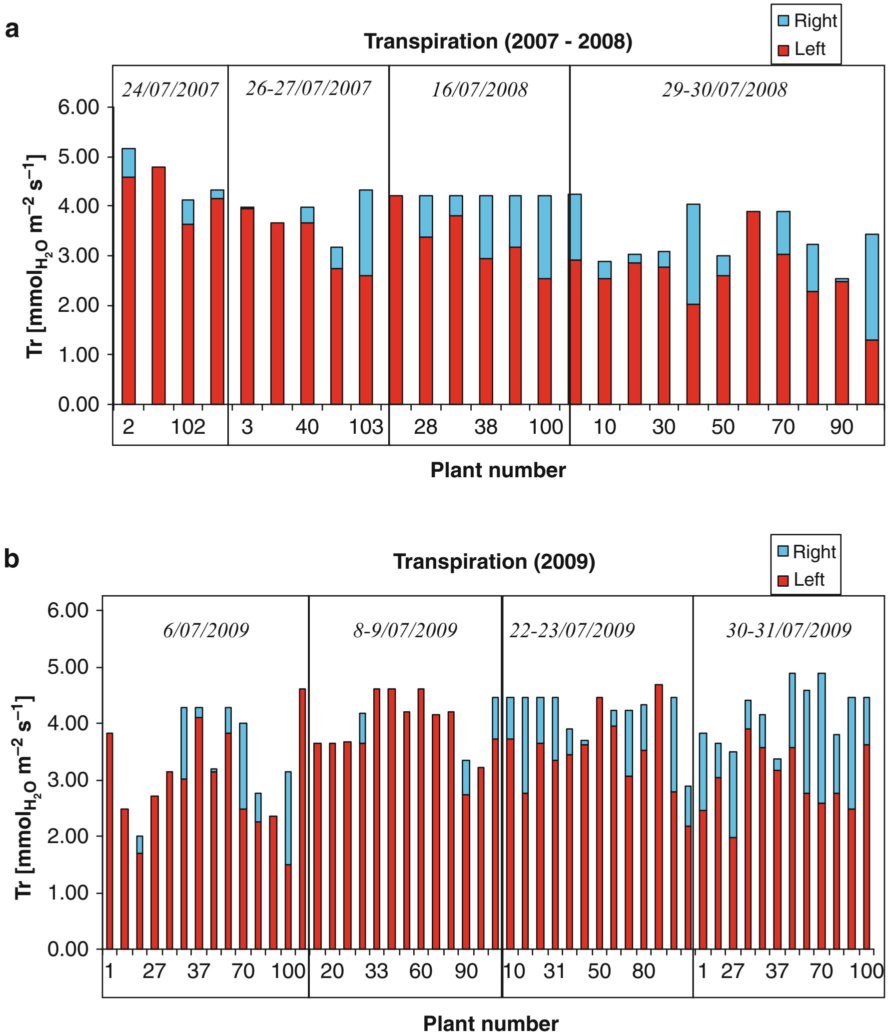

Fig. 29.3 Transpiration (T_r) values measured after irrigation events in L and R rows (plants from No. 1 to No. 100) in 2007, 2008 (**a**) and 2009 (**b**)

transpiration rates than L row plot plants; in other words, stomatal conductances and associated transpiration rates were highly correlated to irrigation treatment and soil salinity. However, soil solutions in both R row and L row irrigation plots maintained the same hydrological and meteorological conditions throughout the experiment (Table 29.4). Therefore, stomatal closure and resultant decline in transpiration rates occurred in L row plot plants due to the increased salinity and lower osmotic potential of the soil solution in this treatment, which was irrigated with saline lake water, and not due to soil moisture or hydrological differences. Since no significantly different AW_{max} and θ_r values were measured in the two treatments, the

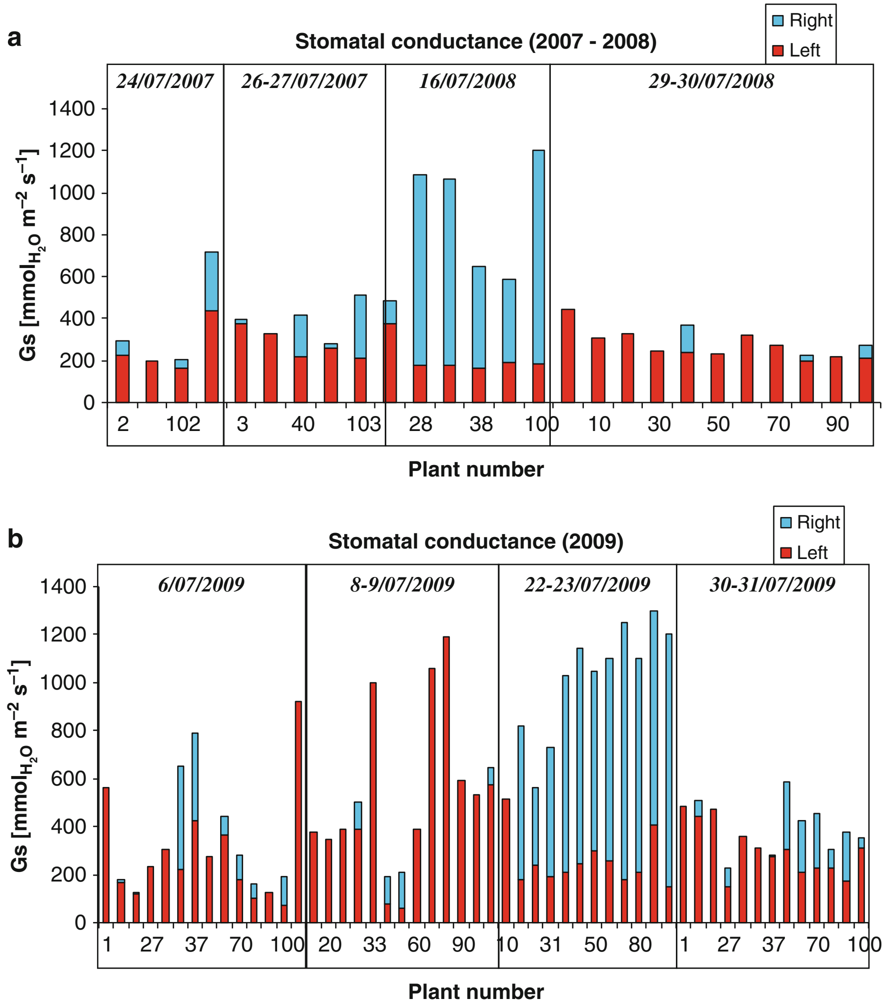

Fig. 29.4 Stomatal conductance (G_s) values measured after irrigation events in L and R rows in 2007, 2008 (**a**) and 2009 (**b**)

higher T_r and G_s measured in the R row plots can only be attributed to the significantly lower (less saline) EC_e measurements in R plots.

29.3.4 Crop Water Stress Index

Figure 29.6 illustrates crop water stress index (CWSI) values calculated for the R and L row plots during 2007, 2008 and 2009. Plants located in L row plots experienced higher CWSI's (closer to 1) than those located in R row plots, indicating that L row plants were under greater stress.

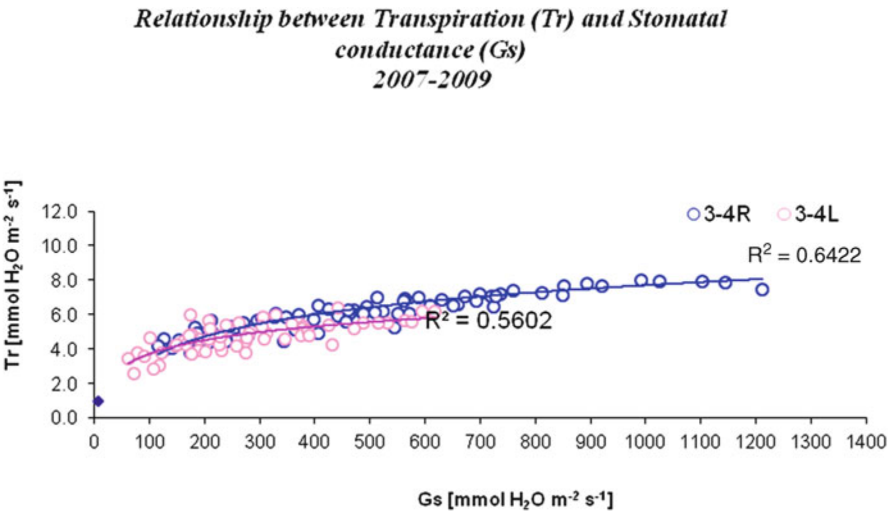

Fig. 29.5 Relationship between T_r and G_s (R and L rows)

Statistical analysis (paired *t*-test) proved that significantly higher CWSI's occurred during 2007, 2008 and 2009 in the L row plants, indicating stronger stress conditions, compared to those measured in R row plants.

Annual averages for T_r, G_s, CWSI, EC_e, θ_r and AW_{max} values are shown in Table 29.5.

Table 29.5 indicates that the two irrigation row treatments experienced similar (not significantly different) soil hydrological conditions in terms of maximum water available to crops (AW_{max}) and of wilting point (θ_r). The significantly lower T_r and G_s and significantly higher CWSI values measured in the L row plots were therefore a consequence of the significantly higher EC_e measured in the L plot soils during the course of the 3 years. In addition, EC_e value differences between R and L row treatments increased in magnitude from 2007 to 2009, indicating salt accumulation processes occurring in the L plot soil.

29.3.5 Yield Reduction Due to Water and Salinity stress

Table 29.6 reports yield reduction values (Y_r) calculated according to Eq. (29.2) for the R and L row plots using CWSI values averaged over the years and using a Ky factor of 0.85 (Doorenbos and Kassam 1979). As can be seen in Table 29.6, higher Y_r values (%), consistent with the higher CWSI values, were predicted for the L row compared to those obtained for the R row over the 3 years. The difference (ΔY_r) between the Y_r obtained for the L and R row treatments was equal to 18.78% in 2008 and 8.16% in 2009, the years for which yield data (Y_{meas}) was available for R and L row plots.

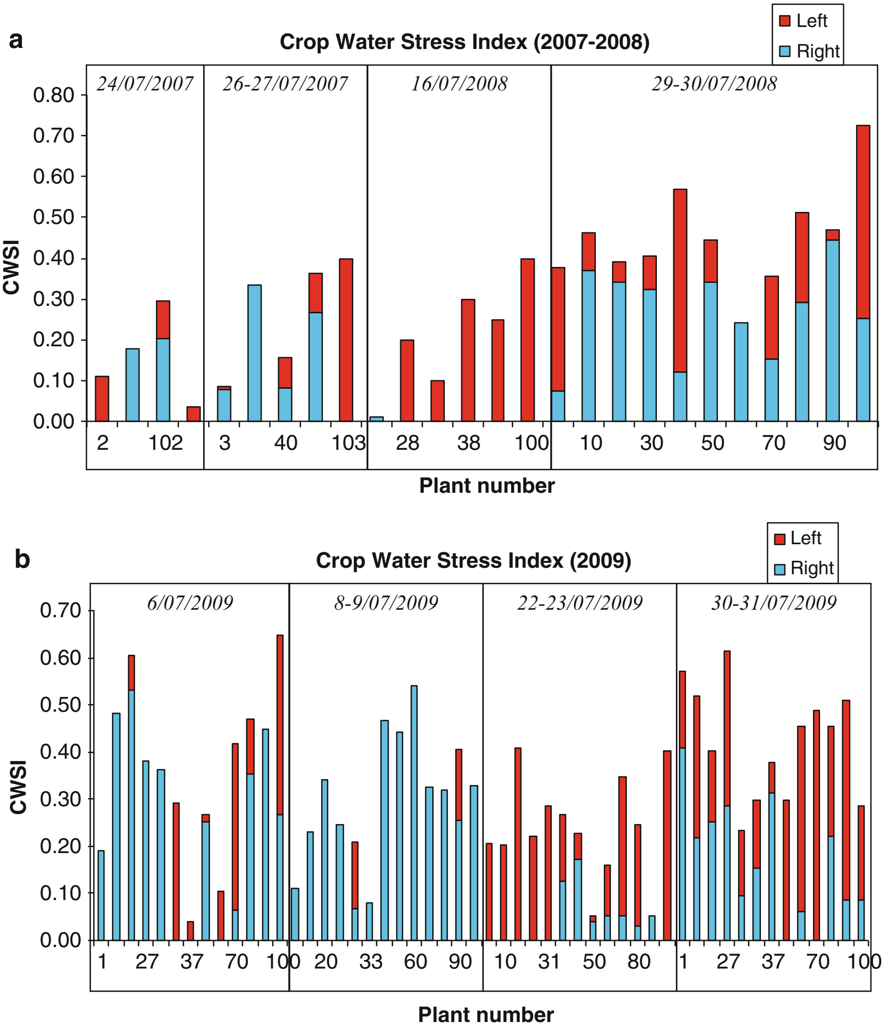

Fig. 29.6 CWSI determined in the R and L rows during 2007, 2008 (**a**) and 2009 (**b**)

Table 29.5 Annual average values for T_r, G_s, CWSI, EC_e, θ_r and AW_{max} (2007–2009)

Year	Row	T_r (mmol m^{-2} s^{-1})	G_s (mmol m^{-2} s^{-1})	CWSI [–]	EC_e (dS m^{-1})	ΔEC_e (dS m^{-1})	θ_r (cm^3 cm^{-3})	AW_{max} (mm)
2007	R	6.22	357.43	0.13	1.58	0.16	0.284	42.82
	L	5.68	285.83	0.19	1.74		0.294	43.53
2008	R	6.73	462.22	0.17	1.44	0.39		
	L	4.20	252.17	0.40	1.83			
2009	R	5.77	487.83	0.19	1.10	0.52		
	L	5.07	347.37	0.28	1.62			

Table 29.6 Annual averages of CWSI, Y_r, Y_{meas}, ΔY_{meas} and ΔY_r (2007–2009). Ky = 0.85

	Crop water stress index		Yield reduction (Eq. 29.2) Ky = 0.85		Measured yield		Difference between Y_{meas} in the L and R plots	Difference between Y_r predicted by Eq. 29.2 in the L and R plots
	CWSI		Y_r (%)		Y_{meas} (kg ha^{-1})			$\Delta Y_r = \frac{(Y_{rL} - Y_{rR})}{Y_{rR}}$
	R	L	R (%)	L (%)	R	L	ΔY_{meas} (%)	
2007	0.126	0.187	10.7	15.9	–	–	not available	5.1
2008	0.175	0.395	14.8	33.6	1.38E+04	1.18E+03	15	18.8
2009	0.188	0.284	16.0	24.2	1.50E+04	1.43E+04	5	8.2

Table 29.7 Y_r, ΔY_{meas}, ΔY_r, Y'_r and R_Y (2007–2009). Ky = 0.70

	Yield reduction (Eq. 29.2) Ky = 0.70		Difference between Y_{meas} in the L and R plots	Difference between Y_r predicted by Eq. 29.2 in the L and R plots	Yield reduction Eq. 29.4		Yield reduction predicted by Eq. 29.4/yield reduction predicted by Eq. 29.2	
	Y_r (%)			$\Delta Y_r = \frac{(Y_{rL} - Y_{rR})}{Y_{rR}}$	Y'_r (%)		$R_Y = Y'_r/Y_r$	
Year	R (%)	L (%)	ΔY_{meas} (%)		R (%)	L (%)	R (%)	L (%)
2007	8.8	13.1	not available	4.2%				
2008	12.2	27.7	15	15.5	0.4	3.2	3.3	11.7
2009	13.2	19.9	5	6.7	0.2	2.2	1.6	10.9

Predicted ΔY_r were higher than those measured (ΔY_{meas}), which may indicate that a Ky lower than 0.86 would be more appropriate for the local conditions under which these experiments were carried out. Table 29.7 reports recalculated Y_r values, again according to Eq. 29.2, but using a Ky = 0.7.

Table 29.7 shows that ΔY_r values predicting a Ky = 0.70 value were closer to those measured (ΔY_{meas}) both in 2008 and in 2009. These results indicate that accurately predicted Y_r can be calculated by Eq. 29.2 using Ky values calibrated under specific soil-plant conditions. Table 29.7 also reports the value of yield reduction due to salinity (Y'_r) calculated for the L and the R row treatments according to Eq. 29.4. Higher Y'_r values, consistent with the higher EC_e values (Table 29.5), were found for the L row. However, Table 29.7 shows that the Y'_r values were always lower than Y_r, and lower than ΔY_{meas}. These results can be explained by the fact that in our case, as is always the case where deficit irrigation is practised, concomitant conditions of water stress and salinity stress occurred. In this case transpiration (T_r), used to calculate CWSI, included crop response to water and salinity stress, and therefore, Y_r calculated by Eq. 29.2 took into account both the effects of water deficit and of the salinity stress.

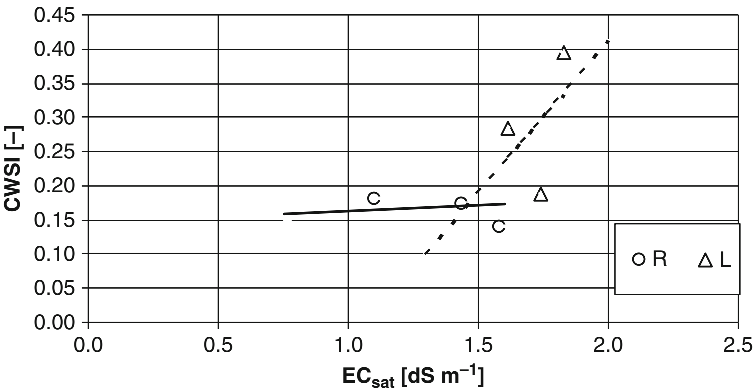

Fig. 29.7 Regression lines between CWSI and EC_e obtained using values reported in Table 29.5

Table 29.7 also reports the ratio (R_Y) between the yield reduction predicted by Eq. 29.4 (Y_r') and the yield reduction predicted by Eq. 29.2 (Y_r). The R_Y obtained indicated that the yield reduction due to salinity represented a percentage of the total yield reduction of up to 3.3% for the R row and up to 11.7% for the L row treatments. These results showed that salinity had a considerable influence on the physiological processes occurring in plants in the L plot compared to the effect of salinity on plants located in the R plot, significantly affecting crop yield.

Figure 29.7 illustrates the CWSI as a function of EC_e (mean annual values for 2007, 2008 and 2009) for the L and the R row plots.

The figure shows a different behaviour of the CWSI- EC_e relationship obtained for the L row compared to the relationship obtained for the R row plots. The two different regression lines obtained cross close to the value of 1.5 dS m^{-1}. This indicates that a value of EC_e 1.5 dS m^{-1} discriminated plant response to salinity under our experimental conditions and can be considered an indirect confirmation of the threshold value for grapes indicated by Maas (1990).

29.4 Conclusions

Crop transpiration (T_r) and stomatal conductance (G_s) measured in grapevines irrigated with water of different salinity proved to be significantly affected by soil salinity conditions, expressed by electrical conductivity of soil saturated extract (ECe). Significant reductions in T_r and G_s were measured in plants in the treatment irrigated with water having $EC_w = 1.6$ dS m^{-1} (L plots) compared to T_r and G_s values measured in plants irrigated with water having a salinity of 0.6 dS m^{-1} (R plots).

Significantly higher crop water stress index (CWSI) values were measured in the L plot compared to those measured in the R plot, indicating significantly lower transpiration in the L plot. Validity of the linear relationship between relative yield and relative transpiration was confirmed by this investigation. A value of 0.7 for the yield response factor provided accurate prediction of yield reduction both in 2008 and in 2009. However, although CWSI is generally considered an index of water stress only, when conditions of salinity occur during deficit irrigation, as in our case, CWSI incorporates both water stress and salinity stress.

Yield reductions due to salinity, calculated according to Maas and Hoffman (Eq. 29.4), showed that under our concomitant conditions of water and salinity stress, the yield reduction due to salinity (Y_r') represented a percentage of the total yield reduction (Y_r) up to 11% in the L treatment plots and up to 3.5% in the R treatment plots. The investigation also indicated that under our conditions a value of $EC_e = 1.5$ dS m^{-1}, which is the salinity threshold proposed by Maas, discriminated a different plant response to salinity between the L and R plots. Under the irrigation conditions investigated in the Foraci vineyard, it might therefore be advised to implement management strategies aimed at keeping salinity under this threshold value. This objective could be realized by irrigation performed using the lower-salinity water only or by alternating the two irrigation waters.

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References

Bresler E (1987) Application of conceptual model to irrigation water requirement and salt tolerance of crops. Soil Sci Soc Am J 51:788–793

Bresler E, Hoffman GJ (1986) Irrigation management for salinity control: theories and tests. Soil Sci Soc Am J 50:1552–1560

Brutsaert W (1966) Probability laws for pore-size distribution. Soil Sci 101:85–92

Cardon GE, Letey J (1994) Plant water uptake terms evaluated for soil water and solute movement models. Soil Sci Soc Am J 32:1876–1880

Crescimanno G (2001) Irrigation practices affecting land degradation in Sicily. Ph.D. dissertation thesis, Wageningen University, Wageningen. ISBN 9058084264

Crescimanno G (2009) Irrigation, salinization and desertification in Sicily. In: Crescimanno G, KB Marcum (eds) Irrigation, salinization and desertification. Evolution of Cropping Systems as Affected by Climate Change (CLIMESCO), Aracne. ISBN 978-88-548

Crescimanno G, Garofalo P (2005) Application and evaluation of the SWAP model for simulating water and solute transport in a cracking clay soil. Soil Sci Soc Am J 69:1943–1954

Crescimanno G, Garofalo P (2006a) Management scenarios optimizing irrigation with saline water in cracking clay soils. Soil Sci Soc Am J 70:1774–1787

Crescimanno G, Garofalo P (2006b) Salinization, land degradation and management of irrigation in arid and semi-arid countries. In: Plenary conference. Proceedings of the X National and II International Soil Science Congress, soil: food security and poverty. Agrarian University La Molina, Lima, Peru, 6–10 Nov 2006

Crescimanno G, Marcum KB (2009) Irrigation, salinization and desertification. In: Evolution of cropping systems as affected by climate change (CLIMESCO), Aracne. ISBN 978-88-548

Crescimanno G, Provenzano G (1999) Soil shrinkage characteristic in clay soils: measurement and prediction. Soil Sci Soc Am J 63:25–32

Crescimanno G, Lane M, Owens PN, Rydell B, Jacobsen OH, Düwel O, Holger Böken H, Berényi-Üveges J, Castillo V, Imeson A (2004) Taskgroup 5. Link with organic matter and contamination working group and secondary soil threats. Reports of the technical working groups established under the thematic strategy for soil protection. Volume 2 Erosion (Lieve Van-Camp, Benilde Bujarrabal, Anna Rita Gentile, Robert JA Jones, Luca Montanarella, Claudia Olazabal, Senthil-Kumar Selvaradjou (eds) (2004) EUR 21319 EN/2. http://ec.europa.eu/environment/soil/pdf/vol2.pdf

De Wit CT (1958) Transpiration and crop yield. Versl Landbouwk Onderz 64.6 Institute of Biological Chemical Research Field Crops and Herbage, Wageningen

Doorenbos J, Kassam AH (1979) Yield response to water. Land and Water Development Division, FAO, Rome

Downton WJS, Loveys BR, Grant WJR (1990) Salinity effects on the stomatal behaviour of grapevine. New Phytol 116:499–503

Hargreaves GH, Samani ZA (1982) Estimating potential evapotranspiration. J Irrig Drain Eng ASCE 108(IR3):223–230

Hasegawa P, Bressan R, Zhu JK, Bohnert H (2000) Plant cellular and molecular responses to high salinity. Annu Rev Plant Physiol Plant Mol Biol 51:464–497

Maas EV (1990) Crop salt tolerance. In: Tanji KK (ed) Agricultural salinity assessment and management. ASCE manuals and reports on engineering, no 71. ASCE, New York, pp 262–304

Maas EV, Hoffman GJ (1977) Crop salt tolerance-current assessment. J Irrig Drain Div ASCE 103:115–134

Nimah M, Hanks RJ (1973) Model for estimating soil, water, plant and atmospheric interrelations: I. Description and sensitivity. Soil Soil Sci Soc Am Proc 37:522–527

Rhoades JD (1993) Electrical conductivity methods for measuring and mapping soil salinity. In: Sparks DL (ed) Adv Agron 49:201–251

Shani U, Dudley LM (2001) Field studies of crop response to water and salt stress. Soil Sci Soc Am J 65:1522–1528

Shannon MC, Grieve CM (1999) Tolerance of vegetable crops to salinity. Am Soc Hort Sci 78:5–38

Soil Survey Division Staff (1993) Soil Survey Manual. USDA handbook no. 18. Soil Survey Division Staff, Washington, DC

Szabolcs I (1994) Prospects of soil salinity for the 21st century. In: 15th International Congress of Soil Science, Acapulco, Mexico

United Nations Population Division (1994) International conference on population and development (CPD), Cairo. www.ilga-europe.org/content/download/9950/58625/file/34-37.pdf

Walker RR, Blackmore DH, Clingeleffer PR, Correll RL (2002) Rootstock effects on salt tolerance of irrigated field-grown grapevines (*Vitis vinifera* L. cv. Sultana) 1. Yield and vigour inter-relationships. Aust J Grape Wine Res 8:3–14

Chapter 30
Yield and Growth Responses of Autochthonous Pearl Millet Ecotype (*Pennisetum glaucum* (L.) R. Br.) Under Saline Water Irrigation in Tunisia

Leila Radhouane

Abstract Saline water use is one way of water saving in water-scarce regions. It allows preserving drinking water for other uses. In Tunisia, pearl millet (*Pennisetum glaucum* (*L.*) *R. Br.*) is mainly cultivated under irrigation in the arid and saline areas. Therefore, it is essential to make selection of salt-tolerant genotypes. It offers a scope for understanding the traits related to tolerance and to integrate these tolerant crop species/genotypes into appropriate management programmes to improve the productivity of the saline soils. Identifying autochthonous ecotypes growing under local agricultural conditions with significant levels of beneficial factors may promote the value-added cultivation and enhance the agricultural economy. The objective of this study was to identify morphological and physiological traits for salinity tolerance in Tunisian autochthonous ZZ pearl millet ecotype under local conditions. The ability of this ecotype to cope with severe salt stress is the combined characteristic of many plant features, both morphological and physiological. These mechanisms enable ZZ pearl millet ecotype to store the large amounts of salt in the leaves while maintaining high leaf water content and without a grave consequent on panicle yield.

Keywords Autochthonous ecotype • Pearl millet • Saline water • Tunisia • Yield

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30.1 Introduction

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is one of the major cereal crops of the semiarid regions of Africa and Asia, and it is certainly the mainstay for millions of people in the Sahel. It is grown as grain and fodder crop (Blummel et al. 2003). In Tunisia, pearl millet is not used as staple food by rural populations as in Africa. Nevertheless, it is grown in the centre and south of Tunisia. In 2003, local grain production of pearl millet was 19,150 t principally from Kairouan (50%), Medenine (26%), Nabeul (15.6%) and Mahdia (3.4%) regions (FAO 2003). All pearl millet production is used for a variety of food products.

Pearl millet is a summer irrigated crop. However, Tunisia, as in the majority of the arid areas, is classified among the countries threatened by dryness and salinity (Qadir et al. 2006). Tunisia exhibits water availability below the threshold of 1,000 m^3 $person^{-1}$ $year^{-1}$ (Paranychianakis and Chartzoulakis 2005). In order to overcome water scarcity, many countries have adopted the use of marginal water and in particular, for irrigation (Oron et al. 2002). However, salinity of these water sources typically exceeds the limit tolerated by conventional crop plants majority of which are sensitive glycophytes (Hu et al. 2005). Regardless the plants are glycophyte or halophyte, they cannot tolerate large amounts of salt in the cytoplasm, so they develop a plethora of mechanisms to cope with salt stress and to facilitate their metabolic functions (Zhu 2003). In fact, salt stress affects all the major processes such as growth, photosynthesis, protein synthesis and energy and lipid metabolism (Parida and Das 2005). However, some moderately or highly salt-tolerant plants can survive in salty environments. These species are able to avoid ion toxicity and maintain water uptake in the presence of high salt concentrations (Flowers et al. 1977; Munns 2002).

Pearl millet (*Pennisetum glaucum* (*L.*) *R. Br*.) is rated to be fairly tolerant to salinity (Mass and Hoffman 1977; Shannon 1984; Ashraf and McNeilly 1987; Dua 1989). Moreover, availability of high levels of tolerance in other species of Pennisetum (Ashraf and McNeilly 1987, 1992; Muscolo et al. 2003) and within the *P. glaucum* (Krishnamurthy et al. 2007) offers a scope for understanding the traits related to tolerance and to integrate these tolerant crop species/genotypes into appropriate management programmes to improve the productivity of the saline soils (Chopra and Chopra 1993; Baisakh et al. 2008).

Identifying autochthonous ecotypes growing under local agricultural conditions with significant levels of beneficial factors may promote the value-added cultivation and enhance the agricultural economy. The effects of salt stress on plant growth and physiology have been well documented in other cereals (Neves-Piestun and Bernstein 2005; Munns et al. 2006; López et al. 2010; Mehta et al. 2010). However, data on specific effects of salt stress in autochthonous pear millet (*Pennisetum glaucum* (L.) R. Br.) are still fragmentary, especially effects on pearl millet physiology.

The research objective was to identify morphological and physiological traits for salinity tolerance in Tunisian autochthonous ZZ pearl millet ecotype under local conditions.

30.2 Material and Methods

30.2.1 Plant Material

Autochthonous (ZZ) pearl millet ecotype whose salt tolerance characteristics were previously determined (Radhouane 2008) was used. It is tall statured (>2 m) and has an intermediate duration of cycle (about 80 days). It was collected in Zarzis. The site is located at 33° 30′ latitude and 11° 07′ longitude and has a Mediterranean climate.

The autochthonous pearl millet ecotype (ZZ) originates from Zarzis (Zarzis is a littoral zone in the south of Tunisia, where this ecotype is cultivated).

30.2.2 Plant Growth and Treatments

The experiment was conducted at the farm of Tunisian Agricultural Research Institute in Tunis during the cropping season of 2007. The site is located at 36°51′ latitude and 10° 11′ longitude. This experimental station has a Mediterranean climate (warm winter and hot summer). The soil texture of the experimental site is clay loam (35.5% clay). The soil has these specific data: pH = 8.2, ECe = 2.3 dS m^{-1} and $CaCO_3$ = 12%. Crop was sowed on 22 May 2007 in randomized complete block design (RCBD) with four replications.

The sampling area was 5.5 m^2 (each subplot) and rows were 5 m long. Sowing was done in hills with 50 cm row to row and 30 cm hill to hill distance.

A basal dose of 50 kg N in the form of ammonium nitrate (33% N) fertilizer was applied at sowing. Standard irrigation and other agronomic practices were used uniformly for the experimental units. Total irrigation of 420 mm was applied (splitted weekly, once a week) and treatments were initiated at the emergence of fourth leaf.

Three salt levels were applied:

T_0: water containing 1 g L^{-1} NaCl (control, no NaCl added)
T_3: $T_0 + 3$ g NaCl = 4 g L^{-1}
T_6: $T_0 + 6$ g NaCl = 7 g L^{-1}

30.2.3 Data

Data were recorded on plant height (HAT), flag leaf surface (SFD), panicle grain yield (RGC), flag leaf water content (RWC), leaf water potential (LWP) and Na^+, K^+ and Ca^{2+} contents.

Plant height was determined using a graduated ruler (from the neck to the insertion of the panicle). Flag leaf surface area (cm^2) was measured with leaf area metre (MK 2) immediately after harvesting. The panicle grain yield (g) was measured by shelling mature panicles and weighing individually. Percent of relative water content (RWC) was determined on flag leaf tissues excised in the morning (around 8:00 am). Excised leaves were measured for fresh weight (FW) and then rehydrated in a water-filled petri dish at room temperature. Turgor weight (TW) was measured by allowing full rehydration (16 h), removing all water on the leaf surface, weighing, and then drying of leaves at 70°C for 48 h to determine DW (Hensen 1982).

The relative water content was calculated from the following equation:

$$\mathrm{RWC}(\%) = 100\left[\frac{\mathrm{FW}-\mathrm{DW}}{\mathrm{TW}-\mathrm{DW}}\right]$$

The leaf water potential (MPa) was measured at the abaxial surface of intact plants with pressure chamber (Scholander et al. 1965). For the determination of ion contents, the mature flag leaves were oven dried for 72 h at 70°C. After desiccation, samples were minced and incubated overnight in a 0.1 N HNO_3. After filtering, 0.5 mL of the solution was used for the determination of ion contents (Na^+, K^+, Ca^{2+}) using flame photometer (Model 410, Corning, England) (Gulati and Jaiwal 1992).

30.2.4 Statistical Analysis

Data regarding plant height, flag surface leaf, panicle grain yield, relative water content and ions content were recorded on 50 plants at the time of maturity. Data were statistically analysed using analysis of variance technique appropriate for randomized complete block design (RCBD). Main and interaction effects were separated by LSD test at 0.05 level of probability, if the *F*-values were significant.

30.3 Results and Discussion

The detrimental effects of high salinity on plants can be observed at the whole-plant level. Salinity is known to affect also various facets of plant metabolism (Waisel 1972). In fact, various NaCl concentrations have significant effect on ZZ pearl millet ecotype behaviour.

30.3.1 Plant Height (HAT)

The statistical analysis of the data indicated that salinity had significant effect on plant height of autochthonous ZZ pearl millet ecotype (Fig. 30.1). The HAT decreased significantly by salt treatments. Maximum plant height of 207 cm was

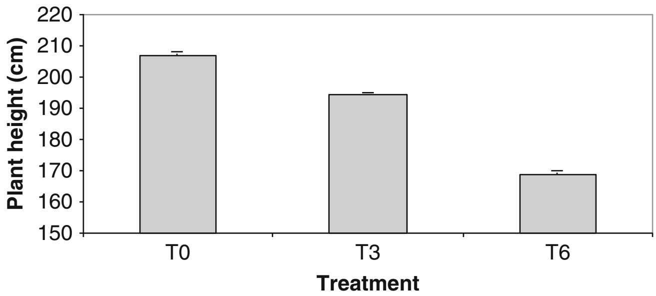

Fig. 30.1 Plant height of ZZ pearl millet ecotype in relation to salinity treatments

attained by control (T_0), and plants treated with T_6 had the lowest mean HAT of about 169 cm. Plant height for T_6 was 18 % significantly lower ($p \leq 0.01$) than T_0 and 13% than $T_{3.}$ Generally, salinity stress results in a clear stunting of plants (Cherian et al. 1999; Takemura et al. 2000). Slower growth is a general adaptive feature for plant survival under stress, allowing redirecting cell resources (e.g. energy and metabolic precursors) towards the defence reactions against stress (Zhu 2001).

In fact, salt in soil water inhibits plant ability to take up water, and this leads to slower growth (Manchanda and Neera 2008). Suppression of growth occurs in all plants, but their tolerance levels and rates of growth reduction at lethal concentrations of salt vary widely among different plant species. Processes that regulate growth reduction have not been well documented (Hasegawa et al. 2000).

30.3.2 Flag Leaf Surface (SFD)

Increasing NaCl concentration resulted in reduced leaf size for ZZ ecotype (Fig. 30.2). The ZZ pearl millet ecotype had maximum flag leaf area at T_0 treatment. Leaf area for T_6 was 6.5% significantly lower ($p \leq 0.01$) than T_0 and 2.5% than T_3. Muscolo et al. (2003) reported that *Panicum clandestinum* growth and leaf length decreased with increase in salinity. The decreased rate of leaf growth after an increase in soil salinity is primarily due to the osmotic effect of the salt around the roots (Passioura and Munns 2000). According to Neumann et al. (1988), salt stress initially inhibits leaf expansion through reduced turgor and may in fact eventually result in increased cell wall extensibility, which counteracts the negative effects of low turgor. In the presence of salt, cell wall extensibility of the growing region may decrease (Cramer 1992; Nonami et al. 1995). The reduction in leaf growth must be regulated by long distance signals in the form of hormones or their precursors. It is independent of carbohydrate supply (Munns et al. 2000) and water status (Fricke and Peters 2002).

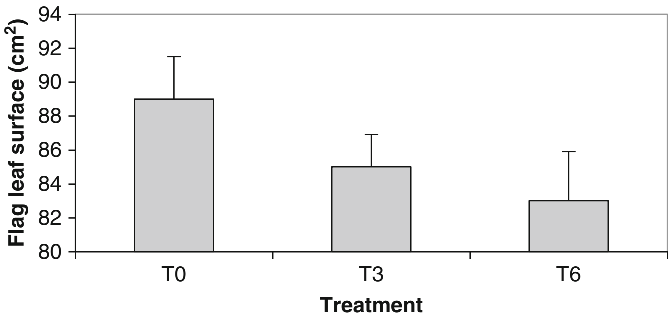

Fig. 30.2 Flag leaf surface of ZZ pearl millet ecotype in relation to salinity treatments

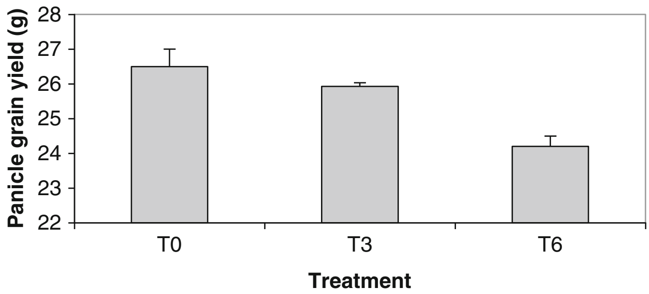

Fig. 30.3 Panicle grain yield of ZZ pearl millet ecotype in relation to salinity treatments

30.3.3 Panicle Grain Yield (RGC)

Grain head yield of ZZ ecotype continuously decreased with increasing salinity (Fig. 30.3). The lowest head yield for ZZ ecotype occurred with T_6 treatment. The panicle grain yield declined by 8.7% as planting was affected with high salinity. Nevertheless, RGC reduction was about 1.8% when T_3 treatment was applied. Salinity is the major environmental factor limiting plant growth and productivity (Allakhverdiev et al. 2000). The altered water status leads to initial growth reduction and limitation of plant productivity (Parida and Das 2005). Salt stress affects uptake, transport and utilization of different nutrients (Gratten and Grieve 1999), which may result in excessive accumulation of Na^+ and Cl^- in tissue (Saqib et al. 2005) and ultimately reduction in crop yield. Pearl millet grain yields were slightly affected by moderate saline irrigation. These results are corroborated by Isla and Aragüés (2010), Zeng et al. (2002) and Hussain et al. (2008), respectively, on maize, rice and pearl millet crops. Katerji et al. (2009) showed that salinity affected the durum wheat by reducing the grain when the soil salinity was higher than 5.8 dS m^{-1}. This reduction was due to the fact that there were fewer grains per ear. Depressed photosynthesis has been suggested to be responsible for at least part of the growth and yield reduction (Prior et al. 1992; Munns 2002).

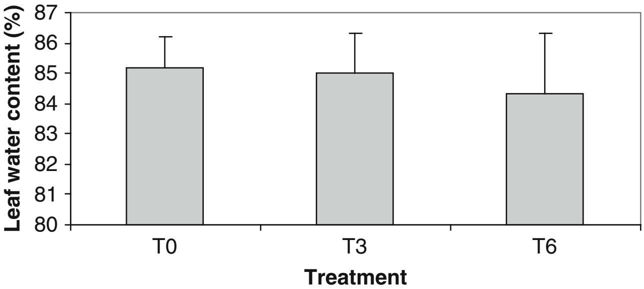

Fig. 30.4 Leaf water content of ZZ pearl millet ecotype in relation to salinity treatments

30.3.4 Leaf Water Content (RWC)

Within a salinity level, differences in RWC were not significant ($p \leq 0.01$) with a range of 84–87% of saturated water content (Fig. 30.4). Relative water content was statistically similar to that of the control. Similar results were found in the RWC of *Sorghum bicolor* by (Yang et al. 1990), barley (Eleuch et al. 2004) and sugar beet (Sahraoui and Zid 2003). Lu et al. (2002) showed that RWC remained relatively unchanged under salinity for *Suaeda salsa*. Maintenance of favourable plant water status contributes to salinity tolerance of the salt-tolerant ecotypes (Katerji and Bethenod 1997). Maintaining a high water content in the growing leaves and in leaves expansion in the presence of stress indicates osmotic adjustment effectiveness (Meloni et al. 2004). The osmotic adjustment (if any) results in a slower decrease of RWC when the leaf water potential continues to decline as observed by some authors on *T. durum* and *T. polonicum* (Al Hakimi et al. 1995). The ZZ pearl millet ecotype was able to balance the low external water potential and may potentially generate turgor and growth by many mechanisms to protect sensitive cellular sites of the salt adverse effects. This ZZ ecotype performance suggests a tolerance to salinity.

30.3.5 Leaf Water Potential (LWP)

The leaf water potential (ψ flag leaf) of ZZ pearl millet ecotype was higher in control plants as compared to the two different treatments (Fig. 30.5). Brackish water irrigation has reduced water potential of 28 and 37 %, respectively, for moderate treatment (T_3) and severe stress (T_6). Water potential becomes more negative with an increase in salinity (Gulzar et al. 2003; Jimenez et al. 2003). Decrease of the leaf water potential under salt stress has been reported by many authors and several plants including sugarcane (Plaut et al. 2000), *Beta vulgaris* (Koyro et al. 2001) and *Sorghum bicolor* (Yang et al. 1990). Water potential reduction is the result of a rapid osmotic adjustment and an increase of the concentrations osmotically (Koyro 2006).

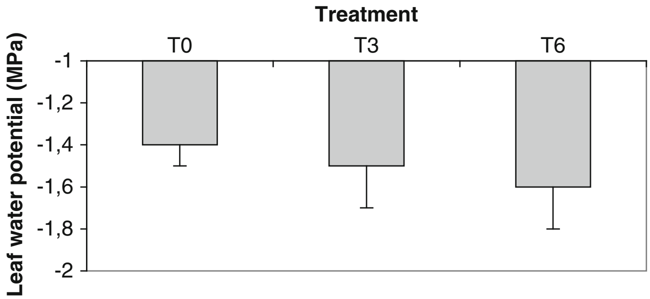

Fig. 30.5 Leaf water potential of ZZ pearl millet ecotype in relation to salinity treatments

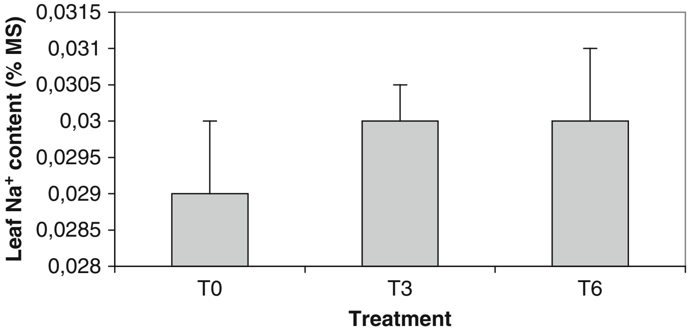

Fig. 30.6 Foliar Na^+ content of ZZ pearl millet ecotype in relation to salinity treatments

30.3.6 Ion Contents

Saline environment, most commonly mediated by high NaCl, results in perturbation of ionic steady state not only for Na^+ and Cl^- but also for K^+ and Ca^{2+} (Niu et al. 1995). Plants showed a change of the mineral composition towards Na^+ and Cl^- uptake, especially in the leaf (Koyro 2006). Accumulation of Na^+, K^+ and Ca^{2+} ions in flag leaf of ZZ pearl millet ecotype under three NaCl concentrations was presented in Figs. 30.6, 30.7 and 30.8.

30.3.6.1 Sodium (Na^+)

Na^+ is the predominate soluble cation in many of the soils of arid and semiarid areas (Wang et al. 2004). When saline water applications were made, Na^+ ions were increased in the leaves of ZZ ecotype resulting in positive correlations between leaf Na content and NaCl (Fig. 30.6). As in some other plants (Karanlýk 2001; Kusvuran et al. 2007), tolerance to salinity has been related to Na^+ ion accumulation in plant green matter. The ZZ pear millet ecotype which grows and survives in saline media is fitted for a selective sodium sequestration in the vacuole (Muhling and Lauchli

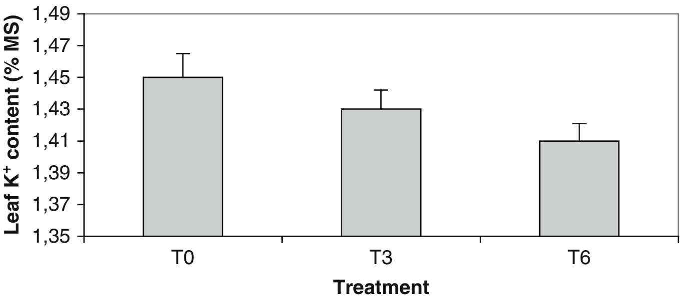

Fig. 30.7 Foliar K^+ content of ZZ pearl millet ecotype in relation to salinity treatments

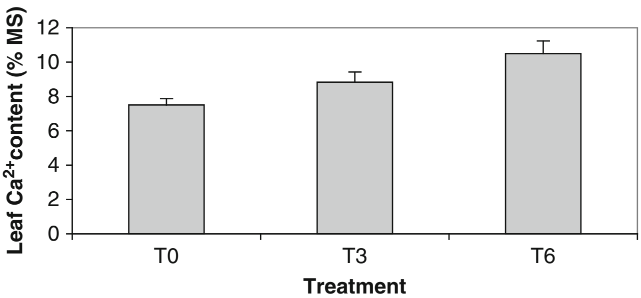

Fig. 30.8 Foliar Ca^{2+} content of ZZ pearl millet ecotype in relation to salinity treatments

2002; Cuin et al. 2003). This system therefore functions as a metabolic regulatory cycle to avoid critical concentrations in the cell. This adaptive mechanism thus has a homeostatic function in supplying metabolism with essential elements as well as detoxifying function (Smekens and Tienderen 2001). Sodium sequestration into vacuole appears to constitute the most effective mechanism of plant cells to handle efficiently high concentrations of salts and to prevent their toxic effects on cytoplasm. The compartmentalization of Na^+ into vacuoles allows plants to use Na^+ as an osmoticum, maintaining the osmotic potential that increases the water content within the cells (Blumwald 2000). Na^+ compartmentation is regulated by Na^+/H^+ antiporters (Hasegawa et al. 2000). The overexpression of genes encoding Na^+/H^+ antiporters in different plant species induced the tolerance of plants to salinity (Zhang and Blumward 2001).

30.3.6.2 Potassium (K^+)

Potassium (K^+) concentration in mature leaves was significantly ($p<0.05$) lower in plants grown with salinity (Fig. 30.7). Although it has been found that there were increases in Na^+ ion intake, there has been a decrease in K^+ ion intake. External Na^+ negatively impacts intracellular K^+ influx, attenuating acquisition of this essential nutrient by cells (Niu et al. 1995). It has been reported that leaf potassium concentration is lowered by increasing NaCl concentration in maize and barley (Benes et al. 1996), wheat (Ozalp et al. 2002) and corn (Fageria and Baligar 1999).

Under saline soils, higher levels of external Na^+ interfere with K^+ acquisition limiting plant K uptake (Perez-Alfocea et al. 2000; Saqib et al. 2004), whereas Liu et al. (2000) reported that high-affinity K^+ transporters in Eucalyptus may act as low-affinity Na^+ transporters under salt stress which may reduce K^+ uptake.

In the cytosol, the presence of K^+ is essential for the activation of many enzymes, for example, those involved in pyruvate synthesis and protein translation. Due to physicochemical similarities between Na^+ and K^+, excess Na^+ tends to substitute K^+, for Na^+ at these binding sites hence impairs cellular biochemistry (Manchanda and Neera 2008).

30.3.6.3 Calcium (Ca^{2+})

Saline water irrigation has increased calcium content in the leaf of ZZ ecotype (Fig. 30.8) of 17 and 40%, respectively, for moderate treatment (T_3) and severe stress (T_6). These results are corroborated by Ashraf and McNeilly (1987), Zhu (2002) and Munns and Tester (2008). Calcium has been shown to ameliorate the adverse effects of salinity on plants (Ehret et al. 1990). Calcium is well known to have regulatory roles in metabolism (Cramer et al. 1985), and sodium ions may compete with calcium ions for membrane-binding sites. Therefore, it has been hypothesized that high calcium levels can protect the cell membrane from the adverse effects of salinity (Busch 1995). Increase of Ca^{2+} uptake is associated with the rise of ABA under salt stress and thus contributes to membrane integrity maintenance, which enables plants to regulate uptake and transport under high levels of external salinity in the longer term (Chen et al. 2001).

30.4 Conclusion

Because of the increasing land surfaces affected by salinity, understanding how some crop plants cope with salinity is becoming a major topic. The aim is to select and to engineer crops that will be able to grow on such soils. For this study, we selected autochthonous ZZ pearl millet, an ecotype known to be salt tolerant. We defined the growth parameters, water relations and mineral content under different levels of salinity.

The ability of this ecotype to cope with severe salt stress is the combined characteristic of many plant features, both morphological and physiological. These mechanisms enable ZZ pearl millet ecotype to store the large amounts of salt in the leaves while maintaining high leaf water content and without a grave consequence on panicle yield. The ZZ pearl millet ecotype is a widely distributed species on all continents, especially near the sea, and utilized for different applied purposes: production of biomass for energy, enzymes or antioxidants and phytoremediation programmes of saline soils.

References

Al Hakimi A, Monneveux P, Galiba G (1995) Soluble sugars, proline and relative water content (RWC) as traits for improving drought tolerance and divergent selection for RWC from *Triticum polonicum* into *Triticum durum*. J Genet Breed 49:237–244

Allakhverdiev SI, Sakamoto A, Nishiyama Y, Inaba M, Murata N (2000) Ionic and osmotic effects of NaCl-induced inactivation of photosystems I and II in Synechococcus sp. Plant Physiol 123:1047–1056

Ashraf M, McNeilly TM (1987) Salinity effects on five cultivars/lines of pearl millet (*Pennisetum americanum* [L.] Leeke). Plant Soil 103:13–19

Ashraf M, McNeilly TM (1992) The potential for exploiting variation in salinity tolerance in pearl millet (*Pennisetum americanum* [L.] Leeke). Plant Breed 104:234–240

Baisakh N, Prasanta KS, Varadwaj P (2008) Primary responses to salt stress in a halophyte, smooth cordgrass (*Spartina alterniflora Loisel.*). Funct Integr Genomics 8:287–300

Benes SE, Aragues R, Grattan SR, Austin RB (1996) Foliar and root absorption of Na and Cl in maize and barley: implications for salt tolerance screening and the use of saline sprinkler irrigation. Plant Soil 180:75–84

Blummel M, Zerbini E, Reddy BVS, Hash CT, Bidinger F, Khan AA (2003) Improving the production and utilization of sorghum and pearl millet as livestock feed: progress towards dual-purpose genotypes. Field Crops Res 84:143–158

Blumwald E (2000) Sodium transport and salt tolerance in plants. Curr Opin Cell Biol 12(4):431–434

Busch DS (1995) Calcium regulation in plant cell and its role in signalling. Annu Rev Plant Physiol 46:95–102

Chen S, Li J, Wang S, Huttermann A, Altman A (2001) Salt, nutrient uptake and transport, and ABA of *Populus euphratica*; a hybrid in response to increasing soil NaCl. Trees-Struct Funct 15:186–194

Cherian S, Reddy MP, Pandya JB (1999) Studies on salt tolerance in Avicennia marina (Forstk) Vierh: effect of NaCl salinity on growth, ion accumulation and enzyme activity. Indian J Plant Physiol 4:266–270

Chopra N, Chopra N (1993) Relative salt tolerance of pearl millet (*Pennisetum glaucum*) varieties in Marwar tract of Rajasthan. Indian J Agric Res 63:652–654

Cramer GR (1992) Kinetics of maize leaf elongation. II. Responses of a Na^+-excluding cultivar and a Na^+ including cultivar to varying Na/Ca salinities. J Exp Bot 43:857–864

Cramer GR, Läuchli A, Politic VS (1985) Displacement of calcium by sodium from the plasmalemma of root cells: primary response to salt stress. Plant Physiol 79:207–211

Cuin TA, Miller AJ, Laurie SA, Leigh RA (2003) Potassium activities in cell compartments of salt-grown barley leaves. J Exp Bot 54:657–661

Dua RP (1989) Salinity tolerance in pearl millet. Indian J Agric Res 23:9–14

Ehret DL, RemannHarvey BL, Cipywnyk A (1990) Salinity-induced calcium deficiencies in wheat and barley. Plant Soil 128:143–151

Eleuch L, Slim-Amara H, Daaloul A (2004) Comportement variétal de 2 génotypes d'orge d'origine maghrébine cultivés sur milieu salin. Revue de l'Institut des Régions Arides 200–209

Fageria NK, Baligar VC (1999) Growth and nutrient concentrations of common bean, lowland rice, corn, soybean, and wheat at different soil pH on an inceptisol. J Plant Nutr 22(9):1495–1507

FAO (2003) La production et la surface du mil dans certains pays et dans le monde. Rome 57(177):10
Flowers TJ, Troke PF, Yeo AR (1977) The mechanism of salt tolerance in halophytes. Annu Rev Plant Physiol 28:89–121
Fricke W, Peters WS (2002) The biophysics of leaf growth in salt-stressed barley: a study at the cell level. Plant Physiol 129:374–388
Gratten SR, Grieve CM (1999) Salinity mineral nutrient relation in horticultural crops. Sci Hortic 78:127–157
Gulati A, Jaiwal PK (1992) Comparative salt responses of callus cultures of *Vigna radiata* (L.) wilczek to various osmotic and ionic stresses. J Plant Physiol 141:120–124
Gulzar S, Khan MA, Ungar IA (2003) Salt tolerance of a coastal salt marsh grass. Commun Soil Sci Plant Anal 34:2595–2605
Hasegawa PM, Bressan RA, Zhu JK, Bohnert HJ (2000) Plant cellular and molecular responses to high salinity. Plant Mol Biol 51:463–499
Hensen IE (1982) Osmotic adjustment to water stress in pear millet (*Pennisetum americanum* (L.) Leake) in a controlled environment. J Exp Bot 33(132):78–87
Hu Y, Fricke W, Schmidhalter U (2005) Salinity and the growth of non halophytic grass leaves: the role of mineral nutrient distribution. Funct Plant Biol 32:973–985
Hussain K, Ashraf M, Ashraf MY (2008) Relationship between growth and ion relation in pearl millet (*Pennisetum glaucum* (L.) R. Br.) at different growth stages under salt stress. Afr J Plant Sci 2(3):23–27
Isla R, Aragüés R (2010) Yield and plant ion concentrations in maize (*Zea mays* L.) subject to diurnal and nocturnal saline sprinkler irrigations. Field Crops Res 116(1–3):175–183
Jimenez JS, Debouck DG, Lynch JP (2003) Growth, gas exchange, water relations, and ion composition of Phaseolus species grown under saline conditions. Field Crop Res 80:207–222
Karanlýk S (2001) Resistance to salinity in different wheat genotypes and physiological mechanisms involved in salt resistance. PhD thesis, Cukurova Uni Fen Bil Enst, Adana (in Turkish), p 122
Katerji N, Bethenod O (1997) Comparaison du comportement hydrique et de la capacité photosynthétique du maïs et du tournesol en conditions de contrainte hydrique. Conclusions sur l'efficience de l'eau. Agronomie 17:17–24
Katerji N, Mastrorilli M, Van Hoorn JW, Lahmer FZ, Hamdy A, Oweis T (2009) Durum wheat and barley productivity in saline-drought environments. Eur J Agron 31(1):1–9
Koyro HW (2006) Effect of salinity on growth, photosynthesis, water relations and solute composition of the potential cash crop halophyte *Plantago coronopus* (L.). Environ Exp Bot 56(2):136–146
Koyro HW, Huchzermeyer B, Harrouni MC (2001) Comparison of strategies of halophytes from different plant families to avoid salt injury. In: Horst WJ et al (eds) Food security and sustainability of agroecosystems through basic and applied research. XIV International Plant Nutrition Colloquium, Hannover, Germany, pp 414–415
Krishnamurthy L, Serraj R, Rai KN, Hash CT, Dakheel AJ (2007) Identification of pearl millet [*Pennisetum glaucum* (*L.*) *R. Br.*] lines tolerant to soil salinity. Euphytica 158:179–188
Kusvuran S, Yasar F, Ellialtioglu S, Abak K (2007) Utilizing some of screening methods in order to determine tolerance of salt stress in the melon (*Cucumis melo* L.). Res J Agric Biol Sci 3:40–45
Liu W, Schachtman DP, Zhang W (2000) Partial deletion of a loop region in the high affinity K^+ transporter HKT1 changes ionic permeability leading to increased salt tolerance. J Biol Chem 275:27924–27932
López PU, Robredo A, Lacuesta M, Muñoz-Rueda A, Mena-Petite A (2010) Atmospheric CO_2 concentration influences the contribution of osmolyte accumulation and cell wall elasticity to salt tolerance in barley cultivars. J Plant Physiol 167(1):15–22
Lu CM, Qiu NW, Lu QT, Wangand BS, Kuang TY (2002) Does salt stress lead to increased susceptibility of photosystem II to photoinhibition and changes in photosynthetic pigment composition in halophyte Suaeda salsa grown outdoors? Plant Sci 163:1063–1068
Manchanda G, Neera G (2008) Salinity and its effects on the functional biology of legumes. Acta Physiol Plant 30:595–618
Mass EV, Hoffman GJ (1977) Crop salt tolerance and current assessment. J Drain Div Am Soc Civil Eng 103:115–134

Mehta P, Jajoo A, Mathur S, Bharti S (2010) Chlorophyll a fluorescence study revealing effects of high salt stress on photosystem II in wheat leaves. Plant Physiol Biochem 48(1):16–20
Meloni DA, Gulotta MR, Martinez CA, Oliva MA (2004) The effects of salt stress on growth, nitrate reduction and proline and glycinebetaine accumulation in Prosopis alba. Braz J Plant Physiol 16(1):39–46
Muhling KH, Lauchli A (2002) Effect of salt stress on growth and cation compartmentation in leaves of two plant species differing in salt tolerance. J Plant Physiol 159:137–146
Munns R (2002) Comparative physiology of salt and water stress. Plant Cell Environ 25:239–250
Munns R, Tester M (2008) Mechanisms of salinity tolerance. Annu Rev Plant Biol 59:651–681
Munns R, Guo J, Passioura JB, Cramer GR (2000) Leaf water status controls day-time but not daily rates of leaf expansion in salt-treated barley. Aust J Plant Physiol 27:949–5790
Munns R, James RA, Lauchli A (2006) Approaches to increasing the salt tolerance of wheat and other cereals. J Exp Bot 57:1025–1043
Muscolo A, Panuccio MR, Sidari M (2003) Effects of salinity on growth, carbohydrate metabolism and nutritive properties of kikuyu grass (*Pennisetum clandestinum Hochst*). Plant Sci 104:1103–1110
Neumann PM, Van Volkenburgn E, Cleland RE (1988) Salinity stress inhibits bean leaf expansion by reducing turgor, not wall extensibility. Plant Physiol 85:233–237
Neves-Piestun BG, Bernstein N (2005) Salinity-induced changes in the nutritional status of expanding cells may impact leaf growth inhibition in maize. Funct Plant Biol 32:141–152
Niu X, Bressan RA, Hasegawaand PM, Pardo JM (1995) Ion homeostasis in NaCl stress environments. Plant Physiol 109:735–742
Nonami H, Tanimoto K, Tabuchi A, Fukwjama T, Hashimoto Y (1995) Salt stress under hydroponic conditions causes changes in cell wall extension during growth. Acta Hortic 396:91–98
Oron G, DeMalach GL, David I, Lurie S (2002) Effect of water salinity and irrigation technology on yield and quality of pears. Biosys Eng 81:237–247
Ozalp VC, Oktem A, Saqlan Naqvi SM, Yücel M (2002) Photosystem II and cellular membrane stability evaluation in hexaploid wheat seedlings under salt stress conditions. J Plant Nutr 23(2):275–283
Paranychianakis NV, Chartzoulakis KS (2005) Irrigation of Mediterranean crops with saline water: from physiology to management practices. Agric Ecosyst Environ 106:171–187
Parida AK, Das AD (2005) Salt tolerance and salinity effects on plants: a review. Ecotoxicol Environ Saf 60:324–349
Passioura JB, Munns R (2000) Rapid environmental changes that affect leaf water status induce transient surges or pauses in leaf expansion rate. Aust J Plant Physiol 27:941–948
Perez-Alfocea F, Balibera ME, Alarcon JJ, Bolarin MC (2000) Composition of xylem and phloem exudates in relation to the salt – tolerance of domestic and wild tomato species. J Plant Physiol 156:367–374
Plaut Z, Meinzer FC, Federman E (2000) Leaf development, transpiration and ion uptake and distribution in sugarcane cultivars grown under salinity. Plant Soil 218(1–2):59–69
Prior LD, Grieve AM, Slavish PG, Gullis PR (1992) Sodium chloride and soil texture interactions in irrigated field grown Sultana grapevines. II. Plant mineral content, growth and physiology. Aust J Agric Res 43:1067–1084
Qadir M, Schubert S, Noble AD, Saqib M, Saifullah M (2006) Amelioration strategies for salinity-induced land degradation. CAB Rev Perspect Agric Vet Sci Nutr Nat Res 1(69):1–12
Radhouane L (2008) Effet du stress salin sur la germination, la croissance et la production en grains chez quelques écotypes de mil (*Pennisetum glaucum L. R. Br.*) autochtones de Tunisie. CR Biol 331(4):278–286
Sahraoui I, Zid E (2003) Réponses différentielles des feuilles de betterave rouge (*Beta vulgaris* L.) à la contrainte saline. Les XIII Journées Nationales de Biologie de la SSNT 2003. L'essor des bioressources Djerba, le 16-19 Mars 2003, pp 110–111
Saqib M, Akhtar J, Qureshi RH (2004) Pot study on wheat growth in saline and waterlogged compacted soil: I grain yield and yield components. Soil Till Res 77:169–177
Saqib M, Akhtar J, Qureshi RH (2005) Na exclusion and salt resistance of wheat (*Triticum aestivum*) in saline-waterlogged conditions improved by the development of adventitious nodal roots and cortical root aerenchyma. Plant Sci 169:125–130

Scholander PF, Humme HT, Bradstreet ED, Hennigsen A (1965) Sap pressure in vascular plants. Science 148:339–346

Shannon MC (1984) Breeding, selection and the genetics of salt tolerance. In: Staples RC, Toeniessen GH (eds) Salinity tolerance in plants. Wiley, New York, pp 231–254

Smekens MJ, Tienderen PH (2001) Genetic variation and plasticity of *Plantago coronopus* under saline conditions. Acta Oecol 22:187–200

Takemura T, Hanagata N, Sugihara K, Baba S, Karube I, Dubinsky Z (2000) Physiological and biochemical responses to salt stress in the mangrove, *Bruguiera gymnorrhiza*. Aquat Bot 68:15–28

Waisel Y (1972) Biology of halophytes. Academic, New York, p 420

Wang Z, Li P, Fredricksen M, Gong Z, Kim CS, Zhang C, Bohnert HJ, Zhu JK, Bressan RA, Hasegawa PM, Zhao Y, Zhang H (2004) Expressed sequence tags from Thellungiella halophila, a new model to study plant salt-tolerance. Plant Sci 166:609–614

Yang YW, Newton RJ, Miller FR (1990) Salinity tolerance in sorghum. Crop Sci 30:775–781

Zeng L, Shannon MC, Grieve CM (2002) Evaluation of salt tolerance in rice genotypes by multiple agronomic parameters. Euphytica 127:235–245

Zhang HX, Blumward E (2001) Transgenic salt-tolerant tomato plants accumulate salt in foliage but not in fruit. Nat Biotechnol 9:765–768

Zhu JK (2001) Plant salt tolerance trends. Plant Sci 6:66–72

Zhu JK (2002) Salt and drought signal transduction in plants. Annu Rev Plant Biol 53:247–273

Zhu JK (2003) Regulation of ion homeostasis under salt stress. Curr Opin Plant Biol 6:441–445

Chapter 31
Use of Marginal Water for *Salicornia bigelovii* Torr. Planting in the United Arab Emirates

Mohammad Shahid, Abdullah A. Jaradat, and Nanduri K. Rao

Abstract Freshwater resources are not enough to meet the ever increasing demand of the agriculture sector to feed the growing population. Owing to this reason, agriculture scientists are exploring different ways to use saline water as an alternative source for crops. Samphire (*Salicornia bigelovii* Torr.) is one of the best candidates for such plants that can be grown using seawater. It has high culinary value and can be consumed either cooked or raw. The plant can also be used as feed for different domestic animals. Since its seed contains high-quality unsaturated oil (30%) and proteins (40%), it can be used to make biodiesel and as animal feed. At the Dubai-based International Center for Biosaline Agriculture (ICBA), a field experiment was conducted using five different lines of *Salicornia bigelovii* irrigated with seawater. In general, all of the Salicornia lines grew well and gave good results. To evaluate their performance, data were recorded on 50 individual plants from each line at maturity. Data on 12 different morphological characteristics of spikes and plants were collected. The range for plant height varies from 49.2 to 63.0 cm. Minimum of 65.8 g and maximum of 91.8 g plant dry weight were recorded. The lowest seed weight per plant was 6.39 g, and the highest was 9.17 g. The results indicate that highly valuable Salicornia can be grown successfully in arid regions using seawater for irrigation.

Keywords Arid region • Biodiesel • *Salicornia bigelovii* • Samphire • Seawater

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31.1 Introduction

Salicornia is a genus of tender halophytes with compressed succulent leaves that may be transformed into jointed, photosynthetic shoots (de Fraine 1912). It is a widespread genus which is found in all the continents except Antarctica (Shepherd et al. 2005). The genus belongs to subfamily Salicornioideae and family Chenopodiaceae (Short and Colmer, 1999). Salicornioideae contains some of the most salt-tolerant terrestrial plants that thrive well in salt marshlands, coastal areas, and among mangroves of different types (Wilson 1980; Davy et al. 2001). One of its species, *Salicornia bigelovii* can even be grown in hypersaline drainage water (Grattan et al. 2008).

The United Arab Emirates (UAE) which lies between 22°30′ and 26°10′ north latitude and between 51° and 56°25′ east longitude is located southeast of Arabian Peninsula with an area of 83,600 km^2. The UAE has two coastlines; on the Arabian Gulf, it has 650-km long shoreline, while on the Gulf of Oman, its coast length is about 100 km. Most of the country is comprised of desert with sand dunes, gullies, and oases. South and west of the country have deserts that are part of a vast sandy desert called Rub' al Khali or Empty Quarter. In the north, Al Hajar Mountains elevate at some places to more than 2,000 m. The UAE, where the soils usually are poor in nutrients, have four main landforms: sand, salt flat, gravel, and mountains. The line of the Tropic of Cancer passes across the UAE, making the weather in the UAE hot and sunny. During winter, the average daytime temperature in Dubai is 25°C. In the coastal areas, humidity is between 80 and 85% (Table 31.1). While throughout summer, the weather in Dubai is very hot and humid, with temperatures reaching up to 40°C, even the sea temperature can go up to 37°C, with humidity averaging more than 59% (Table 31.1) which may occasionally reach 90%. The rainfall in Dubai is intermittent and low and mostly occurs during winter (Table 31.1) in the form of showers and sometimes as thunderstorm.

Salicornia bigelovii Torr. is an annual halophyte, with erect, succulent, photosynthetic stem (Fig. 31.1a), which grows in coastal estuaries (Rodriguez-Medina et al. 1998) and salt flats (Rueda-Puente et al. 2007) of Mexico's northwestern states of Baja California and Sonora. Many scientists consider it to be the most salt-tolerant vascular plant in the world (Ayala and O'Leary 1995). *S. bigelovii* which is commonly known as samphire is used in salads and appetizer platters as a pickled sea vegetable. Raw samphire, with its sea savor, is ideal as side dish with seafood and fish. The foliage of the halophyte can also be used as an alternative to fodder crops such as alfalfa (Abdal 2009) and Rhodes grass (Glenn et al. 1991) for livestock like sheep and goats.

Salicornia bigelovii Torr. has immense potential to be used as an oilseed crop in the coastal areas of deserts and wastelands, using seawater for irrigation (Glenn et al. 1991). It has been evaluated as an oilseed crop in the desert coastline of Mexico (Troyo-Dieguez et al. 1994). The sandy regions that line Indian Ocean, Gulf of California, Red Sea, and Arabian Gulf can be used to cultivate this halophyte as an oilseed crop (Glenn et al. 1998). Its seed has high contents of oil (30%) and lower

Table 31.1 Mean monthly temperatures, precipitation, and relative humidity in Dubai, UAE

	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Temperature Mean value	°C	18.7	19.3	22.3	26.1	29.9	32.2	34.4	34.4	32.1	28.7	24.3	20.6	26.92
High temperature Mean daily value	°C	24.0	24.6	27.9	32.4	36.8	38.8	40.6	40.4	38.7	35.1	30.5	26.2	33.00
Low temperature Mean daily value	°C	13.7	14.5	17.0	20.1	23.5	26.1	28.9	29.3	26.3	22.7	18.3	15.4	21.32
Relative humidity Mean value	%	65.0	65.0	63.0	55.0	53.0	58.0	56.0	57.0	60.0	60.0	61.0	64.0	59.75
Relative humidity Mean daily maximum value	%	83.0	85.0	84.0	79.0	76.0	82.0	79.0	78.0	84.0	84.0	82.0	84.0	81.67
Relative humidity Mean daily minimum value	%	44.0	43.0	40.0	32.0	29.0	32.0	32.0	34.0	31.0	34.0	38.0	44.0	36.08
Precipitation Mean monthly value	mm	11.3	35.7	22.4	7.6	0.7	0.0	0.0	0.0	0.0	0.0	1.8	14.3	7.82

Fig. 31.1 Young *Salicornia bigelovii* plant (**a**), *Salicornia bigelovii* experimental plot at ICBA (**b**), at flowering (**c**) spikes near maturity (**d**), and *Salicornia bigelovii* seeds (**e**)

concentration of salt (less than 3%), which makes it the most promising oilseed halophyte crop for the future (Glenn et al. 1998). Its oil is considered to be of good quality that contains high amount of linoleic acid (75%), an unsaturated fatty acid essential for human diet, and linolenic acid (2%), an omega-3 fatty acid, which helps fight coronary heart disease (Anwar et al. 2002; Covington 2004). Its meal contains high contents of protein (42–45%) which can be used as an animal feed

(Glenn et al. 1991). Keeping its importance in view, *Salicornia bigelovii* Torr. breeding program has been started in Eritrea and the United States of America for its improvement (Zerai et al. 2010). The Salicornia oil can also be converted into biodiesel. According to one report, Salicornia planted in one hectare of land can produce 225–250 gallons of biodiesel (unpublished data).

The BEHAR (Arabian Saline Water Technology Company Limited) of Saudi Arabia had been working on different halophyte plant species and developed many *Salicornia bigelovii* Torr. lines for vegetable, fodder, and oilseed purposes. They sent seed of some promising Salicornia lines to ICBA to assess their performance in the United Arab Emirates.

31.2 Materials and Methods

The experiment was conducted at the facilities of ICBA (Fig. 31.1b), Dubai, United Arab Emirates, about 23 km from the Arabian Gulf. Details of flowering and spikes at maturity can be seen in Fig. 31.1c, d, respectively. Overall view of matured Salicornia seeds is shown in Fig. 31.1e.

The soils at ICBA experimental fields are sandy in texture, that is, fine sand (sand 98%, silt 1%, and clay 1%), calcareous (50–60% $CaCO_3$ equivalents), porous (45% porosity), and moderately alkaline (pH 8.22). The saturation percentage of the soil is 26 and has very high drainage capacity, while electrical conductivity of its saturated extract (ECe) is 1.2 dS m^{-1}. According to American Soil Taxonomy (Soil Survey Staff 2010), the soil is classified as Typic Torripsamments, carbonatic, and hyperthermic (Shahid et al. 2009).

The sands at ICBA represent the soils of different regions of the UAE, especially some sandy areas close to the seashore. These sandy soils near the coasts are considered to be the most suitable for halophytes including Salicornia farming, using seawater as sole source of irrigation. Keeping these similarities in view, the Salicornia experiment was carried out at ICBA which may provide a guideline for future Salicornia production in the UAE.

The Saudi company of BEHAR provided ICBA with the seed of five prominent lines of *Salicornia bigelovii* Torr. developed by them. The lines were G8/28, SH, LP, K plant, and R12.

Before the sowing, compost was applied at the rate of 40 tonnes per hectare (t ha^{-1}) in the area selected for experiment. The seed of each experimental line was planted in two-row plot of 4-m length with row to row distance of 50 cm. The seed rate was 2 g per plot. The seed was hand-planted in the first week of November 2002 into furrows in sand that had earlier been irrigated with seawater from Arabian Gulf (Table 31.2) and was covered lightly. Irrigation with seawater (41 dS m^{-1}) was started immediately after sowing and continued throughout the crop duration. Irrigation was scheduled to maintain wet soil surface condition during germination and early growth and adjusted later according to crop growth and temperatures to maintain moist soil condition but avoid water logging or wilting of plants. Beginning

Table 31.2 Arabian Gulf water analysis

Units	mg L^{-1}	meq L^{-1}	RSC (meq L^{-1})	SAR (mmoles L^{-1})$^{0.5}$
Cations				
Sodium (Na^{+})	13,044	567	–	65
Magnesium (Mg^{+2})	1,500	125		
Calcium (Ca^{+2})	520	26		
Anions				
Chloride (Cl^{-1})	23,000	648		
Sulfate (SO_4^{-2})	3,100	65		
Bicarbonate (HCO_3^{-1})	171	3		
Carbonate (CO_3^{-2})	24	1		
EC	41 dS m^{-1}			
pH	8.2			
Specific gravity	1.031 g cm^{-3}			

approximately 6 weeks after sowing, plant stands were adjusted to 100 plants per row by thinning and transplanting into gaps.

After 30 days of sowing, daily application of urea at the rate of 0.3 g m^{-1} of row and compound fertilizer at the rate of 0.1 g m^{-1} of row was started. The fertilizer was dissolved in water and applied using watering can for uniform application.

In the middle of June 2003, different morphological characteristics like plant height, plant dry weight, plant biomass, distance between first spike and plant base, number of branches per plant, number of spikes per plant, spike length, spike weight, number of seeds per spike, number of seeds in one gram, seed weight per plant, and seed-to-plant weight ratio were recorded. Both for plant and spike traits, 50 samples from each plot were studied. For dry weight of plants, the samples were dried in oven at 80°C for 48 h.

The data were analyzed using standard statistical methods to ascertain the significant differences among the Salicornia lines for the 12 different morphological characteristics.

31.3 Results and Discussion

Table 31.3 illustrates data of different plant parameters. Data show (Table 31.3) that Salicornia line R12 is the tallest (63.0 cm) followed by LP (59.8 cm), while SH is the shortest (49.2 cm). In case of plant dry weight, R12 again is on the top with 91.8 g of weight, and second in line is LP whose dry weight is 81.0 g, while LP with 65.8 g has the least biomass. For both of the above-mentioned characters, a sizeable variation exists among the five Salicornia lines. Though LP is second in height (59.8 cm), its dry weight and biomass is the least among the five Salicornia lines observed, indicating that plant height is not related to either plant dry weight or biomass. On the other hand, data reveal that there is a direct correlation between

Table 31.3 Twelve different morphological characteristics of five lines of *Salicornia bigelovii* studied in field at ICBA during 2002–2003

	Lines				
	G8/28	SH	LP	K plant	R12
Characteristics	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Plant height (cm)	58.3 ± 0.6	49.2 ± 0.57	59.8 ± 0.57	58.6 ± 0.58	63.0 ± 0.64
Plant dry weight (g)	80.0 ± 0.27	74.1 ± 0.26	65.8 ± 0.26	81.0 ± 0.29	91.8 ± 0.29
Plant biomass (g m^{-2})	4001 ± 178	3704 ± 169	3290 ± 169	4048 ± 173	4588 ± 192
1st spike height (cm)	11.2 ± 3.56	10.3 ± 3.43	11.6 ± 3.39	11.4 ± 3.43	11.0 ± 3.84
No. of branches per plant	16.5 ± 0.19	15.9 ± 0.18	15.7 ± 0.18	16.3 ± 0.18	17.1 ± 0.20
No. of spikes per plant	151.9 ± 7.2	146.6 ± 6.9	70.0 ± 6.8	131.8 ± 7.0	147.3 ± 7.7
Spike length (cm)	6.9 ± 1.16	6.8 ± 1.05	8.1 ± 1.27	7.8 ± 1.17	7.9 ± 1.16
Spike weight (g)	0.32 ± 0.01	0.34 ± 0.01	0.51 ± 0.01	0.39 ± 0.01	0.39 ± 0.01
No. of seeds per spike	59.52 ± 1.38	54.74 ± 1.33	61.91 ± 1.13	57.23 ± 1.34	53.93 ± 1.49
No. of seeds per gram	942.7 ± 22.2	904.3 ± 22.2	778.3 ± 21.1	795.6 ± 21.6	830.2 ± 23.9
Seed weight per plant (g)	8.46 ± 0.40	9.33 ± 0.39	6.39 ± 0.38	8.67 ± 0.39	9.17 ± 0.44
Seed-to-plant weight (%)	11.55 ± 0.57	12.97 ± 0.57	10.26 ± 0.54	10.85 ± 0.55	10.19 ± 0.61

plant dry weight and plant biomass. The more a plant has dry weight, the higher will be its biomass. The larger biomass yield of some of the lines, especially R12, points out their suitability to be grown as fodder for livestock and vegetable for human consumption in the UAE. Though the UAE produces different types of fodder crops (Rhodes grass, alfalfa), it is not enough for its livestock. Currently, Rhodes grass has been banned in Abu Dhabi emirate to save precious groundwater resources.

The country depends heavily on the imported fodder, which for its cost restricts further increase in animal production. The UAE coastal areas comprised of salt flats (Shahid et al. 2004; Abdelfattah and Shahid 2007), while the inland region is mostly desert (Melamid 1997; Shahid 2007; Shahid and Abdelfattah 2008). Here, the salt flats (coastal and inland sabkha) contain 30% or more of salts. To reduce the salt contents in the soil, the salt flats have to be flooded with seawater and water collected in evaporation ponds for salt harvesting. After the reduction in salt contents, the soil can be used to propagate Salicornia, which is again highly unlikely to happen in salt-rich sabkha of the UAE, due to water table usually within 1–2 m from soil surface, and near-surface groundwater EC is more than 250 dS m^{-1}. Salicornia cultivation is only possible in the coastal area of the UAE where sand is accumulated to more than 2 m depth, and these areas have the potential for Salicornia cultivation using seawater. These soils are similar to sandy soils at ICBA where present study was conducted. Such areas have been delineated by Shahid et al. (2004). Planting of Salicornia and other halophytes in the coastal areas rather than inner regions reduces the cost of seawater transportation. In different experiments, Salicornia has successfully been grown as fodder in the coastal regions of Mexico (Glenn et al 1997) and Kuwait (Abdal 2009).

As the results demonstrate, biomass yield of the studied *Salicornia bigelovii* genotypes ranges from 3.3 kg m^{-2} (LP) to 4.6 kg m^{-2} in R12 (Table 31.3), which is higher than the experiments conducted in Mexico where the average yield was 1.7 kg m^{-2} (Glenn et al. 1998). Perhaps this difference is due to Salicornia being grown in coastal area than in clean sandy soil (Abdal 2009). For this trait, R12 is on the top, whereas LP is at the bottom. The outcome of the study is encouraging for *Salicornia bigelovii* planting in the UAE and similar other regions, where seawater is available and freshwater is scarce, to feed the livestock.

The mature *Salicornia bigelovii* plants irrigated with seawater contain 30–40% salt. The salt contents need to be reduced before being used as a feed. To achieve that purpose, it can either be mixed with other available fodders like Rhodes grass or soaked with seawater for some time that reduces the salt contents to a considerable level (Glenn et al. 1992).

The main objective of the experiment was to investigate the potential of the Salicornia genotypes as an oilseed crop. For this reason, nine different morphological characteristics related to seed production were studied in detail. These characteristics are first-spike distance from the plant base, number of branches per plant, number of spikes per plant, spike length, spike weight, number of seeds per spike, number of seed per gram seed weight per plant, and seed-to-plant weight ratio.

First-spike distance from the plant base has an important role in harvesting of Salicornia seed, as the plucking of the higher spikes will be easier than the lower ones. For this character, LP has a slight edge over the other lines (Table 31.3). Its spike is 11.6 cm above ground while the others have a range of 10.3–11.2 cm. The results show that there is relatively small variation among the lines for this trait; however, further investigation is required for statistical assessment.

For the number of branches per plant, small difference was found among the Salicornia lines (Table 31.3). The line R12 has the highest number of branches (17.1), while by means of 15.7, LP has the lowest number for the trait. For this characteristic, genetic variability among the lines is minute, but this is not the case with number of spikes per plant. A considerable variation exists between the lines for this trait (Table 31.3). With 151.9, G8/28 has produced more spikes than the other four genotypes, whereas with the lowest number of spike (70.0 spikes), LP was at the bottom. The difference between the two lines is more than two times for this plant character.

The length of a spike indicates the number of seeds it contains. The longer the length of a spike, the more seeds it encloses. Likewise, spike weight also correlates with seed production. Among the five Salicornia lines studied, LP shows the longest spike with 8.1 cm in length, while SH that has 6.8-cm long spike is the shortest (Table 31.3). The difference between the two lines for this characteristic is 16%. For spike weight, LP also has the heaviest spike (0.51 g); on the other hand, G8/28 produced the lightest spike of 0.32 g (Table 31.3). The variation between the two genotypes for this trait is more than 37% which is quite higher. As far as number of seeds per spike is concerned, the genotype LP has the maximum number of seeds (61.9) while the lowest seed number per spike was recorded in SH (54.7). For this character, the variation between the two Salicornia lines is around 12%. The line LP has given the best performance for all the three spike traits which play very important role in seed yield of a Salicornia plant. But for number of spikes per plant, it was the lowermost. In a Salicornia breeding program, the line can be incorporated for its three excellent spike traits to evolve improved varieties.

The number of seeds per gram points out the size of the seed. For this seed character, G8/28 and SH produced 947 and 904 seeds per gram, respectively, indicating that their seed is smaller in size. While LP has the largest seed among the Salicornia lines as it has 778 seeds per gram, that is more than 20% larger than G8/28. The results show that a sizeable variation is present for the seed size in the Salicornia lines (Table 31.3). For seed size, LP again has outperformed other lines. Large seed for an oilseed crops is a desirable character which is correlated with high oil and protein meal production compared to the smaller ones. For this superior seed trait, LP can be involved in Salicornia improvement projects to introduce cultivars with good oil yield.

Seed weight per plant is the most important character that defines the yield potential of a genotype. This character displays considerable differences among the five Salicornia lines (Table 31.3). The line SH with 9.33 g of seed gave the highest yield per plant, whereas the lowest yield was observed in LP (6.39 g). The difference between the two lines for this trait is more than 31%. The performance of line LP is the worst for this character, but for other traits like spike length, spike weight, number of seed per spike, and seed weight, it gave the best results. Its lowest yield for seed per plant seems to be due to its lower number of spikes per plant which were less than half of the top performer (SH).

For seed-to-plant weight ratio, SH has the highest percentage of 12.97; on the other hand, LP scores the lowest percentage of 10.26 for the character (Table 31.3). The difference between the two genotypes for this trait is around 21%, indicating the presence of large genetic variability. The data display that all the five Salicornia lines, especially SH, have the good yield potential of seed production in the UAE.

As a whole, all the five Salicornia lines have performed well for both biomass and seed production. But the line SH has shown the best results for seed production and other related traits in the experiment. It seems to have good potential to be grown as an oilseed cultivar in the desert. While for biomass, R12 has given the best performance. Therefore, this line can be selected both for vegetable and fodder purposes in the UAE and other similar countries.

The seed yield of the studied Salicornia lines at ICBA is very high. At the rate of 20,000 plants per hectare, SH may give the yield of 18.66 t ha^{-1} followed by R12 with 18.34 t ha^{-1}. This seed yield is much higher than in Eritrea where an experimental farm produced Salicornia seed at the rate of 2 t ha^{-1} and Mexico where seed yield was 5 t ha^{-1} (unpublished data). The significant differences in Salicornia seed yield are believed to be due to the scale of experimental fields and locations, where small plots can be well managed and looked after compared to large fields. In Eritrea, the field size was 80 ha and it was close to the coastal area, whereas in Mexico, the Salicornia planting was done in 400-ha field and the plantation was also near the coast. In the case of ICBA, the experiment was conducted in sandy soils with compost supplement, and plot size for each line was 4 m^2 which is easy to look after and maintain.

In the coastal desert region of Sonora, Mexico, work has been started on 5,000-ha area to cultivate Salicornia for biodiesel production, protein meal, and fodder using seawater for irrigation. The objective was to encourage the use of nonconventional source of irrigation to save the precious freshwater. The work has shown that net profit from Salicornia oil is higher than corn ethanol and soybean oil which are being used to make biofuel. The Salicornia crop needs less fertilizer and pesticides, making it environmentally friendly.

The Masdar Institute of Science and Technology, UAE, with the backing of Boeing, Etihad Airways, and UOP Honeywell is working on a plan to grow Salicornia in Abu Dhabi to produce biofuel for aeronautics industry. For the project, only seawater will be used for irrigation to produce Salicornia seed oil. The purpose of the project is to decrease the use of fossilized oil which emits greenhouse gases that lead to climate change. The production of Salicornia seed oil at a reasonable price will decrease dependency on conventional energy sources, paving way to cleaner environment. ICBA is cooperating with Masdar in Salicornia project.

Since the soils at ICBA are porous with high drainage capacity, it does not tend to build salts when irrigated with salty water. At the center, there is good drainage system which helps in leaching salts. Soils irrigated with seawater for a cropping season reveals that there is about 5% decline in pH, that is, from 8.22 to 7.79, due to salt accretion at a depth of 50 cm (root zone of *Salicornia bigelovii*). But the salt concentration can be decreased by flushing soils with seawater (Duncan et al. 2000). Brine water farming has some problems, but it has many benefits. Arid coastal sandy desert farms have natural drainage system. Even after 10 years of seawater irrigation in the shoreline Salicornia farms, salts did not accumulate in the soils to harm plant growth (Glenn et al. 1998). The areas close to coast may be ideal for Salicornia cultivation as salts accretion due to brine water irrigation will be lower.

31.4 Conclusions

The preliminary research at ICBA demonstrated that Salicornia has the potential to be grown as oilseed, fodder, or vegetable crop in the UAE. As the results show, sandy soil and seawater do not curtail the growth of Salicornia plant. On the sandy areas close to shorelines, availability of seawater ensures the smooth farming of the crop. The country has more than 750-km long coastline, which can partially accommodate its cultivation at a large scale, where sandy soils such as Torripsamments are available. This will help in reducing the country's dependence on imported fodder, which costs foreign exchange.

Farming of Salicornia as an oilseed crop in the UAE not only boosts the edible oil production, but it will also help in establishing the biofuel industry. Use of biofuel instead of fossil fuel will lead to a better environment as it emits less particulates, carbon monoxide, and hydrocarbons which are injurious to health. After extraction of oil from Salicornia seed, its byproduct meal which contains more than 40% protein can be used as feed for poultry and fish farming. This will ultimately help in increase of meat production in the UAE.

Salicornia is a promising crop for the farmers of the UAE and other similar countries that live in desolate and saline region, providing precious oil and nutritious fodder where little else could endure. Extensive cultivation of Salicornia will not only provide different agriculture products, but it also assists in reducing global warming by sequestering the atmosphere carbon.

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References

Abdal MS (2009) Salicornia production in Kuwait. World Appl Sci J 6:1033–1038

Abdelfattah MA, Shahid SA (2007) A comparative characterization and classification of soils in Abu Dhabi coastal area in relation to arid and semiarid conditions using USDA and FAO soil classification systems. Arid Land Res Manage 21:245–271

Anwar F, Bhanger MI, Khalil M, Nasir A, Ismail S (2002) Analytical characterization of *Salicornia bigelovii* seed oil cultivated in Pakistan. J Agric Food Chem 50:4210–4212

Ayala F, O'Leary JW (1995) Growth and physiology of *Salicornia bigelovii* Torr. at suboptimal salinity. Int J Plant Sci 156:197–205

Covington MB (2004) Omega-3 fatty acids. Am Fam Physician 70:133–140

Davy AJ, Bishop GF, Costa CSB (2001) *Salicornia* L. (*Salicornia pusilla* J. Woods, *S. ramosissima* J. Wood, *S. europaea* L., *S. obscura* P.W. Ball & Tutin, *S. nitens* P. W. Ball & Tutin, *S. fragilis* P.W. Ball & Tutin and *S. dolichostachya* Moss). J Ecol 89:681–707

de Fraine E (1912) Anatomy of the genus *Salicornia*. J Linn Soc Lond Bot 41:317–348

Duncan RR, Carrow RN, Huck M (2000) Effective use of seawater irrigation on turfgrass. USGA Green Sect Rec 38:11–17

Glenn EP, O'Leary JW, Watson MC, Thompson TL, Kuehl RO (1991) *Salicornia bigelovii* Torr.: an oilseed halophyte for seawater irrigation. Science 251:1065–1067

Glenn EP, Coates W, Riley JJ, Kuehl R, Swingle RS (1992) *Salicornia bigelovii* Torr.: a seawater-irrigated forage for goats. Anim Feed Sci Technol 40:21–31

Glenn EP, Miyamoto M, Moore D, Brown JJ, Thompson TL, Brown P (1997) Water requirements for cultivating *Salicornia bigelovii* Torr. with seawater on sand in a coastal desert environment. J Arid Environ 36:711–730

Glenn EP, Brown JJ, O'Leary JW (1998) Irrigating crops with seawater. Sci Am 279:76–81

Grattan SR, Benes SE, Peters DW, Diaz F (2008) Feasibility of irrigating pickleweed (*Salicornia bigelovii* Torr) with hyper-saline drainage water. J Environ Qual 37:149–156

Melamid A (1997) The United Arab Emirates. Geog Rev 87:542–545

Rodriguez-Medina M, de la Lanza-Espino G, Hernandez-Pulido S (1998) Decomposition of *Salicornia subterminalis* in Caimanero Lagoon, Mexico. Cienc Mar 24:241–251

Rueda-Puente EO, Garcia-Hernandez JL, Preciado-Rangel P, Murillo-Amador P, Tarazon-Herrera MA, Flores-Hernandez A, Holguin-Pena J, Aybar AN, Barron Hoyos JM, Weimers D, Mwandemele O, Kaaya G, Mayoral JL, Troyo-Dieguez E (2007) Germination of *Salicornia bigelovii* ecotypes under stress conditions of temperatures and salinity and ameliorative effects of plant growth-promoting bacteria. J Agron Crop Sci 193:167–176

Shahid SA (2007) Soils. In: Physical geography sector paper, AGEDI Initiative, Environment Agency, Abu Dhabi, pp 6–41

Shahid SA, Abdelfattah MA (2008) Soils of Abu Dhabi Emirate. In: Perry RJ (ed) Terrestrial environment of Abu Dhabi Emirate. Environment Agency, Abu Dhabi, pp 71–91

Shahid SA, Abdelfattah MA, Arshad KR et al. (2004) Soil survey for the coastline of Abu Dhabi Emirate. Unpublished report by Environmental Research and Wildlife Development Agency, Abu Dhabi, UAE. Volume 1: Report; Volume II: Soil maps

Shahid SA, Dakheel AJ, Mufti KA, Shabbir G (2009) Automated in-situ soil salinity logging in irrigated agriculture. Eur J Sci Res 26(2):288–297

Shepherd KA, MacFarlane TD, Colmer TD (2005) Morphology, anatomy and histochemistry of Salicornioideae (*Chenopodiaceae*) fruits and seeds. Ann Bot 95:917–933

Short DC, Colmer TD (1999) Salt tolerance in the halophyte *Halosarcia pergranulata* subsp. *pergranulata*. Ann Bot 83:207–213

Soil Survey Staff (2010) Keys to soil taxonomy, 11th edn. USDA-NRCS, US. Government Printing Office, Washington, DC

Troyo-Dieguez E, Ortega-Rubio A, Maya Y, Leon JL (1994) The effect of environmental conditions on the growth and development of the oilseed halophyte *Salicornia bigelovii* Torr. in arid Baja California Sur, Mexico. J Arid Environ 28:207–213

Wilson PG (1980) A revision of the Australian species of Salicornieae (*Chenopodiaceae*). Nuytsia 3:1–154

Zerai DB, Glenn EP, Chatervedi R, Lu Z, Mamood AN (2010) Potential for the improvement of *Salicornia bigelovii* through selective breeding. Ecol Eng 36:730–739

Chapter 32
Performance of *Chenopodium quinoa* Under Salt Stress

Meryem Brakez, Khalid El Brik, Salma Daoud, and M. Cherif Harrouni

Abstract Germination and seedling of *Chenopodium quinoa* were evaluated under different salinity concentrations in the culture medium in order to introduce it in Morocco as a crop for the reclamation of saline soils under saline irrigation. *C. quinoa* seeds were treated with aqueous solutions of 0, 75, 100, 125 and 150 mM of NaCl (corresponding respectively to 0, 15, 20, 25 and 30% seawater concentration). The germination percentage was strongly affected by salinity such that only 45% seeds were germinated at 150 mM NaCl compared to the control that germinated at the rate of 80%. Five-week-old seedlings were irrigated with four seawater (SW) dilutions (20, 30, 40 and 50%) in comparison with control plants of the same age irrigated with freshwater. Maximum biomass was registered in 20% SW treatment, and the threshold salinity tolerance was observed in 30% SW treatment. The root-to-shoot ratio went up with the increase of salinity in the culture medium, while the relative growth rates (RGR) decreased significantly. Ionic analysis of vegetative organs and seeds revealed that Na^+ and K^+ concentrations increased in all organs tested, while Ca^{2+} concentration decreased significantly. The concentration of Mg^{2+} was not affected by the presence of salt in the culture medium.

Keywords Biomass production • *Chenopodium quinoa* • Germination • Ionic composition • Salt stress

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32.1 Introduction

Morocco, a Mediterranean country with mainly arid and semiarid climates, has gone through years of drought and still continues to suffer from it. The country has conventional water resources that are inadequately distributed and do not meet the requirements of local people, especially in agriculture. Furthermore, more lands are affected by salinisation due to climate change and lack of good quality water. The combination of these factors constitutes the major cause for crop losses in Morocco (Daoud 2004). These losses result in the reduction of performance in agricultural productivity and thus negatively affect socio-economic development (Choukr-Allah and Harrouni 1996). Modern agriculture that involves major investments to optimise the use of existing resources should take into account a biological approach emphasising on investigations for tolerance to environmental stresses, especially salt stress (El Iklil 2001).

The use of halophytes in saline areas is a biosaline approach that is worth considering. The irrigation of halophytes with seawater or in general with marginal quality water is an opportunity for exploitation of land affected by salts because of the significant production of biomass, thus defining the halophytes as a new form of productive agriculture (O'Leary and Glenn 1984). Morocco, which has 3,500 km of coastline, can easily meet the challenge of lack of water by using seawater as a source of irrigation and can exploit 32,000 km of coastal areas for agriculture. Seawater also contains about 13 minerals necessary for plant survival and at adequate levels (Gooding et al. 1990; Daoud 2004). However, before the use of halophytes at a large scale, it is necessary to determine the degree of salinity tolerance of species with an economic potential and the physiological mechanisms enabling them to survive in saline environments.

Quinoa (*Chenopodium quinoa* wild) is a pseudocereal. It is a seed crop native to the Andean mountains mostly cultivated for human consumption. Quinoa presents a great flexibility to grow under extremely diverse agronomic conditions (Geerts, 2008). For a possible use of this plant in saline areas in Morocco, the present work aims to study the effect of different concentrations of salinity on germination and seedling growth.

The experiment was conducted in a halophyte greenhouse at Hassan II Institute of Agronomy and Veterinary Medicine (IAV) in Agadir. The IAV is a part of the Souss area located southwestern of Morocco (Fig. 32.1). It is bounded on the north by the High Atlas Mountains, in the west by Atlantic Ocean and on the South by the Anti-Atlas Mountains. Lands are relatively flat, and soils are loamy to sandy. The agriculture relies partly on surface water collected and stored in dams but mainly on underground water pumped from the aquifer with a subsequent intrusion of the seawater along the coast. The climate is arid but moderated by the maritime influence. Weather data are summarised in Tables 32.1, 32.2, 32.3, and 32.4. These tables show that rainfall is low and concentrated between October and March (Table 32.1). Temperatures are moderate (18.5°C annual average). December to February are the coldest months with absolute minimum temperature between 1 and

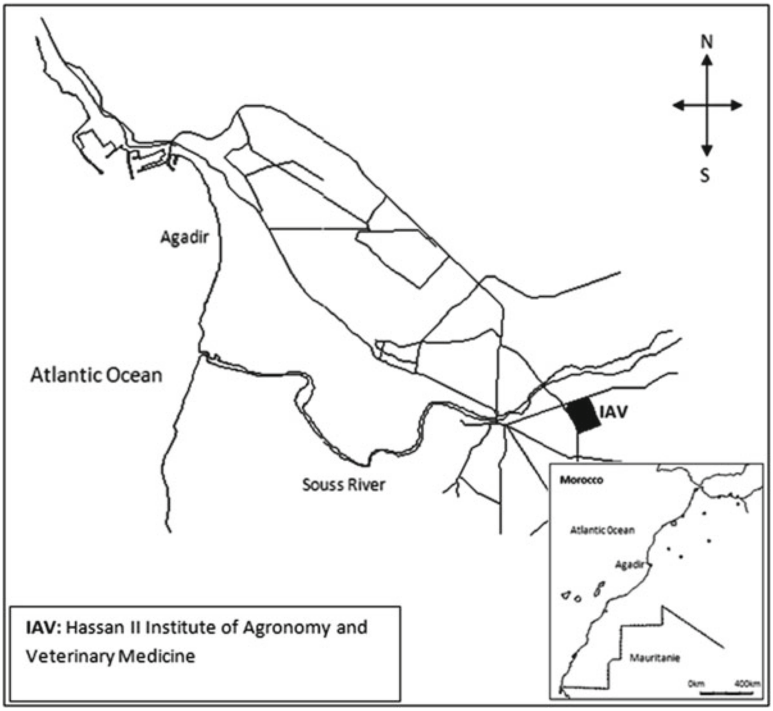

Fig. 32.1 IAV Agadir site location map

2°C. June, July and August are the hottest months (Table 32.2). Air relative humidity is high (especially in summer) (Table 32.3), and the potential evapotranspiration is low (Table 32.4) due to the proximity of the ocean which induces fog formation and so the reduction of evapotranspiration.

32.2 Materials and Methods

32.2.1 Germination Experiment

The effect of salinity was tested on the germination of *C. quinoa* seeds. Seeds were disinfected for 10 min in 10% NaOCl, washed with distilled water several times and transferred into 9-cm petri dishes containing sterile filter paper and then soaked by 5 mL of either distilled water (control) or saline solutions 75, 100, 125 and 150 mM of NaCl corresponding to 15, 20, 25 and 30% seawater concentration. Petri dishes were then incubated in the dark at 20°C. The number of seeds germinated was observed daily, and the germination percentage was recorded 7 days later, when seed

Table 32.1 Monthly temperature of Agadir (°C)

	January	February	March	April	May	June	July	August	September	October	November	December
Average	13.2	15.1	16.3	17.8	18.6	20.6	22.7	22.8	22.0	20.3	17.3	14.7
Average maximum	21.6	23.6	22.8	26.8	26.2	26.5	31.4	29.5	28.4	27.3	26.1	23.7
Average minimum	6.3	6.3	9.1	10.5	11.1	15.7	17.0	17.1	16.1	14.6	9.7	6.1
Absolute maximum	47.0	31.0	37.0	40.0	37.0	43.0	47.0	45.7	39.5	36.0	48.0	32.0
Absolute minimum	1.0	2.6	3.5	1.0	4.0	13.0	13.0	12.0	13.0	9.0	4.0	20

Average records from 2006 to 2011

Table 32.2 Monthly rainfall of Agadir (mm)

	January	February	March	April	May	June	July	August	September	October	November	December
Average	37.0	41.6	32.3	7.0	33.3	0.0	0.0	9.9	6.3	20.8	29.2	49.2
Absolute maximum	60.7	142.7	73.0	11.6	66.0	0.0	0.0	11.8	6.3	30.6	75.2	111.1
Absolute minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Average records from 2006 to 2011

Table 32.3 Monthly relative humidity of Agadir (%). Average records are from 2006 to 2011

	January	February	March	April	May	June	July	August	September	October	November	December
Average maximum	89.6	88.2	88.9	85.5	86.4	86.5	86.4	87.0	87.9	89.4	87.3	88.3
Average minimum	41.3	43.6	41.4	42.6	48.6	51.0	51.3	54.0	49.0	47.0	39.4	39.0

Table 32.4 Monthly potential evapotranspiration (PET) of Agadir (mm)

	January	February	March	April	May	June	July	August	September	October	November	December
Average	1.5	2.1	2.8	3.4	3.7	3.9	3.7	3.3	3.0	2.4	2.0	1.6
Absolute maximum	2.0	2.6	3.3	4.3	3.9	4.1	4.2	3.7	3.3	2.7	2.3	1.9

Average records from 2006 to 2011

Table 32.5 Ionic composition of irrigation water used in the Quick Check system

Treatments	pH	EC ($dS\ m^{-1}$)	Na^+ ($g\ L^{-1}$)	Cl^- ($g\ L^{-1}$)	K^+ ($g\ L^{-1}$)	Mg^{2+} ($g\ L^{-1}$)	Ca^{2+} ($g\ L^{-1}$)	NO_3^- ($mg\ L^{-1}$)	*P* ($mg\ L^{-1}$)
Freshwater	7.18	0.81	0.22	0.71	0.43	0.12	0.21	0.019	0.09
20% seawater	7.32	11.7	2.59	4.26	1.06	0.15	0.32	0.018	0.12
30% seawater	6.89	16.8	2.72	5.33	1.56	0.16	0.33	0.017	0.17
40% seawater	6.91	21.3	3.09	7.81	1.77	0.16	0.35	0.013	0.39
50% seawater	6,90	25.9	3.58	8.52	2.06	0.16	0.43	0.014	0.45

germination reached its maximum in all treatment. The coefficient of velocity (CV) of germination was calculated using the following formula:

$$\mathrm{CV} = 100\left[\frac{\sum N_i}{\sum N_i T_i}\right] \tag{32.1}$$

where *N* is the number of seeds germinated on day *i* and *T* is the number of days from sowing (Scott et al. 1984; Ghadiri and Bagherani 2000).

32.2.2 *Growth Experiment*

Five-week-old seedlings of *C. quinoa* (grown in a substrate made with a mixture of 1/3 peat and 2/3 sand) were planted in black pots containing coastal sand and placed in an automatic irrigation and drainage system called "Quick Check system" (Koyro 1999).

Seedlings were first irrigated with the nutrient solution of Epstein (1972) for 2 weeks. NaCl was added gradually in steps of 1/10 seawater concentration twice a day. The highest concentration was reached after 3 days. After 2 weeks, the nutrient solution with NaCl was replaced with fertilised seawater. Fertiliser concentrations were calculated for each treatment on the basis of the nutrient solution of Johnson. The characteristics of irrigation water used are shown in Table 32.5.

There were five treatments altogether: control (freshwater), 20, 30, 40 and 50% seawater.

The "Quick Check system" was programmed with a timer to water plants every 2 h for 15 min and allowed the saline solution to drain freely from the pots. Maximum temperature in the greenhouse was 43°C, and minimum temperature was 11°C. Relative humidity ranged from 63 to 93.7%.

Statistical analysis was performed by the XLSTAT. The analysis of variance was determined using the Newman–Keuls test at $p < 0.05$.

After 2 months of growth, the plants were harvested to determine growth parameters (biomass, relative growth rate, root-to-shoot ratio) and ionic composition. Relative growth rate based on the increase of dry weight during experiment period was calculated using the formula:

$$\mathrm{RGR} = \frac{\mathrm{In(final\ dry\ weight)} - \mathrm{In(initial\ dry\ weight)}}{\mathrm{time}} \tag{32.2}$$

After measurement of the fresh weight, the plants were placed in a ventilated oven at 60–70°C for 48 h in order to determine the dry weight. Stems, leaves, roots and seeds were ground separately in an electric grinder (Thomas Willey Mill, model ED-5). Ash weight was determined by burning 200 mg of each part of the plant in a furnace overnight at 485°C. Mineral composition was determined using techniques described by Munter (1980). The Na^+, K^+, Ca^{2+} and Mg^{2+} were determined by an atomic absorption spectrophotometer (Perkin Elmer 3110), after the dissolution of the ash in HCl (2N). The rate of mineral elements was expressed on a dry weight basis.

32.3 Results and Discussion

32.3.1 Germination Experiment

The effect of salinity on the germination and the coefficient of velocity of *C. quinoa* are shown in Fig. 32.2. The germination percentage and the coefficient of velocity decreased significantly with the increase of salinity. Seeds germinated best in the non-saline

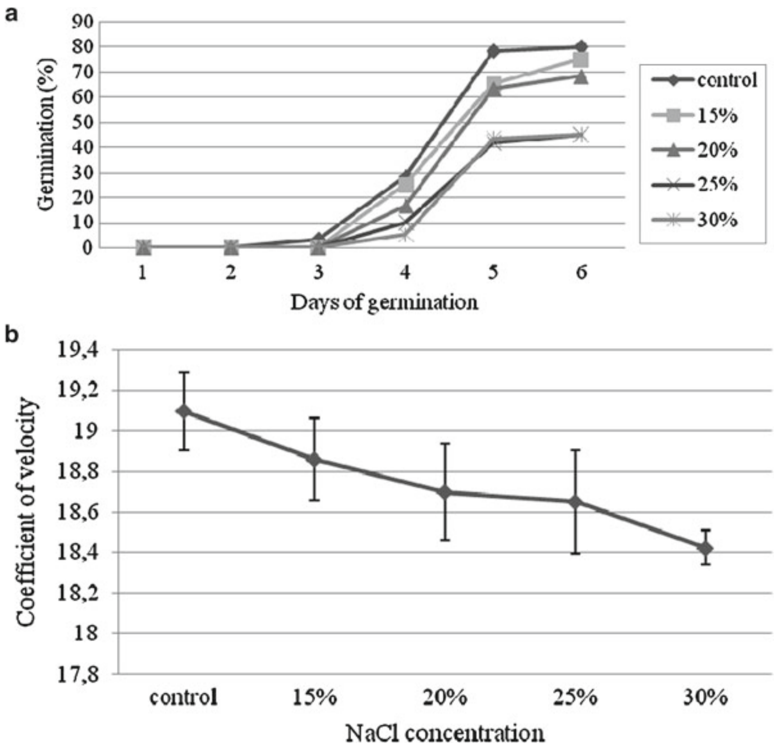

Fig. 32.2 Germination percentage (**a**) and coefficient of velocity (**b**) of *C. quinoa* germinating under saline conditions

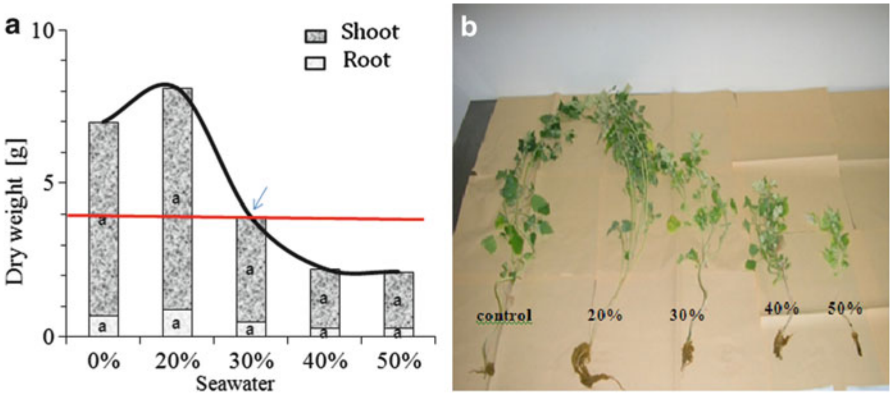

Fig. 32.3 (**a**) Biomass production of *C. quinoa* in different seawater treatments. Horizontal line corresponds to 50% biomass reduction compared to the optimum. The arrow indicates the threshold salinity tolerance. Values with the same letter do not differ significantly at $p<0.05$; (**b**) *C. quinoa* from control (freshwater) and different seawater treatments (20, 30, 40 and 50%)

conditions. The decrease in germination was 45% at 150 mM of NaCl compared to the control which showed 80% of germination. As a matter of fact, in many studies, halophyte species had shown a delay and a decrease in germination percentage and the coefficient of velocity (Ungar and Khan 2001; Shahabaz et al. 2005) under saline conditions.

32.3.2 Growth Parameters

C. quinoa has survived through the four seawater treatments used in the experiment. Growth was stimulated by moderate salinity (20% seawater) and was reduced at high salinity (50% seawater) (Fig. 32.3a, b). Maximum biomass was noted in 20% seawater treatment (EC 12 dS m^{-1}) and decreased with the increase of salinity. This result is close to the one found by Jacobson et al. (2000) on *C. quinoa* where he found that the biomass was stimulated under moderate salinities (10–20 dS m^{-1}). Threshold salinity tolerance, defined by Kinzel (1982) as salinity which reduced 50% of dry weight compared to the treatment with optimal growth, was determined at 30% seawater concentration. According to Koyro et al. (2008), the threshold salinity tolerance of *C. quinoa* is reached at 50% seawater. However, these authors worked under temperature- and humidity-controlled conditions, whereas in the present study, plants experienced fluctuations in temperature and air humidity. The root-to-shoot ratio (R/S) has increased with the increase of salinity (Fig. 32.4), showing that under salt stress, root growth is always less affected by salinity compared to shoot (Munns and Termatt 1986). The relative growth rate (RGR) was affected by salinity (Fig. 32.5). It decreased to 46% at 50% seawater compared to 20% seawater treatment, where *C. quinoa* expressed its maximum RGR. Seed productivity was also affected by salinity (Fig. 32.6). Its optimal rate was obtained at 20% seawater (EC 12 dS m^{-1}) and declined

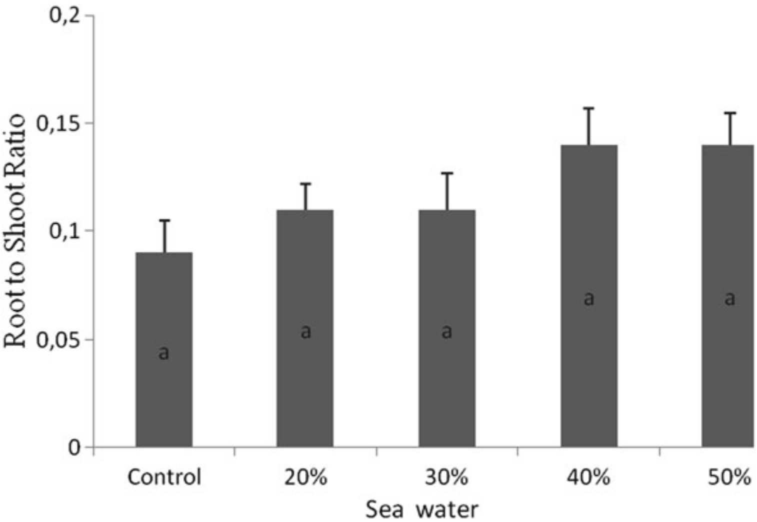

Fig. 32.4 Root-to-shoot ratio (*R*/*S*) of *C. quinoa* irrigated with control and different seawater concentrations (20, 30, 40 and 50%). Values with the same letter do not differ significantly at $p < 0.05$

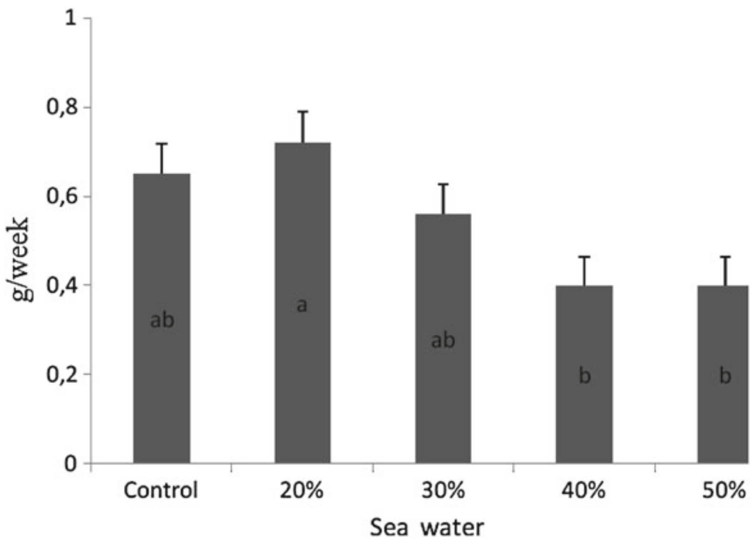

Fig. 32.5 Relative growth rate (*RGR*) of *C. quinoa* irrigated with control and different seawater concentrations (20, 30, 40 and 50%). Values with the same letter do not differ significantly at $p < 0.05$

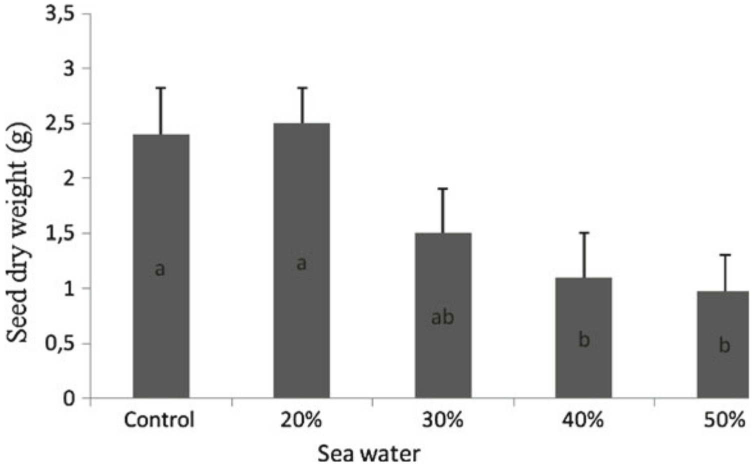

Fig. 32.6 Seed productivity of *C. quinoa* expressed by dry weight irrigated with control and different seawater concentrations (20, 30, 40 and 50%). Values with the same letter do not differ significantly at $p<0.05$

with increasing salinity in the culture medium. Jacobson et al. (2000) found that the highest seed yield for *quinoa* was obtained at an EC of 15 dS m^{-1} and at ECs higher than 15 dS m^{-1}, yield began to decrease.

32.3.3 Ionic Composition

Na^+ is the most absorbed ion by the plant, its concentration increased in parallel with the increase in seawater concentration (Fig. 32.7). The rate of Na^+ was higher in leaves compared to roots at 20, 30 and 40% seawater treatments, whereas at 50% seawater treatment, there was a significant accumulation of Na^+ in the roots compared to leaves. Jacobson et al. (2000) reported that *C. quinoa* is capable of accumulating inorganic ions in its tissues to regulate leaf water potential. This enables it to maintain cell turgor. Koyro et al. (2008) argued that one reason for *C. quinoa* survival in saline environments is the adjustment of its leaf water potential which is achieved partly by an accumulation of Na^+ and sucrose in roots and leaves. Na^+ concentration affects K^+ and Ca^{2+} absorption, which were in low concentrations compared to Na^+, although the K^+ concentration increased with the increase in salinity, probably attributed to the fact that seawater contains high amounts of K^+. Salinity disturbs nutritional balance of plants by the interactions between different ions and the selectivity in absorption sites at membrane level (Zhang et al. 2005). The Na^+ ion uptake by the plant limits the absorption of essential ions such as K^+ and Ca^{2+} (Jendoubi 1997). The assimilation of Mg^{2+} was not affected by increasing salinity, because its concentration did not show any significant differences between different treatments (Fig. 32.7). There were high concentrations of K^+ and Mg^{2+} in *quinoa* seeds, while Ca^{2+} decreased with the increase of salinity (Fig. 32.7). The concentration of Na^+ remained lower compared to that of K^+. These results are close to those obtained by Koyro and Hamdy (2008). Indeed, they found that at high salinity, the passage of the NaCl inside the seed was hindered by the seed cover. They also found that K^+ was located in all tissues of the seed whereas Na^+ was located mainly in the pericarp.

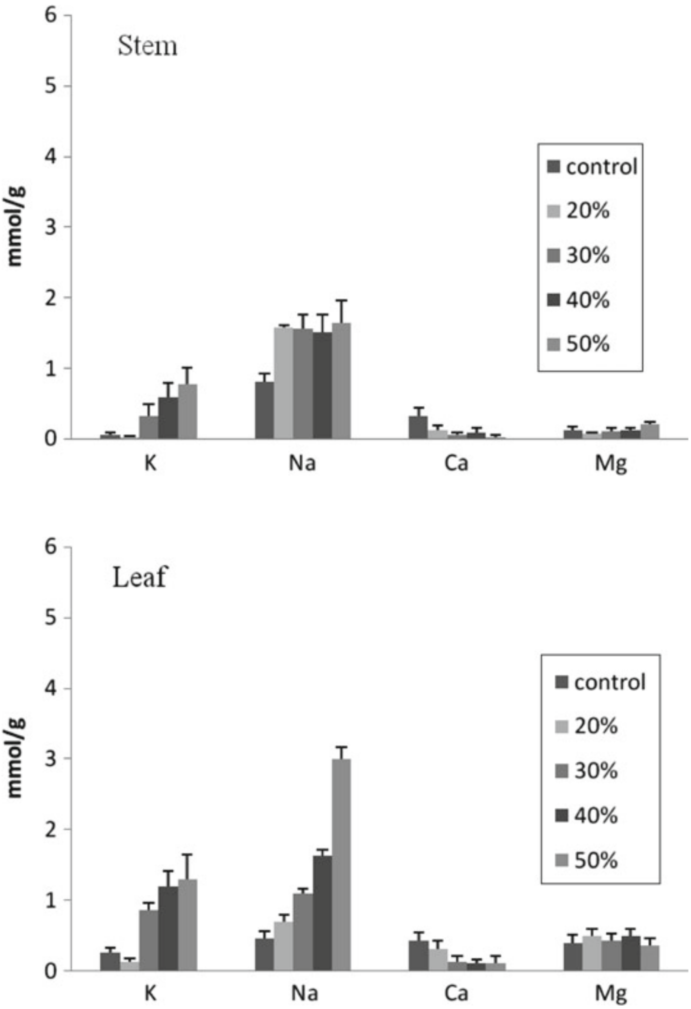

Fig. 32.7 Effect of salinity on Na^+, K^+, Ca^{2+} and Mg^{2+} concentration in mmol g^{-1} of dry weight in the stems, leaves, roots and seeds of *C. quinoa* irrigated with control and four seawater concentrations (20, 30, 40 and 50%)

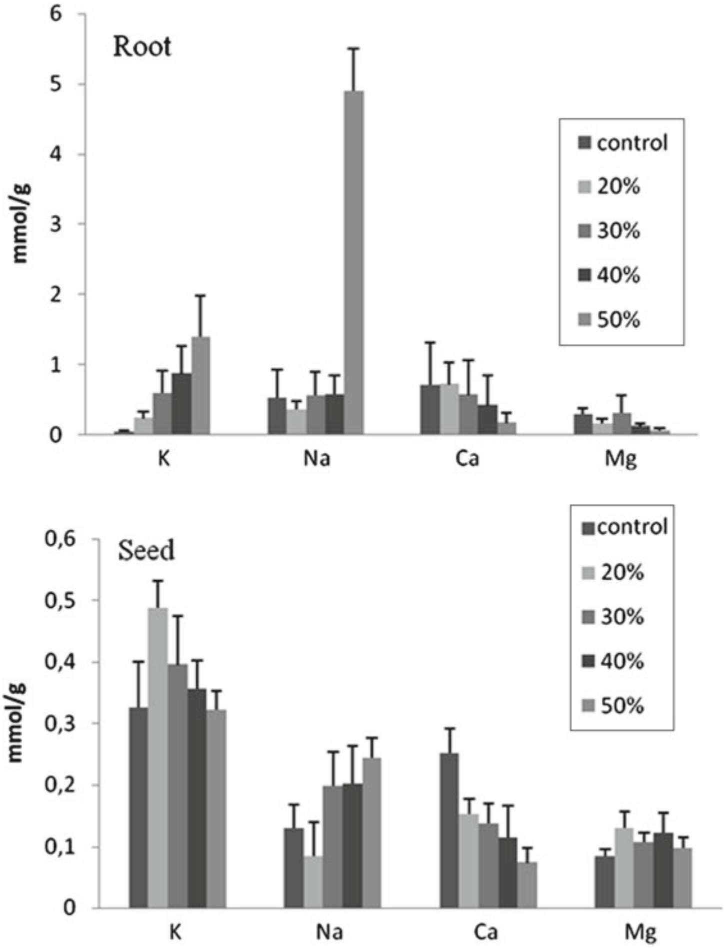

Fig. 32.7 (continued)

32.4 Conclusion

The germination of *Chenopodium quinoa* was not affected by low salinity. The rate of germination under 75 and 100 mM NaCl remained comparable to the control. However the coefficient of velocity was reduced even at low salinity. It started to decrease at 75 mM NaCl, corresponding to 15% seawater concentration.

C. quinoa was able to complete its life cycle at high salt concentrations. Growth was stimulated by moderate salinity (20% seawater) and decreased at high salinity (50% seawater). The threshold salinity tolerance was observed in 30% seawater. Salinity tolerance in *C. quinoa* is attributed to the balance between sodium and potassium but also to calcium uptake, which reduces the effect of salt. *C. quinoa* is a seed-producing plant. This production was stimulated by the presence of salt in the culture medium; it was optimal in 20% seawater. The use of plants that are resistant to excessive salt concentration in the culture medium is an option for the management of land affected by salt. Indeed, *C. quinoa* can be used as an alternative crop since *quinoa* seeds are rich in minerals, amino acids and proteins compared to wheat (Benlhabib 2005). Given the importance of *C. quinoa* as a crop plant, it is planned to carry out more investigations to study the effect of salinity on proline and protein contents of its seeds and undertake its culture under natural conditions (fields affected by salinity) in order to determine the feasibility of its use as an alternative to cereal crops in areas affected by salinity in Morocco.

References

Benlhabib O (2005) Bulletin mensuel d'information et de liaison du PNTTA. Transfert de technologie en Agricultiure. No. 133

Choukr-Allah R, Harrouni MC (1996) The potential use of halophytes under saline irrigation in Morocco. In: Symposium on the conservation of mangle ecosystems, Al-Ain, United Arab Emirates, 15–17 Dec 1996

Daoud S (2004) Effet de l'irrigation à l'eau de mer sur les paramètres agronomiques et physiologiques de quelques espèces halophytes. Doctorate thesis, Faculty of Sciences, University Ibn Tofail, Kenitra, Morocco, pp 4–28

El Iklil Y (2001) Identification de critères agro-physiologiques et biochimiques de la tolérance à la salinité chez la tomate. Doctorate thesis, Faculty of Sciences Semlalia, University Cadi Ayyad, Marrakech, Morocco, pp 21–23

Epstein E (1972) Mineral nutrition of plants: principles and perspectives. Wiley, New York

Geerts S (2008) Deficit irrigation strategies via crop water productivity modeling: field research of quinoa in the Bolivian Altiplano. PhD thesis submitted to the Faculty of Bioscience Engineering of the University Leuven , pp 27–33

Ghadiri H, Bagherani TN (2000) Effects of scarification and temperature on germination of Licorice (*Glycyrrhiza glabra* L.) Seeds. J Agric Sci Technol 2:257–262

Gooding JR, Mckell CM, O'Leary JW (1990) Introduction in "saline agriculture, salt-tolerant plants for developing countries". National Academy Press, Washington, DC, pp 1–9

Jacobson SE, Monteros C, Christiansen JL, Mujica A (2000) Agronomic and physiological response of quinoa (*Chenopodium quinoa* Willd) to frost at three phonological stages. European Cooperation in the field of scientific and technical research (Commision E ed), Bruxelles, pp 541–546

Jendoubi S (1997) Contribution à la caractérisation physiologique et biochimique de parois racinaires chez 2 espèces de blé: *Triticum durum* (Ben Béchir) et *Triticum aestivum* (Tani) cultivées en milieu salin. DEA de la Faculté des Sciences de Tunis, Tunis, p 86

Kinzel H (1982) Planzenökologie und mineralstoffwechsel. Verlag Eugen Ulmer, Stuttgart, p 534

Koyro HW (1999) Protocol for the installation of an improved quick check system in the IAV Hassan II (Agadir, Morocco). Third report: Sustainable Halophyte Utilisation in the Mediterranean and subtropical dry regions.

Koyro HW, Hamdy A (2008) Effect of salinity on composition, viability and germination of seeds of Chenopodium quinoa Willd. Plant Soil 302:79–90

Koyro HW, Eaisa SS, Leith H (2008) Salt tolerance of chenopodium quinoa willd. grains of the Andes: Influence of salinity on biomass production, yield, composition of reserves in the seeds, water and solute relations. In: Lieth H et al (eds) Mangroves and halophytes: restoration and utilisation. Springer, Dordrecht, pp 133–145

Munns R, Termatt A (1986) Whole plant responses to salinity. Aust J Plant Physiol 13:143–160

Munter CR (1980) Preparation of plant material: research analytical laboratory. University of Minnesota, St. Paul

O'Leary JW, Glenn EP (1984) New crop opportunities from halophytes. In: University of Arizona, Annual meeting, New York, 24–29 May 1984, pp 1–19

Scott SJ, Jones RA, Williams WA (1984) Review of data analysis methods for seed germination. Crop Sci 24:1192–1199

Shahabaz A, Nosratik K, Zehtabiane GR (2005) Investigation of seed germination characteristics and recovery of germination in the *Haloxylon Aphyllum* under different temperatures and salinity condition. BIABAN J 10(1–1):29–35

Ungar IA, Khan MA (2001) Effect of bracteoles on seed germination and dispersal of two species of Atriplex. Ann Bot 87:233–239

Zhang ZH, Tang C, Rengel Z (2005) Salt dynamics in rhizosphere of Puccinellia ciliata Bor. in a loamy soil. Pedosphere 15:784–791

Chapter 33
Inducing Pea Plants for Conquering the Adverse Conditions of Saline Reclaimed Soils with Some Support Application

Mostafa M. Rady

Abstract The possibility of inducing pea plants for better growth and yield in reclaimed soil with ECe (7.9 dS m^{-1}) was investigated in a private farm in Fayoum, Egypt. The experiments were conducted during the two successive seasons of 2007/2008 and 2008/2009 using a soil classified at the family level as Typic Torriorthents, fine-loamy, mixed, and hyperthermic. The calcium paste-treated pea seeds were sown in beds fecundated with ground sunflower heads; the plants were sprayed with ascorbic acid at the rates of 100, 200, 300, and 400 mg L^{-1}. Significant positive influences of calcium paste plus ground sunflower heads applied solely or in combination with all ascorbic acid treatments were observed on growth traits (plant height, number of branches $plant^{-1}$, and shoot dry weight $plant^{-1}$), some chemical components (leaf pigments, some photosynthates, Ca, Na, and Ca/Na ratio), and green yield of pods and seeds. As for ascorbic acid foliar application, all studied rates revealed significant increase in all aforementioned parameters with superiority of 300 mg L^{-1} rate as compared to the control (water application). It has been concluded that spraying pea plants "cv. Master-B," produced from calcium paste-treated seeds sown in beds fecundated with ground sunflower heads, with ascorbic acid at the rate of 300 mg L^{-1} proved to be the best combined treatment and may overcome the adverse conditions of newly reclaimed soils particularly ECe of 7.9 dS m^{-1}, and consequently, economic green yield of pods and seeds is obtainable.

Keywords ECe • Egypt • Peas • Reclaimed soil • Saline soils

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33.1 Introduction

Pea (*Pisum sativum* L.) is one of the popular vegetable crops in Egypt. It is commonly cultivated as winter crop for local consumption, processing, and exportation due to its high food value. Besides the trials for improving pea productivity in soils under pea cultivation since long time, it is important to grow pea to improve the growth and yield in newly reclaimed soils. Pea is classified as a salt-sensitive vegetable crop (Pasternak 1987). Nevertheless, it is an important crop in newly reclaimed areas in Egypt where much of the soils are saline. Egypt is one of the countries that have been highly affected by salinity and a large area of agricultural lands is now rated as unproductive as a result of salinity. In Fayoum governorate, vast area of lands becomes infertile and unsuitable for crop productivity because of soil salinization (Hans and Kevin 1992). Saline conditions disrupt several physiological processes in plants leading to a general reduction in growth and yield (El-Saidi 1997; Greenway and Munns 1980). The drastic influence of salinity on plant growth and metabolism was attributed, principally, to the enhanced Na^+ uptake which causes ion excess in plant tissues (Abbas et al. 1991) besides the inhibition of K^+, Ca^{2+}, and NO_3^- uptake by plant roots (Maas 1986). In addition, it is well established that salinity stress damages plant cells through production of reactive oxygen species including superoxide, hydrogen peroxide, hydroxyl anions, and singlet oxygen (Scandalios 1997). Efforts have been made to control salinity and sodicity by technological means, such as reclamation, drainage, use of high leaching fractions, and application of soil amendments (Abdel-Naby et al. 2001). On the other hand, some trials have been made to alleviate the disturbances in plant metabolism excreted by salinity stress. It has been suggested that ascorbic acid is one of natural and safe substances that may help to overcome some of these inhibitory effects (Rady 2006). Ascorbic acid is an important antioxidant defense in plant cells (Foyer and Halliwell 1976) to protect them by scavenging the reactive oxygen species. It also stimulates respiration activities, cell division, and many enzyme activities (Rautenkranz et al. 1994). It has synergistic effects on growth, yield, and chemical composition of several crops under favorable and unfavorable environmental conditions, i.e., salinity (Ahmed et al. 2002, 2003; Mostafa 2004; Rady 2006). It has also been suggested that calcium is an important factor in the maintenance of membrane integrity and ion-transport regulation. It is essential for K^+/Na^+ selectivity and membrane integrity (Epstein 1961; Hanson 1984). Elevated Ca^{2+} concentrations in the nutrient solution mitigated the adverse effects of salinity by inhibition of Na^+ uptake (Greenway and Munns 1980) and reduction in leakage of membranes (Leopold and Willing 1984). LaHaye and Epstein (1969) clearly postulated that the Ca^{2+}/Na^+ interaction takes place at the plasmalemma. They suggested that Na^+ acted by displacing Ca^{2+} from membranes, leading to increased membrane permeability and intracellular Na^+ concentrations.

The present study was conducted to see the influence of seed treatment by calcium paste plus fecundating their beds with ground sunflower heads and ascorbic acid foliar application on the growth of produced plants, green yield of pods and seeds, and some chemical constituents of pea plants grown under saline reclaimed soil conditions.

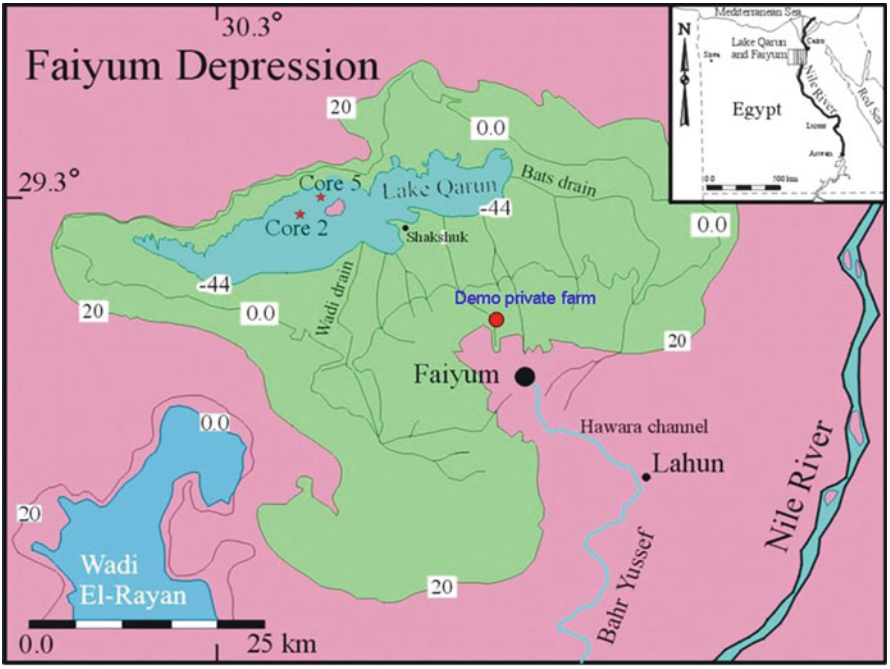

Fig. 33.1 Site location map of experimental site (*red dot*)

33.2 Materials and Methods

During the two successive winter seasons of 2007/2008 and 2008/2009 (November 15, 2007 and 2008) using the same experimental site, a field trial was carried out at a private farm (reclaimed soil 5 years ago) in Fayoum (Fig. 33.1), Egypt, using pea seeds "cv. Master-B" obtained from agricultural research center in Giza, Egypt. Before sowing, soil samples to 25 cm depth from the experimental site were collected and analyzed by the standard procedures of Jackson (1967). Results of the soil samples analysis are presented in Table 33.1. According to the USDA soil taxonomy (USDA-NRCS 1999, 2010), the soil of the study area is classified at the family level as Typic Torriorthents, fine-loamy, mixed, and hyperthermic. A seasonal total of 200, 200 and 100-kg feddan^{-1} calcium superphosphate (15.5% P_2O_5), ammonium sulfate (20.5% N) and potassium sulfate (48% K_2O), respectively, were applied as recommended dose. All amounts of fertilizers were broadcasted and incorporated during the soil preparation for planting. Irrigation was accomplished with a 2-week interval using the Nile water. Other recommended cultural practices for growing pea plants were followed. Treatments comprised ascorbic acid rates of 100, 200, 300, and 400 mg L^{-1} besides water application as a control of submain treatments. These treatments were applied alone or in combination with calcium paste-treated seeds sown in beds fecundated with ground sunflower heads.

Table 33.1 Physical and chemical characteristics of the selected site in both 2007/2008 and 2008/2009 seasons

Soil characteristics	2007/2008	2008/2009
Physical		
Clay %	29.75	29.15
Silt %	20.05	20.45
Sand %	50.20	50.40
Soil texture	Sandy clay loam	Sandy clay loam
Chemical		
pH (1:2.5)	7.85	7.69
ECe (dS m^{-1})	7.89	7.78
Organic matter %	1.19	1.23
$CaCO_3$%	8.14	8.06
Total *N*%	0.074	0.071
Available nutrients (mg kg^{-1} soil)		
K	71.25	69.70
P	18.07	18.65
Fe	6.14	6.00
Mn	4.69	5.04
Zn	1.05	0.96
Cu	1.63	1.70

33.2.1 Calcium Paste and Seed Treatment as a Novel Strategy

Calcium nitrate was mixed with wheat bran at the ratio of 1:2 by weight. The wheat bran (a by-product of wheat grains) and calcium nitrate were kneaded together by using Arabic Gum solution (8%) as a sticking agent to obtain paste of calcium to stick around seeds for a long time. Before sowing, pea seeds were well covered with calcium paste and allowed to dry.

33.2.2 Fecundating the Seedbeds with Ground Sunflower Heads as a Novel Strategy

Air-dried sunflower heads (a by-product of sunflower crop) were washed with tap water and dried in forced-air oven at 70°C for 48 h; these were then ground in high-speed laboratory grinding mill (The Straub Company Model 4E Grinding Mill) and passed through 2.5-mm sieve. The ground sunflower heads were added at the amount of palm filled into each seedbed along with sowing to surround the seeds as a water retainment agent in the rhizosphere.

Table 33.2 Some characteristics of wheat bran and ground sunflower heads used in the experiment

Characteristics	Wheat bran	Ground sunflower heads
Moisture %	4.50	10.80
Ash %	5.20	15.36
Total fibers %	35.30	39.10
Water holding capacity (g/g)	3.30	7.70

The values are mean of the two seasons analyses

33.2.3 Ascorbic Acid Application

Ascorbic acid at mentioned concentrations was sprayed two times (25 and 40 days after sowing) on the shoots of plants. Half ml of Tween 20 was added to the treatment solution as a wetting agent.

33.2.4 Analysis of Wheat Bran and Ground Sunflower Heads

Wheat bran and ground sunflower heads were analyzed for important analysis (Table 33.2) as outlined by AOAC (1995). Moisture content was estimated by oven drying the contents for 3 h at 105°C. Ash contents were determined by ashing in muffle furnace at 550°C for 6 h. Total fibers (%) were determined by an enzymatic gravimetric method as described by Prosky et al. (1988), and water holding capacity was measured as outlined by Eastwood (1973).

33.2.5 Experimental Design

The split-plot experimental design was used with four replicates. The main plots were calcium paste-treated seeds sown in beds fecundated with ground sunflower heads or untreated seeds and their beds, and ascorbic acid treatment was occupied the submain plots. Each experimental unit consisted of five rows 3 m long and 70 cm width, within row spacing 20 cm apart.

Treatments were as follows:

*T*1 = Seeds were not coated with calcium paste and sown in beds without ground sunflower heads + produced plants were not sprayed with ascorbic acid.

*T*2 = Seeds were not coated with calcium paste and sown in beds without ground sunflower heads + produced plants were sprayed with 100 mg L^{-1} ascorbic acid.

*T*3 = Seeds were not coated with calcium paste and sown in beds without ground sunflower heads + produced plants were sprayed with 200 mg L^{-1} ascorbic acid.

*T*4 = Seeds were not coated with calcium paste and sown in beds without ground sunflower heads + produced plants were sprayed with 300 mg L^{-1} ascorbic acid.
*T*5 = Seeds were not coated with calcium paste and sown in beds without ground sunflower heads + produced plants were sprayed with 400 mg L^{-1} ascorbic acid.
*T*6 = Seeds coated with calcium paste and sown in beds fecundated with ground sunflower heads + produced plants were not sprayed with ascorbic acid.
*T*7 = Seeds coated with calcium paste and sown in beds fecundated with ground sunflower heads + produced plants were sprayed with 100 mg L^{-1} ascorbic acid.
*T*8 = Seeds coated with calcium paste and sown in beds fecundated with ground sunflower heads + produced plants were sprayed with 200 mg L^{-1} ascorbic acid.
*T*9 = Seeds coated with calcium paste and sown in beds fecundated with ground sunflower heads + produced plants were sprayed with 300 mg L^{-1} ascorbic acid.
*T*10 = Seeds coated with calcium paste and sown in beds fecundated with ground sunflower heads + produced plants were sprayed with 400 mg L^{-1} ascorbic acid.

33.2.6 Recorded Determinations

33.2.6.1 Vegetative Growth Traits

Sixty days after sowing, four plants were randomly chosen from each experimental unit and cut off at ground level to obtain plant height (cm), number of branches plant^{-1}, and shoot dry weight plant^{-1} (g).

33.2.6.2 Green Yield of Pods and Seeds

The marketable green pods were harvested from all experimental units to determine the green pod yield feddan^{-1} (tonnes). The seeds were then separated from 30-kg pods as a representative sample of each experimental unit to determine the green seed yield feddan^{-1} (tonnes).

33.2.6.3 Chemical Constituents

Shoots of six randomly selected plants were collected on January 15, in both growing seasons from each experimental unit to determine chemical constituents. Total chlorophyll and total carotenoids were extracted from fresh leaves by acetone (80%) then determined (mg g^{-1}) using colorimetric method as described by Arnon (1949). Total phenols were extracted from fresh shoots using 80% ethanol and colorimetrically determined (mg g^{-1}) using Folin-Denis reagent by the method of Snell and Snell (1953). Ascorbic acid was determined (mg g^{-1}) using the dye 2,6-dichlorophenolindophenol method as outlined by AOAC (1995) in fresh shoots. Using dry matter of shoots, following parameters were determined. Total soluble sugars (mg g^{-1}) were colorimetrically determined using phosphomolybdic acid reagent according to Dubois et al. (1956). Free proline was extracted by 5-sulphosalicylic acid (3%) then determined colorimetrically (mg g^{-1}) using acid ninhydrin reagent as outlined by Bates et al. (1973). Wet digestion of 0.1 g of fine dry material of shoots from each treatment was made with mixture of sulfuric and perchloric acids to determine Ca and Na using Piper (1947) method. Calcium (%) was determined using a Perkin-Elmer, Model 3300, atomic absorption spectrophotometer (Chapman and Pratt, 1961). Sodium (%) was determined using a Perkin-Elmer flame photometer (Page et al. 1982).

33.2.7 Statistical Analysis

Due to the corresponding trend, means of all parameters obtained from both seasons (2007/2008 and 2008/2009) were subjected to analysis of variance. The LSD at 0.05 was used to differentiate means according to Snedecor and Cochran (1980).

33.3 Results and Discussion

33.3.1 Vegetative Growth Traits

Table 33.3 illustrates that plant height, number of branches plant^{-1}, and shoot dry weight significantly increased by 24.1, 57.5, and 60.2%, respectively, when seeds were treated with calcium paste and sown in beds fecundated with ground sunflower heads compared with untreated seeds and their beds. These improving effects seem to be due to Ca^{2+} that may have reduced the effects of salinity on seeds and consequent positive effect on the germination and emergence rates. In addition, it has been explained in a way that root hairs of plants were able to maintain higher levels of membrane-associated Ca^{2+} when exposed to high concentrations of NaCl (Cramer et al. 1985). In fact, it is essential to have Ca^{+} for selective permeability, i.e., membrane integrity (Poovaiah and Reddy 1993), to help in improving the growth traits. Furthermore, ground sunflower heads of seedbeds are able to maintain soil moisture (Table 33.2) in the rhizosphere and consequently diluted the salinity around plant roots. Increase of Ca/Na ratio (Table 33.6) induced by calcium paste of seeds and ground sunflower heads of seedbeds led to the significant increase in the studied growth traits.

All submain treatments, such as ascorbic acid at the rates of 100, 200, 300, and 400 mg L^{-1} (Table 33.3), reveal a gradual significant increase in all studied growth traits, i.e., plant height, number of branches plant^{-1}, and shoot dry weight plant^{-1}; such increase was observed as a result of raising the ascorbic acid rate gradually up to 300 mg L^{-1}. Ascorbic acid at the rate of 400 mg L^{-1} slightly decreased the same

Table 33.3 Influence of calcium paste, ground sunflower heads, and ascorbic acid on some growth traits of pea plants under saline reclaimed soil conditions in both 2007/2008 and 2008/2009 seasons

	0 Ca^{+2}	+Ca^{+2}	Mean *B*	0 Ca^{+2}	+Ca^{+2}	Mean *B*	0 Ca^{+2}	+Ca^{+2}	Mean *B*
Ascorbic acid (mg L^{-1})	Plant height (cm)			Number of branches $plant^{-1}$			Dry weight of shoot $plant^{-1}$ (g)		
0	29.8	39.1	34.5	1.16	2.00	1.58	6.15	10.12	8.14
100	34.1	45.8	40.0	1.34	2.30	1.82	7.08	11.90	9.49
200	39.8	50.6	45.2	1.51	2.58	2.05	8.15	13.75	10.95
300	51.0	59.8	55.4	2.01	2.86	2.44	10.07	15.32	12.70
400	50.8	59.6	55.2	2.00	2.86	2.43	10.02	15.30	12.66
Mean *A*	41.1	51.0		1.60	2.52		8.29	13.28	
$LSD_{0.05}$ *A*	7.4			0.35			1.63		
B	4.2			0.20			0.93		
A×*B*	12.6			0.60			2.79		

+Ca = Seeds covered with calcium paste and sown in beds fecundated with ground sunflower heads
0 Ca = Seeds without calcium paste and sown in beds without ground sunflower heads

Table 33.4 Influence of calcium paste, ground sunflower heads, and ascorbic acid on leaf pigments and shoot ascorbic acid of pea plants under saline reclaimed soil conditions in both 2007/2008 and 2008/2009 seasons

	0 Ca^{+2}	+Ca^{+2}	Mean *B*	0 Ca^{+2}	+Ca^{+2}	Mean *B*	0 Ca^{+2}	+Ca^{+2}	Mean *B*
Ascorbic acid (mg L^{-1})	Total chlorophyll (mg g^{-1} fresh weight)			Total carotenoids (mg g^{-1} fresh weight)			Ascorbic acid (mg g^{-1} fresh weight)		
0	0.84	1.39	1.12	0.34	0.42	0.38	0.75	1.54	1.15
100	0.89	1.49	1.19	0.38	0.46	0.42	0.80	1.70	1.25
200	0.96	1.69	1.33	0.43	0.55	0.49	0.87	1.96	1.42
300	1.20	1.93	1.57	0.51	0.63	0.57	1.11	2.46	1.79
400	1.19	1.91	1.55	0.50	0.62	0.56	1.10	2.44	1.77
Mean *A*	1.02	1.68		0.43	0.54		0.93	2.02	
$LSD_{0.05}$ *A*	0.12			0.07			0.16		
B	0.07			0.04			0.09		
A×*B*	0.21			0.12			0.27		

+Ca = Seeds covered with calcium paste and sown in beds fecundated with ground sunflower heads
0 Ca = Seeds without calcium paste and sown in beds without ground sunflower heads

traits as compared with the rate of 300 mg L^{-1} which recorded super results that surpassed the results of water foliar spray by 60.6, 54.4, and 56.0% for plant height, number of branches $plant^{-1}$, and shoot dry weight $plant^{-1}$, respectively. These results indicate that the most pronounced counteracted effects of studied soil salinity, i.e., 5,000 ppm (ECe 7.8 dS m^{-1}), on the growth traits were overcame by the exogenous application of ascorbic acid which led to the increase in endogenous level of this antioxidant (Table 33.4) which may protect plant cells including the protection of

Table 33.5 Influence of calcium paste, ground sunflower heads, and ascorbic acid on some shoot photosynthates of pea plants under saline reclaimed soil conditions in both 2007/2008 and 2008/2009 seasons

	$0\ Ca^{+2}$	$+Ca^{+2}$	Mean *B*	$0\ Ca^{+2}$	$+Ca^{+2}$	Mean *B*	$0\ Ca^{+2}$	$+Ca^{+2}$	Mean *B*
Ascorbic acid (mg L^{-1})	Free proline (mg g^{-1} dry matter)			Total soluble sugars (mg g^{-1} dry matter)			Total soluble phenols (mg g^{-1} fresh matter)		
0	0.17	0.21	0.19	20.5	24.2	22.4	0.88	1.04	0.96
100	0.20	0.24	0.22	24.2	28.6	26.4	0.98	1.14	1.06
200	0.23	0.29	0.26	28.3	32.0	30.2	1.15	1.30	1.23
300	0.29	0.34	0.32	33.1	37.6	35.4	1.34	1.50	1.42
400	0.29	0.33	0.31	33.0	37.4	35.2	1.33	1.50	1.42
Mean *A*	0.24	0.28		27.8	32.0		1.14	1.30	
$LSD_{0.05}$ *A*	0.04			4.3			0.12		
B	0.02			2.5			0.07		
$A \times B$	0.06			7.5			0.21		

+Ca = Seeds covered with calcium paste and sown in beds fecundated with ground sunflower heads
0 Ca = Seeds without calcium paste and sown in beds without ground sunflower heads

photosynthetic apparatus by scavenging reactive oxygen species (Zhang and Schmidt 2000); thus, vigorous plant growth will be obtained under salinity stress. In this connection, Prusky (1988) and Elade (1992) stated a positive action of antioxidants especially ascorbic acid on growth and attributed this finding to their auxinic action and their effects on counteracting drought, salinity, and diseases stresses and protecting plant cells against free radicals that are responsible for plant senescence. In addition, ascorbic acid might regulate cell wall expansion, cell division, and cell elongation through its action in cell vacuolization (Arrigoni 1994; Navas and Gomez-Diaz 1995 and Cordoba-Pedregosa et al. 1996) and improve absorption of phenolic compounds which lead to save the growing tissues from toxic effects of the oxidized phenols (Gupta et al. 1980) and/or enhance the biosynthesis of soluble sugars (Table 33.5) and carbohydrates (Rady 2006). These findings are in coincidence with those obtained by Ahmed et al. (1998, 2003), Ragab (2002), Mostafa (2004), and Rady (2006).

The effect of the interactions between the main treatments (untreated seeds and their beds or treated seeds and their beds with calcium paste and ground sunflower heads, orderly) and submain treatments (ascorbic acid foliar application) was significant. The highest values of plant height, number of branches plant^{-1}, and shoot dry weight plant^{-1} were obtained from the combined treatment of 300 mg L^{-1} ascorbic acid under calcium paste-treated seeds sown in beds fecundated with ground sunflower heads recorded 52.9, 43.0, and 51.4% increases, respectively, more than the combined treatment of water spray under calcium paste-treated seeds sown in beds fecundated with ground sunflower heads and scored 100.7, 146.6, and 149.1% increases above the combined treatment of water application under untreated seeds and their beds. The superiority of the treatment having the highest values might come from improving the Ca^{2+} content of plants to take away Na^{+}; thus, the shortage of Na^{+} (Table 33.6) and the increase in total soluble sugars

Table 33.6 Influence of calcium paste, ground sunflower heads, and ascorbic acid on shoot calcium, sodium, and Ca/Na ratio of pea plants under saline reclaimed soil conditions in both 2007/2008 and 2008/2009 seasons

Ascorbic acid ($mg\ L^{-1}$)	0 Ca^{+2}	+Ca^{+2}	Mean *B*	0 Ca^{+2}	+Ca^{+2}	Mean *B*	0 Ca^{+2}	+Ca^{+2}	Mean *B*
	Ca (% dry weight)			Na (% dry weight)			Ca/Na ratio		
0	0.19	0.45	0.32	0.41	0.29	0.35	0.46	1.55	1.01
100	0.25	0.49	0.37	0.36	0.26	0.31	0.69	1.88	1.29
200	0.30	0.58	0.44	0.32	0.22	0.27	0.94	2.64	1.79
300	0.35	0.65	0.50	0.28	0.16	0.22	1.25	4.06	2.66
400	0.33	0.64	0.49	0.28	0.17	0.23	1.18	3.76	2.47
Mean *A*	0.28	0.56		0.33	0.22		0.90	2.78	
$LSD_{0.05}$ *A*	0.07			0.05			0.37		
B	0.04			0.03			0.21		
A × *B*	0.12			0.08			0.63		

+Ca = Seeds covered with calcium paste and sown in beds fecundated with ground sunflower heads
0 Ca = Seeds without calcium paste and sown in beds without ground sunflower heads

and proline (Table 33.5) saved more osmotic solutes which enabled plant cells to maintain more water against salinity. The water-imbibing properties of ground sunflower heads and wheat bran fibers (Schneeman 1986) and their ability to absorb water and/or organic compound (Mongeau and Brassard 1982) have supported the rhizosphere by water to cope the effect of drought, salinity, and acidity to facilitate more solubility and absorption of nutrients. As for ascorbic acid, Wise and Naylor (1987) stated that antioxidants such as ascorbate, glutathione, and α-tocopherol are directly correlated with the ability to defend plant cells against oxidative damage resulting from salinity stress and consequently producing healthy plants having better growth traits.

33.3.2 *Chemical Constituents*

33.3.2.1 Leaf Pigments and Shoot Photosynthates

Tables 33.4 and 33.5 reveal that leaf total chlorophyll and total carotenoids as well as shoot ascorbic acid, free proline, total soluble sugars, and total soluble phenols were significantly increased in the order of 64.7, 25.6, 117.2, 16.7, 15.1, and 14.0%, respectively, as a result of treating the seeds with calcium paste plus fecundating their beds with ground sunflower heads as compared with untreated seeds and their beds. These pronounced increments may be due to the increase in ascorbic acid in plant shoots (Table 33.4), which has an auxinic actions and also synergistic effects on biosynthesis of sugars and carbohydrates (Al-Qubaie 2002). The increase in phenols of plant shoots (Table 33.5) resulted due to the increase in ascorbic acid as an antioxidant, thus a linear relationship between ascorbic acid and total phenol concentration in plant shoots has been found. In addition, the effective role of Ca^{2+} and ground sunflower heads in inhibiting Na^+ effects and more water retention in rhizosphere.

The influence of ascorbic acid on the total chlorophyll, total carotenoids, ascorbic acid, free proline, total soluble sugars, and total soluble phenols concentrations in plant leaves or shoots (Tables 33.4 and 33.5) exhibits all parameters gradually increased by significant quantities as a result of foliar application with ascorbic acid up to 300 mg L^{-1} then negligibly decreased. The proportions of 40.2, 50.0 55.7, 68.4, 58.0, and 47.9% for aforementioned parameters, respectively, were the increments of the best treatment, spraying the plant shoots with ascorbic acid at the rate of 300 mg L^{-1} as compared with water foliar spray. The enhanced effect of ascorbic acid on chlorophyll, carotenoids, and the other components might be attributed to the enhancing effects of this antioxidant on the Ca/Na ratio of plant shoots, and its role which is directly involved in the regulation and protection of photosynthetic processes (Farago and Brunhold 1994) could be led to the enhancing effect on pigments and other components under study. This super treatment which showed the highest values of the components under study bestowed the tested plants the ability to satisfactorily overcome soil salinity under study in respect to their containing sufficient amounts of soluble sugars, proline, and soluble phenols (Table 33.5) which form sufficient cellular solutes able for sustenance of cell turgor leading to maintenance of metabolic activities in plant cells and/or protect plants against adverse condition, i.e., drought and salinity of such soil under study. The enhancing effect of ascorbic acid on tested soluble sugars might be attributed to its promotive effect also on the studied pigments (Table 33.4) leading to the enhancement of photosynthesis and, consequently, the increase in photosynthates. The positive effects of ascorbic acid on above-mentioned parameters obtained are in agreement with those obtained by Tarraf et al. (1999), Ali (2002), Ahmed et al. (2003), and Rady (2006).

Tables 33.4 and 33.5 reveal that the combined treatment of calcium paste-treated seeds sown in ground sunflower head-fecundated beds and spraying plant shoots with ascorbic acid at 300 mg L^{-1} preferable to all other combinations granted the increases 38.8, 50.0, 59.7, 61.9, 55.4, and 44.2% for total chlorophyll, total carotenoids, ascorbic acid, free proline, total soluble sugars, and total soluble phenols, respectively, as compared to calcium paste-treated seeds plus ground sunflower head-fecundated seedbeds interacted with foliar spray with water; however, when compared with the combined treatment of water foliar spray under untreated seeds and their beds, it scored increments at 129.8, 85.3, 228.0, 100.0, 83.4, and 70.5% for the same components, respectively. These significant increases may be scored as a result of the application with Ca^{2+}, ground sunflower heads as a fibrous source having high water holding capacity, and ascorbic acid. Calcium may reduce the harmful effects of salinity by taking the place of Na^+ in rhizosphere and may be on membranes in the absorbing roots. The ground sunflower heads save more water to overcome drought caused by salinity in the soil. The ascorbic acid as one of the antioxidants prevents enzyme inactivation, prevents the generation of more dangerous radicals, and allows flexibility in the production of photosynthetic assimilatory power. Moreover, electron transfer to O_2 prevented overreduction of electron transport chain which reduced the risk of harmful back reaction within the photosystem (Foyer et al. 1990). In addition, Elade (1992) and Farag (1996) proved that most antioxidants were responsible for accelerating the biosynthesis of various pigments and consequently more photosynthesis produces more quantities of photosynthates. Besides, Shahidi and Wanasundara (1992) stated that phenolic antioxidants play important roles as free-radical terminators and, sometimes, as metal chelators.

33.3.2.2 Calcium, Sodium, and Ca/Na Ratio

Table 33.6 states that Ca and Ca/Na ratio significantly increased with the treatment of calcium paste-treated seeds plus ground sunflower head-fecundated seedbeds compared with other treatments in which seeds and their beds were free from calcium paste and ground sunflower heads. These increases were recorded at 100.0 and 208.9%, respectively. On the other side, Na represents reversed behavior that is decreased with increasing Ca and Ca/Na ratio at 33.3% in plant shoots. The shortage occurred in Na^+ and the increase in Ca^{2+}; the increase in Ca/Na ratio under this study besides the high water retention capacity of ground sunflower heads and wheat bran (Table 33.6) has supported these results.

Table 33.6 reveals that regardless of Na which behaved contrary case, Ca and Ca/Na ratio represented significant gradual increases with increasing ascorbic acid rate. The applied treatment of ascorbic acid at the rate of 300 mg L^{-1} proved to be the best which exhibited, in general, the most pronounced counteracted effect on soil salinity of this study. Such treatment surpassed the treatment of water foliar spray by 56.3 and 163.4% for Ca and Ca/Na ratio, respectively. On the other hand, Na recorded a shortage at 37.1% under the best treatment compared with the treatment of water application. The beneficial effect of ascorbic acid on increasing tolerance of pea plants especially at the rate of 300 mg L^{-1} under studied soil salinity has reflected improving growth traits (Table 33.3), photosynthetic pigments and endogenous ascorbic acid (Table 33.4), photosynthates (Table 33.5), and green yield of pods and seeds (Table 33.7); it also reflected on improving Ca and Ca/Na ratio status of plants. The obtained results are supported by Ahmed and Abd El-Hameed (2004) and Rady (2006), who reported that the effect of antioxidants especially ascorbic acid on producing healthy plants leads to enhancing the plants to have a great ability for uptake of elements, among them is Ca. Moreover, Gonzalez-Reyes et al. (1994) concluded that ascorbate free radical caused hyperpolarization of plasma membranes, and this energization could then facilitate transport processes across such membranes. Most of the previous results are consistent with those of Ali (2000), Ahmed et al. (2002), and Rady (2006).

Table 33.6 shows that the best combined treatment by which plant shoots collected the highest amount of Ca with the reverse regarding Na was treating the seeds with calcium paste plus fecundating their beds with ground sunflower heads interacted with spraying plant shoots with 300 mg L^{-1} ascorbic acid solution. This treatment scored 44.4 and 161.9% for Ca and Ca/Na ratio, respectively, when compared

Table 33.7 Influence of calcium paste, ground sunflower heads, and ascorbic acid on green yield of pea plants under saline reclaimed soil conditions in both 2007/2008 and 2008/2009 seasons

	0 Ca^{+2}	+Ca^{+2}	Mean *B*	0 Ca^{+2}	+Ca^{+2}	Mean *B*	0 Ca^{+2}	+Ca^{+2}	Mean *B*
Ascorbic acid (mg L^{-1})	Total green pods yield feddan^{-1} (tonnes)			100-green seed weight (g)			Total green seed yield feddan^{-1a} (ton)		
0	0.42	1.00	0.71	11.0	19.8	15.4	0.07	0.42	0.25
100	0.49	1.10	0.80	14.0	20.5	17.3	0.12	0.49	0.31
200	0.57	1.43	1.00	18.6	21.3	20.0	0.26	0.66	0.46
300	0.90	2.12	1.51	20.2	24.2	22.2	0.43	1.04	0.74
400	0.90	2.10	1.50	20.0	24.0	22.0	0.42	1.02	0.72
Mean *A*	0.66	1.55		16.8	22.0		0.26	0.73	
$LSD_{0.05}$ *A*	0.14			2.8			0.11		
B	0.08			1.6			0.06		
A×*B*	0.24			4.8			0.18		

+Ca = Seeds covered with calcium paste and sown in beds fecundated with ground sunflower heads
0 Ca = Seeds without calcium paste and sown in beds without ground sunflower heads
[a]Feddan = 0.42 ha

with the combined treatment in which seeds and their beds treated with calcium paste and ground sunflower heads, respectively, interacted with spraying plant shoots with water, while Na decreased down to 44.8%. In addition, the same best treatment granted increases at 242.1 and 782.6% for the same parameters, respectively, as compared with the combined treatment under the interaction between untreated seeds and their beds and spraying plant foliage with water, whereas Na reduced at 61.0%. The increments obtained from the above-mentioned super combined treatment may be explained with the increasing value of Ca/Na ratio which reveals that Ca^{2+} to behave oneself when takes out Na^{+} at significant amounts from rhizosphere and consequently from plant shoots (Table 33.6). Besides, the properties of ground sunflower heads and wheat bran fibers (Table 33.2) which improve seed and root medium in addition to the role of ascorbic acid as an antioxidant against salinity.

33.3.3 Green Yield of Pods and Seeds

Table 33.7 indicates that total green pod yield feddan^{-1}, 100 green seed weight, and total green seed yield feddan^{-1} were significantly increased as a result of calcium paste-treated seeds sown in ground sunflower head-fecundated beds which recorded 134.8, 31.0, and 180.8%, respectively, as compared with untreated seeds and their beds. The enhanced green yield of pods and seeds may be due to the existence of Ca^{2+} to take the place of Na^{+} in the rhizosphere and in plant shoots (Table 33.6) which may be positively reflected on plant growth (Table 33.3) and plant pigments

(Table 33.4), as well as other components, proline, total soluble sugars, and total phenols (Table 33.5) as osmotic substances, and consequently the increase in studied green yields. Moreover, the better water retention capacity of ground sunflower heads and wheat bran (Table 33.2) may have enabled rhizosphere to retain more water to counteract the harmful effects of salinity.

Submain treatment of ascorbic acid foliar application at the rate of 300 mg L^{-1} gave the highest significant increases for green yield of pods and seeds as compared with other ascorbic acid rates: 100, 200, and 400 mg L^{-1}. These increases which scored by 300 mg L^{-1} ascorbic acid were 112.7, 44.2, and 196.0% for total green pod yield $feddan^{-1}$, 100 green seed weight, and total green seed yield $feddan^{-1}$, respectively, as compared to water foliar treatment. The improving effect of ascorbic acid on green yield of pods and seeds was mainly attributed to its positive action on enhancing growth traits (Table 33.3), photosynthetic pigments of plant leaves (Table 33.4), and cellular solutes, i.e., free proline, soluble sugars, and soluble phenols (Table 33.5), for sustenance of cell turgor leading to maintenance of metabolic activities in plants. In this respect, Al-Qubaie (2002) stated that ascorbic acid as an antioxidant compound has an auxinic action and also synergistic effect on the biosynthesis of carbohydrates, and controlling the incidence of most fungi on plants makes them in vigor states and reflects on green pods and seeds yields. Besides, the induced effect of ascorbic acid as one of vitamins on growth and yield may be due to those vitamins which are recognized to be coenzymes involved in specific biochemical reactions in plants such as oxidative and non-oxidative decarboxylations (Robinson 1973). The results regarding the beneficial effect of ascorbic acid on green yields of pods and seeds are confirmed with those reported by Ahmed et al. (2002, 2003), Mostafa (2004), and Rady (2006).

Regarding the interaction between treated or untreated seeds and their beds with calcium paste and ground sunflower heads, orderly, and ascorbic acid foliar application at various rates, data presented in Table 33.7 represent that the highest significant increases were obtained from the application of 300 mg L^{-1} ascorbic acid combined with treated seeds and fecundated beds with calcium paste and ground sunflower heads, orderly, of total green pod yield $feddan^{-1}$, 100 green seed weight, and total green seed yield $feddan^{-1}$. These increases obtained from this super combined treatment scored at 112.0, 22.2, and 147.6%, respectively, as compared to the combined treatment of water foliar spray under calcium paste-treated seeds sown in ground sunflower head-fecundated beds as well as recorded at 404.8, 120.0, and 1,385.7%, orderly, compared with the combined treatment of water foliar application under untreated seeds and their beds. This favorable production may be due to the positive combined effect of calcium and ground sunflower heads. The former has antagonistic effect to the harmful effects of Na^{+} and the latter has high percentage of fibers (Table 33.2) which have several physiological effects, depending upon the physical and chemical properties; among them are their ability to retain water and to bind organic compounds (Schneeman 1986, 1989) diluting the salinity concentration and saving acidity effect in rhizosphere and consequently more solubility and absorption of nutrients by plant roots.

33.4 Conclusion

Within the experimental conditions of the present study, it is concluded that the work gave evidence to the role of Ca^{2+} in the form of the calcium paste by which the seeds were covered before sowing and ground sunflower heads as a material with high water holding capacity by which seedbeds were fecundated before planting. In addition, the role of ascorbic acid, an antioxidant by which plant foliage was sprayed especially at the concentration of 300 mg L^{-1} in inducing salinity tolerance of pea plants cultivated in salt-affected reclaimed soil with salt concentration at about 5,000 ppm (ECe 7.8 dS m^{-1}) leading to favorable growth and consequently obtain economic yields under such conditions.

References

Abbas MA, Younis ME, Shukry WM (1991) Plant growth, metabolism and adaptation in relation to stress conditions. III. Effect of salinity on the internal solute concentrations in *Phaseolus vulgaris* L. J Plant Physiol 138:722–729

Abdel-Naby A, El-Beltagy MS, Abou-Hadid AF, Helmy TI, El-Abd SO (2001) Effect of salinity stress modified by calcium application on potato plants. Egypt J Hort 28(4):519–530

Ahmed FF, Abd El-Hameed HM (2004) Influence of some antioxidants on growth, vine nutritional status, yield and quality of berries in Banaty grapevines. Assiut J Agric Sci 35(4):131–140

Ahmed FF, Darwish OH, Gobara AA, Ali AH (1998) Growth, nutritional status and productivity of flame seedless grapevine as influenced by the application of citrine and ascobine. American Society of Agronomics Crops Science, Society of American Soil Science, Baltimore, p 252

Ahmed FF, Darwish OH, Gobara AA, Ali AH (2002) Physiological studies on the effect of ascorbic and citric acids in combined with some micronutrients on Flame seedless grapevine. Minia J Agric Res Dev 22(1):105–114

Ahmed FF, Abdalla AS, Sabour AMT (2003) Growth and fruiting of Williams banana as affected by some antioxidant and biofertilizer treatments. Minia J Agric Res Dev 23(1):51–68

Ali AH (2000) Response of Flame seedless grapevines to spraying with ascorbic acid and boron. Minia J Agric Res Dev 20(1):159–174

Ali ZA (2002) Effect of foliar application with ascorbic acid on vegetative growth and some biochemical constituents of tomato plants. J Agric Sci Mansoura Univ 27(10):6765–6775

Al-Qubaie AI (2002) Response of *Ficus nitida* L. seedlings to the application of some antioxidants under soil salinity conditions. Minia J Agric Res Dev 22(3):235–254

AOAC (1995) Association of official analytical chemists: official methods of analysis, 15th edn. AOAC, Washington, DC

Arnon DI (1949) Copper enzymes in isolated chloroplasts: polyphenol-oxidase in *Beta vulgaris* L. Plant Physiol 24:1–5

Arrigoni O (1994) Ascorbate system in plant development. J Bioenerg Biomembr 26:407–419

Bates LS, Waldren RP, Teare ID (1973) Rapid determination of free proline for water stress studies. Plant Soil 39:205–207

Chapman HD, Pratt PF (1961) Methods of analysis for soil, plants and waters. University of California, Berkeley

Cordoba-Pedregosa MC, Gonzalez-Reyes JA, Sandillas MS, Navas P, Cordoba F (1996) Role of apoplastic and cell-wall peroxidases on the stimulation of root elongation by ascorbate. Plant Physiol 112:1119–1125

Cramer GR, Lauchli A, Polito VS (1985) Displacement of Ca^{2+} by Na^{+} from the plasmalemma of root cell. Plant Physiol 79:207

Dubois MF, Gilles KA, Hamiton JK, Robers PA, Smith F (1956) Colorimetric methods for determination of sugars and related substances. Anal Chem 28:350–354

Eastwood MA (1973) Methods for determining physical characteristics of fiber. Cereal Foods World Abstr 21:426

Elade Y (1992) The use of antioxidants to control gray mould (*Botrytis cinerea*) and white mould (*Sclerotinia sclerotiorum*) in various crops. Plant Pathol 141:417–426

El-Saidi MT (1997) Salinity and its effect on growth, yield and some physiological processes of crop plants. In: Jaiwal PK, Singh RP, Gulati A (eds) Strategies for improving salt tolerance in higher plants. Oxford and IBH Publishing Co Pvt Ltd., New Delhi, pp 111–127

Epstein E (1961) The essential role of calcium in selective cations transports by plant cells. Plant Physiol 36:437

Farag KM (1996) Use of urea, phenylalanine, thiamine or their combinations to accelerate anthocyanins development and their effect on the storage life of flame seedless grapes. In: First Egyptian Hungarian horticultural conference, Kafr El-Sheikh, Egypt, 15–17 Sept 1996

Farago S, Brunhold C (1994) Regulation of thiol contents in maize roots by intermediates and effectors of glutathione synthesis. J Plant Physiol 144:433–437

Foyer CH, Halliwell B (1976) The presence of glutathione and glutathione reductase in chloroplasts: a proposed role in ascorbic acid metabolism. Planta 157:239–244

Foyer CH, Furbank RT, Harbinson J, Horton P (1990) The mechanism contributing to photosynthetic control of electron transport by carbon assimilation in leaves. Photosynth Res 25:83–100

Gonzalez-Reyes JA, Alcain FJ, Caler JA, Serrano A, Cordoba F, Navas P (1994) Relationship between apoplastic ascorbate regeneration and stimulation of root growth in *Allium cepa* L. Plant Sci 100:23–29

Greenway HR, Munns R (1980) Mechanisms of salt tolerance in non-halophytes. Ann Rev Plant Physiol 31:149

Gupta PK, Nadgir AL, Macarentias AF, Jagannathan V (1980) Tissue culture of forest trees: Clonal multiplication of *Tectona grandis* L. (teak) by tissue culture. Plant Sci Lett 17:259–268

Hans CJ, Kevin WJ (1992) Environmental profile Fayoum Governorate. Euroconsult/Darwish Conts Eng, Ershem

Hanson JB (1984) The function of calcium in plant nutrition. In: Tinker PB, Lauchi A (eds) Advances in plant nutrition, vol 1. Praeger, New York, pp 149–208

Jackson ML (1967) Soil chemical analysis. Prentice-Hall of India Private Limited, New Delhi, pp 144–197, 326–338

LaHaye PA, Epstein E (1969) Salt tolerance by plants: enhancement with calcium. Science 166:395

Leopold AC, Willing RP (1984) Evidence for toxicity effects of salt on membranes. In: Staples RC, Toenniessen GH (eds) Salinity tolerance in plants: strategies for crop improvement. Wiley, New York, p 67

Maas EV (1986) Crop tolerance to saline soil and water. In: Proceedings of the US Pakistan Biosaline research workshop, Department of Botany, Karachi University, Karachi, Pakistan, pp 205–219

Mongeau R, Brassard R (1982) Insoluble dietary fiber from breakfast cereals and brans: bile salt binding and water holding capacity in relation to particle size. Cereal Chem 59:413

Mostafa EAM (2004) Effect of spraying with ascorbic acid, vitamin B and active dry yeast on growth, flowering, leaf mineral status, yield and fruit quality of grand Nain banana plants. Ann Agric Sci Ain Shams Univ Cairo 49(2):643–659

Navas P, Gomez-Diaz C (1995) Ascorbate free radical and its role in growth control. Protoplasm 184:8–13

Page AI, Miller RH, Keeny DR (1982) Methods of soil analysis. Part II. Chemical and microbiological methods, 2nd edn. American Society of Agronomics, Madison

Pasternak D (1987) Salt tolerance and crop production: a comprehensive approach. Ann Rev Phytopathol 20:271–291

Piper CS (1947) Soil and plant analysis. The University of Adelaide, Adelaide

Poovaiah BW, Reddy ASN (1993) Calcium and signal transduction in plants. CRC Crit Rev Plant Sci 12(3):185

Prosky L, Asp NG, Scheizer TF, Devries JW, Furda I (1988) Determination of insoluble, soluble and total dietary fiber in foods and food products: interlaboratory study. J Am Anal Chem 71:1017

Prusky D (1988) The use of antioxidants to delay the onset of anthracnose and stem end decay in avocado fruits after harvest. Plant Dis 72:381–384

Rady MM (2006) Efficiency of growth and productivity of sunflower plants as affected by ascorbic acid under saline reclaimed soil conditions. In: 2nd conference on Farm Integrated Pest Management, Faculty of Agriculture, Fayoum University, Fayoum, pp 186–200

Ragab MM (2002) Effect of spraying urea, ascorbic acid and NAA on fruiting of Washington Navel orange trees. MSc thesis, Faculty of Agriculture, Minia University Egypt

Rautenkranz A, Machler F, Martinoia E, Oerti J (1994) Transport of ascorbic and dehydroascorbic acids across protoplast and vacuole membranes isolated from barley (*Hordeum vulgare* L. cv. Gebrel) leaves. Plant Physiol 106:187–193

Robinson FA (1973) Vitamins. In: Miller LP (ed) "phytochemistry", vol III. Van Nostrand Reinhold Co., New York, pp 195–198

Scandalios JG (1997) Molecular genetics of superoxide dismutases in plants. In: Scandalios JG (ed) Oxidative stress and the molecular biology of antioxidant defenses. Cold Spring Harbor Lab Press, Plainview, pp 527–568

Schneeman BO (1986) Dietary fiber: physical and chemical properties, methods of analysis, and physiological effects. Food Technol 40:104

Schneeman BO (1989) Dietary fiber: a scientific status summary by the Institute of Food Technologists Expert Panel on Food Safety and Nutrition. Food Technol 41:133

Shahidi F, Wanasundara PK (1992) Phenolic-antioxidants. Crit Rev Food Sci Nutr 32:67–103

Snedecor WC, Cochran WG (1980) Statistical methods, 7th edn. Iowa State University Press, Ames

Snell FD, Snell CT (1953) Colorimetric methods of analysis including some turbimetric and morpholometric methods, vol III. D Van-Nastrod Co, Inc., Toronto\New York\London, p 606

Tarraf SA, Gamal El-Din KM, Balbaa LK (1999) The response of vegetative growth, essential oil of lemongrass (*Cymbopogon citratus* Hort.) to foliar application of ascorbic acid, nicotinamide and some micronutrients. Arab Univ J Agric Sci Ain Shams Univ Cairo 7(1):247–261

USDA-NRCS (1999) Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. United States Department of Agriculture, Natural Resources Conservation Service Agriculture Handbook Number 436. http://soils.usda.gov/technical/classification/taxonomy/. Accessed Jan 2012

USDA-NRCS (2010) Keys to soil taxonomy, 11th edn. USDA–Natural Resources Conservation Service, Washington, DC. http://soils.usda.gov/technical/classification/tax_keys/. Accessed May 2011

Wise RR, Naylor AW (1987) The peroxidative destruction of lipids during chilling injury to photosynthesis and ultrastructure. Plant Physiol 83:272–277

Zhang X, Schmidt RE (2000) Hormone-containing products impact on antioxidant status of tall fescue and creeping bentgrass subjected to drought. Crop Sci 40:1344–1349

Chapter 34
Prospects of Crop and Forage Production in Coastal Saline Soils of Bangladesh

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Abstract Of 2.83×10^6 hectares (ha) coastal area of Bangladesh, about 1.0×10^6 ha is suffering from various levels of salinity. During monsoon, rice can be grown in these areas due to rainfall-induced natural leaching. In dry seasons, soil salinity increases in the soil profile and hence the entire coastal saline belt remains fallow. Considering this, International Center for Biosaline Agriculture jointly with Bangladesh Agricultural Research Institute initiated a project to grow cash and forage crops using irrigation and water management technologies in the coastal saline soils.

In 2007–2008, an initial pilot assessment was made and basic soil properties were determined in Satkhira District, where soil salinity (EC_e 11 dS m^{-1}) was recorded in dry months (March–April). Tomato, cowpea, and barley were used as test crops and harvested rain water was used for irrigation. Tomato crop with drip irrigation on mulched raised beds produced 55–66 t ha^{-1} yield, which is 3.13–3.36 times of control treatment (flat lands with traditional can irrigation). A net return of US$ 2,658–3,559 ha^{-1} was obtained which is 5.76–5.92 times more than the control treatment. The hosepipe irrigation in mulched raised bed gives net return of US$ 2,696–3,610 ha^{-1}, about 5.84–6.00 times more than the control treatment. These returns are higher than those obtained from drip irrigation due to less investment in

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irrigation setup. Fodder crops (i.e., cowpea and barley) were also found profitable. These were irrigated by both fresh and saline water using hosepipes with different irrigation scheduling. The net returns of cowpea and barley were about 4.00–4.23 and 2.11–2.60 times more than the control treatment, respectively, in various locations. The study indicates that 770,000 ha saline coastal land ($EC_e \leq 12.0$ dS m^{-1}) has the potential for crop and fodder cultivations through proper irrigation and soil management practices.

Keywords Bangladesh • Coastal land • Fodder • Raised beds • Tomato

34.1 Introduction

The coastal area of Bangladesh accounts for about 20% of the total land area (Fig. 34.1). The entire coastal land and offshore island area belongs to deltaic floodplains. About 1.0×10^6 ha coastal lands of Bangladesh are affected by various salinity levels (Islam et al. 2007) at various depths. The seasonal variation of ground and surface waters also regulates soil salinity in the region (MPO 1986; SRDI 2000). Soil Resources Development Institute (SRDI) has developed salinity-based 5 land units (Table 34.1) of the entire coastal zone (SRDI 2000), categorized as S_1 (2.0–4.0 dS m^{-1}), S_2 (4.1–8.0 d Sm^{-1}), S_3 (8.1–12.0 dSm^{-1}), S_4 (12.1–16.0 dS m^{-1}), and S_5 (>16.0 dS m^{-1}). About 0.23×10^6 ha of land is currently under S_4 and S_5 categories.

Field investigation revealed surface (0–15 cm) soil salinity in dry season ranging between 4.0–9.0 dS m^{-1} at Mirzapur and 5–12 dS m^{-1} in Barodanga. In wet season, the corresponding surface salinities range between 1.5 and 2.5 dS m^{-1} and from 2.0 to 3.0 dS m^{-1}, respectively (Mondal et al. 2001). Soil pH ranges between 6.0 and 8.4 (slightly acid to moderately alkaline). The organic matter is very low (1.0–1.5%). Nutrient (N, P) deficiencies are common in saline soils. Micronutrients, such as Cu and Zn, are widely varied (Haque 2006).

In monsoon season, rice can be cultivated in the coastal soils due to rainfall-induced natural leaching in the cultivation zone. However, in dry season when rainfall is negligible, soil salinity increases in the cultivation zone due to upward flux of saline groundwater and subsequent evaporation and due to negligible natural leaching during the season. It is projected that sea level rise as a consequence of climate change impact will increase soil and water salinity in the coastal region and perhaps large coastal area will be under sea. The sea level rise occurred at a mean rate of 3.1 mm $year^{-1}$ during 1993–2003 (Abedin 2010). Thus, salinity is (and will be) the most dominant factor limiting crop production during dry winter season (November–May) in the coastal soils. To overcome this situation, cultivation of salt-tolerant crops with appropriate soil and water management practices can bring substantial change in the agricultural practices toward increased cropping intensity (Rahman et al. 1995). Moreover, there is an urgent need for producing

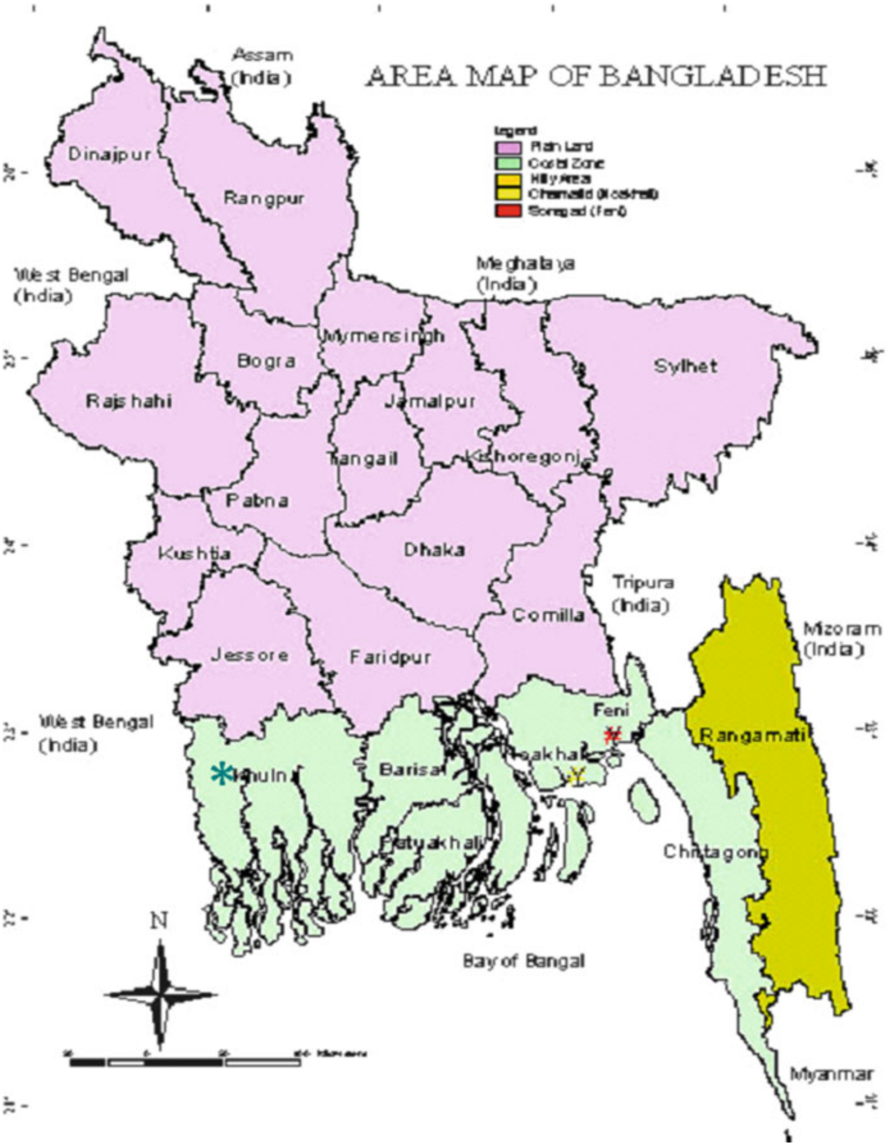

Fig. 34.1 Map of Bangladesh showing coastal area (*light blue*) and location of study area (*blue star*) (Source: Center for Environmental and Geographical Information Services, Bangladesh)

fodders to feed substantial number of livestock in the region (BLRI 2007). Considering the above facts, a pilot testing of irrigation technologies, crops, and cultivation practices was carried out in Satkhira District of Bangladesh during 2007–2008 cropping season.

Table 34.1 Soil salinity-based units and locations

Units	Soil salinity class	EC_e (dS m^{-1})	Locations under the unit
S1	Nonsaline to slightly saline	2.0–4.0	A large part of Satkhira, Khulna, Bagerhat, Narail, Jessore, Gopalgonj, Madaripur, Pirojpur, Jhalokathi, Barisal, Bhola, Patuakhali, Borguna, Laxmipur, Noakhali, Feni and Chittagong
S2	Slightly saline to low saline	4.1–8.0	Many parts of Satkhira, Khulna, Bagerhat, Narail, Jessore, Madaripur, Pirojpur, Bhola, Patuakhali, Borguna, Laxmipur, Noakhali, Feni, Chittagong and Cox's Bazar
S3	Low saline to medium saline	8.1–12.0	Many parts of Satkhira, Khulna, Bagerhat, Narail, Jessore, Madaripur, Pirojpur, Bhola, Patuakhali, Borguna, Laxmipur, Noakhali, Feni, Chittagong and Cox's Bazar
S4	Medium saline to high saline	12.1–16.0	Many parts of Satkhira, Khulna, Bagerhat, Bhola, Patuakhali, Borguna, Noakhali, Chittagong and Cox's Bazar
S5	High saline to very high saline	>16.0	Many parts of Satkhira, Khulna, Bagerhat, Bhola, Patuakhali, Borguna, Noakhali, Feni and Cox's Bazar

34.2 Materials and Methods

The pilot testing site is shown in Fig. 34.1, and the information on testing site and treatments is given below.

34.2.1 Soil and Water Testing Procedures

The soil EC was measured by standard EC meter after calibration with KCl solution, pH of saturated soil paste by pH meter, texture by hydrometer, bulk density by core, soil moisture by oven drying soil at 105°C, infiltration by double-ring infiltrometer, and organic matter by wet oxidation method.

Water samples were analyzed for Na, K, Ca, and Mg using atomic absorption spectrophotometer, chlorides by chloride analyser, and phosphorous and boron by colorimeter, using standard procedures.

34.2.2 Testing Site

The field testing was carried out in farmers' fields at Doulatpur and Kulia in Satkhira District located in the northwest part of Bangladesh between 22°37′0″ N and 89°18′0″

Table 34.2 Physical soil characteristics of the study sites

Location	Sand (%)	Silt (%)	Clay (%)	Textural[a] class (USDA)	Bulk density ($g\ cm^{-3}$)	Field capacity (%)
Doulatpur	30.5	27.3	42.2	Clay	1.34	43.12
Bolarati	30.6	31.2	38.2	Clay loam	1.36	42.95
Kulia	32.4	28.2	39.4	Clay loam	1.38	41.50

[a]Soil Survey Division Staff (1993)

E. Annual average maximum and minimum temperatures are 35.5 and 12.5°C, respectively. The annual rainfall amounts to 1,710 mm, mainly occurring in the wet season (May–October), and the salts in the crop root zone are leached out. This helps the farmers to grow rice in the wet season in almost nonsaline soil conditions. About 65% of the total area of this district remains saline during dry season (SRDI 2000).

34.2.3 Soil Characteristics

The soil texture ranged from clay to clay loam. The pH and bulk density of the soils ranged from 6.8 to 7.6 (neutral to slightly alkaline) and from 1.34 to 1.38 g cm^{-3}, respectively (Table 34.2). The soil salinity (EC) reached up to 11 dS m^{-1} in March–April. Selected soil characteristics are shown in Table 34.3.

34.2.4 Crop Selection, Cultivation, and Irrigation Management

Major cultivated crops include rice, jute, sugarcane, mustard, potato, onion, and betel leaf in the nonsaline and low-saline areas. In this study, tomato (variety: BARI Tomato-3) was selected as the cash crop, and cowpea (variety: BARI Fallon-1) and barley (variety: BARI Barley-4) were selected as forage crops. Both flatland and raised bed plantations were tested. Locally available paddy straw was used as mulching material. Tomato was planted on 31 December 2007, and cowpea and barley were planted on 1 January 2008. Normally, the crops are irrigated by cans from existing pond or canal waters. This was considered as farmers' practice. Other irrigation methods included drip and hosepipe irrigation.

34.2.4.1 Estimation of Leaching Requirement

To estimate the leaching requirement, both the irrigation water salinity (EC_w) and the crop tolerance to soil salinity (EC_e) were obtained. The EC_e was taken from crop tolerance data (Table 34.4). The equation given by Rhoades (1974) and Rhoades and Merrill (1976) was used for leaching requirement:

Table 34.3 Chemical characteristics of the selected sites

Location	pH	OM (%)	Ca (meq L^{-1})	Mg (meq L^{-1})	K (meq L^{-1})	N (%)	P (μg mL^{-1})	S (μg mL^{-1})	B (μg mL^{-1})	Cu (μg mL^{-1})	Zn (μg mL^{-1})
Doulatpur	7.0	1.48	255	150	3.0	0.078	28	17	0.4	8.55	2.69
Bolarati	6.8	0.89	410	160	2.0	0.047	30	14	0.32	5.73	2.50
Kulia	7.6	1.07	350	190	5.0	0.056	37	28	0.46	5.60	2.48

Table 34.4 Crop tolerance and yield potentials of tomato, cowpea, and barley[a]

	Yield potentials							
	100%		90%		75%		50%	
Crop	EC_e (dS m^{-1})	EC_w (dS m^{-1})	EC_e (dS m^{-1})	EC_w (dS m^{-1})	EC_e (dS m^{-1})	EC_w (dS m^{-1})	EC_e (dS m^{-1})	EC_w (dS m^{-1})
Barley	8.0	5.3	10	6.7	13	8.7	18	12
Cowpea	4.9	3.3	5.7	3.8	7.0	4.7	9.1	6.0
Tomato	2.5	1.7	3.5	2.3	5.0	3.4	7.6	5.0

[a]Adopted from Maas and Hoffman (1977)

$$LR = \frac{EC_w}{5EC_e - EC_w} \tag{34.1}$$

where LR is the minimum leaching requirement needed to control salts within the tolerance (EC_e) of the crop, EC_w is salinity of the applied irrigation water in dS m^{-1}, and EC_e is the average soil salinity tolerated by the crop as measured on a soil saturation extract. The values of EC_e for the given crop and the appropriate acceptable yield were taken from Table 34.4. In this study, 90% yield target was considered.

34.2.4.2 Estimation of Water Depth

Irrigation water depth required to meet both the crop water demand and leaching requirement was estimated using Eq. 34.2.

$$AW = \frac{ET}{1 - LR} \tag{34.2}$$

where AW is the irrigation water depth (mm), ET is the crop water demand (mm), and LR is the leaching requirement expressed as a fraction (leaching fraction). However, any effective rainfall during the crop season was adjusted to the total irrigation water needs.

34.2.4.3 Soil and Irrigation Management Treatments

All the management aspects were arranged in the following treatments for the selected crops and sites.

Treatments for tomato in Doulatpur and Kulia

T_1 = Drip irrigation in raised bed with mulch
T_2 = Drip irrigation in raised bed without mulch
T_3 = Hosepipe irrigation in raised bed with mulch
T_4 = Hosepipe irrigation in raised bed without mulch

T_5 = Can irrigation in flatland without mulch

Shallow tube well water having salinity 1.0–1.5 dS m^{-1} (fresh water) was used for tomato irrigation in Doulatpur and Kulia site.

Treatments for cowpea and Barley at Doulatpur
T_6 = Hosepipe irrigation with fresh water in raised bed at 7-day interval
T_7 = Hosepipe irrigation with fresh water in raised bed at 15-day interval
T_8 = Hosepipe irrigation with fresh water in flatland at 7-day interval
T_9 = Hosepipe irrigation with fresh water in flatland at 15-day interval

Treatments for cowpea and barley at Kulia
T_{10} = Hosepipe irrigation with saline water in raised bed at 7-day interval
T_{11} = Hosepipe irrigation with saline water in raised bed at 15-day interval
T_{12} = Hosepipe irrigation with saline water in flatland at 7-day interval
T_{13} = Hosepipe irrigation with saline water in flatland at 15-day interval

For barley and cowpea, irrigation in both the sites was accomplished by using canal water (salinity 4.0–7.5 dS m^{-1}) by pipe irrigation on interval basis; leaching requirement was not applicable in this case.

34.3 Results and Discussion

34.3.1 Soil and Water Salinities

The initial soil salinities (EC_e) during plantation were 3.14 and 5.20 dS m^{-1} at Doulatpur and Kulia, respectively. However, the maximum salinities were 9.97 dS m^{-1} at Doulatpur in March and 11.15 dS m^{-1} at Kulia in April. Saline water was used for irrigation only at Kulia for barley and cowpea. The level of water salinity at first irrigation was 5 dS m^{-1}, and at last irrigation, it was 6.5 dS m^{-1}. In Doulatpur, nonsaline water (EC 1.0–1.5 dS m^{-1}) was used for all the crops. The month-wise development of salinity in the soils of the sites is shown in Fig. 34.2. The soil salinities of different crops with various growth stages for different locations are given in Tables 34.5, 34.6, 34.7, 34.8, 34.9, 34.10, 34.11 and 34.12.

34.3.2 Crop Performance Against Salinity

All the selected crops were tested in saline soils under the designed soil and irrigation treatments. It was found that the levels of soil salinity development in the root zone were different for different treatments. For tomato crop, minimum soil salinity was developed with drip irrigation in raised bed with mulch (T_1) in both Doulatpur

Table 34.5 Month-wise soil salinity levels in the experimental field of tomato at Doulatpur, Satkhira

Treatment	Soil dep. (cm)	EC_e (dS m^{-1}) December BP	RZ	% of salinity reduction	EC_e (dS m^{-1}) January BP	RZ	% of salinity reduction	EC_e (dS m^{-1}) February BP	RZ	% of salinity reduction	EC_e (dS m^{-1}) March BP	RZ	% of salinity reduction
T_1	0–30	2.90	2.37	18.27	4.89	2.53	48.26	5.50	3.32	39.63	7.11	4.71	33.75
T_2	0–30	2.90	2.37	18.27	5.95	3.34	43.86	7.15	4.93	31.04	8.65	6.33	26.82
T_3	0–30	2.90	2.37	18.27	3.45	3.00	13.04	4.88	4.33	11.27	6.15	5.75	6.50
T_4	0–30	2.90	2.37	18.27	5.48	5.22	4.74	7.25	6.94	4.27	8.98	8.52	5.12
T_5	0–30	2.90	2.37	18.27	7.32	7.10	3.00	8.96	8.69	3.01	12.00	11.79	
IW (STW)	–	3.79		–	4.58			4.79			5.1		

BP Between plants, *RZ* Root zone

Table 34.6 Month-wise soil salinity levels in the experimental field of tomato at Bolarhati, Satkhira

Treatment	Soil dep. (cm)	EC_e (dS m^{-1}) December		% of salinity reduction	EC_e (dS m^{-1}) January		% of salinity reduction	EC_e (dS m^{-1}) February		% of salinity reduction	EC_e (dS m^{-1}) March		% of salinity reduction
		BP	RZ		BP	RZ		BP	RZ		BP	RZ	
T_1	0–30	1.22	1.00	18.03	4.32	2.10	51.38	5.40	3.25	39.81	6.75	4.39	34.96
T_2	0–30	1.22	1.00	18.03	5.96	3.70	37.91	6.98	4.75	31.91	7.95	6.10	23.27
T_3	0–30	1.22	1.00	18.03	3.35	3.00	10.44	4.65	4.15	10.75	5.84	5.40	7.53
T_4	0–30	1.22	1.00	18.03	4.87	4.50	7.59	6.24	5.85	6.25	7.77	7.12	8.36
T_5	0–30	1.22	1.00	18.03	7.00	6.50	7.14	8.33	7.90	5.16	11.00	10.73	2.45
IW (STW)	–	1.00			1.20			1.34			1.50		

Table 34.7 Month-wise soil salinity levels in the experimental field of tomato at Kulia, Debhata, Satkhira

Treatment	Soil dep. (cm)	EC_e (dS m^{-1}) December		% of salinity reduction	EC_e (dS m^{-1}) January		% of salinity reduction	EC_e (dS m^{-1}) February		% of salinity reduction	EC_e (dS m^{-1}) March		% of salinity reduction
		BP	RZ		BP	RZ		BP	RZ		BP	RZ	
T_1	0–30	1.83	1.47	19.67	3.74	2.18	41.71	5.52	3.27	40.76	6.68	4.43	33.68
T_2	0–30	1.83	1.47	19.67	5.11	3.90	23.67	6.48	4.78	26.23	8.08	6.16	23.76
T_3	0–30	1.83	1.47	19.67	3.55	3.25	8.45	4.60	4.22	8.26	5.95	5.60	5.88
T_4	0–30	1.83	1.47	19.67	4.89	4.70	3.88	6.20	5.89	5	7.90	7.39	6.45
T_5	0–30	1.83	1.47	19.67	7.22	6.85	5.12	8.25	7.96	3.51	11.12	10.84	2.51
IW (Canal)	–	4.63			4.83			5.12			5.36		

Table 34.8 Month-wise soil salinity levels in the experimental field of cowpea at Doulatpur, Satkhira

Treatment	Soil dep. (cm)	EC_e (dS m^{-1}) December		% of salinity reduction	EC_e (dS/m) January		% of salinity reduction	EC_e (dS m^{-1}) February		% of salinity reduction	EC_e (dS m^{-1}) March		% of salinity reduction
		BP	RZ		BP	RZ		BP	RZ		BP	RZ	
T_1	0–30	3.14	2.79	11.14	3.25	2.98	8.30	3.50	3.40	2.85	4.75	4.61	2.94
T_2	0–30	3.14	2.79	11.14	3.62	3.35	7.4	5.10	4.98	2.35	5.74	5.50	4.18
T_3	0–30	3.14	2.79	11.14	3.85	3.60	6.49	5.12	5.03	1.75	5.90	5.75	2.54
T_4	0–30	3.14	2.79	11.14	5.58	5.30	5.0	7.40	7.22	2.43	9.97	9.65	3.20
IW (STW)	–	3.79			4.58			4.79			5.10		

Table 34.9 Month-wise soil salinity levels in the experimental field of cowpea at Bolarhati, Satkhira

Treatment	Soil depth (cm)	EC_e (dS m^{-1}) December		% of salinity reduction	EC_e (dS m^{-1}) January		% of salinity reduction	EC_e (dS m^{-1}) February		% of salinity reduction	EC_e (dS m^{-1}) March		% of salinity reduction
		BP	RZ		BP	RZ		BP	RZ		BP	RZ	
T_1	0–30	1.25	1.10	12	2.55	2.40	5.88	3.53	3.35	5.09	4.90	4.40	10.20
T_2	0–30	1.25	1.10	12	3.50	3.10	11.42	4.38	4.30	1.82	5.88	5.60	4.76
T_3	0–30	1.25	1.10	12	3.84	3.50	8.85	4.84	4.65	3.92	6.27	6.00	4.30
T_4	0–30	1.25	1.10	12	4.69	4.50	4.05	7.21	7.97	−10.54	10.00	9.82	1.8
IW (STW)	–	1.00			1.20			1.34			1.50		

Table 34.10 Month-wise soil salinity levels in the experimental field of cowpea at Kulia, Debhata, Satkhira

Treatment	Soil depth (cm)	EC_e ($dS\ m^{-1}$) February		% of salinity reduction	EC_e ($dS\ m^{-1}$) March		% of salinity reduction	EC_e ($dS\ m^{-1}$) April		% of salinity reduction
		BP	RZ		BP	RZ		BP	RZ	
T_1	0–30	4.55	4.05	10.98	4.75	4.54	4.42	5.35	5.23	2.24
T_2	0–30	4.55	4.05	10.98	6.93	6.19	10.76	7.56	7.22	4.49
T_3	0–30	4.55	4.05	10.98	7.05	6.64	5.81	8.05	7.57	5.96
T_4	0–30	4.55	4.05	10.98	10.30	9.94	3.49	11.15	10.64	4.57
IW (Canal)	–	5.14			5.36			5.83		

Table 34.11 Month-wise soil salinity levels in the experimental field of barley at Doulatpur, Satkhira

Treatment	Soil depth (cm)	EC_e (dS m^{-1}) December		% of salinity reduction	EC_e (dS m^{-1}) January		% of salinity reduction	EC_e (dS m^{-1}) February		% of salinity reduction	EC_e (dS m^{-1}) March		% of salinity reduction
		BP	RZ		BP	RZ		BP	RZ		BP	RZ	
T_1	0–30	3.15	2.74	13.01	3.42	3.08	9.94	3.80	3.54	6.84	4.98	4.75	6.61
T_2	0–30	3.15	2.74	13.01	3.74	3.43	8.28	5.48	5.18	5.47	6.00	5.60	6.66
T_3	0–30	3.15	2.74	13.01	3.97	3.76	5.28	5.92	5.60	5.40	6.18	5.80	6.14
T_4	0–30	3.15	2.74	13.01	5.85	5.40	7.69	7.88	7.50	4.82	10.25	9.85	3.90
IW (STW)	–	3.79			4.58			4.79			5.1		

Table 34.12 Month-wise soil salinity levels in the experimental field of barley at Kulia, Debhata, Satkhira

		EC(dS m^{-1}) February			EC(dS m^{-1}) March			EC(dS m^{-1}) April		
Treatment	Soil depth (cm)	BP	RZ	% of salinity reduction	BP	RZ	% of salinity reduction	BP	RZ	% of salinity reduction
T_1	0–30	4.50	4.00	11.11	4.75	4.50	5.26	5.30	5.18	2.26
T_2	0–30	4.50	4.00	11.11	6.93	6.15	11.25	7.50	7.19	4.13
T_3	0–30	4.50	4.00	11.11	7.05	6.60	6.38	8.00	7.53	5.87
T_4	0–30	4.50	4.00	11.11	10.30	9.90	3.88	11.10	10.60	4.50
IW (Canal)	–	5.12			5.36			5.83		

Table 34.13 Yield of tomato under different soil and irrigation management treatments

	Doulatpur		Kulia	
Sequence	Maximum soil salinity – EC_e (dS m^{-1})	Yield (t ha^{-1})	Maximum soil salinity – EC_e (dS m^{-1})	Yield (t ha^{-1})
*T*1	4.71	66.00	4.43	55.33
*T*2	6.33	53.33	6.16	41.66
*T*3	5.75	58.81	5.60	48.00
*T*4	8.52	42.33	7.39	38.66
*T*5	11.79	19.66	10.84	17.66
CV (%)	–	7.24	–	6.66
LSD (0.05)	–	5.94	–	4.79

Table 34.14 Yield of cowpea under different soil and irrigation management treatments

	Doulatpur		Kulia	
Sequence	Maximum soil salinity – EC_e (dS m^{-1})	Yield (green fodder) (t ha^{-1})	Maximum soil salinity – EC_e (dS m^{-1})	Yield (green fodder)(t ha^{-1})
*T*6	4.75	53.00	5.35	50.66
*T*7	5.74	45.00	7.56	43.00
*T*8	5.90	44.00	8.05	42.50
*T*9	9.97	25.66	11.15	24.66
CV (%)	–	6.42	–	6.63
LSD (0.05)	–	5.44	–	5.12

and Kulia (Tables 34.5 and 34.13). The farmer's practice (Treatment T_5: can irrigation in flatland without mulch) produced the lowest yield in both the sites.

Tables 34.14 and 34.15 present the performance of cowpea and barley under saline soils irrigated with fresh and saline water in the selected sites, respectively. As expected, the yield of cowpea and barley decreased with the increase in soil salinity. At plantation, the soil salinity was 3.14 dS m^{-1} in Doulatpur and 4.55 dS m^{-1} in Kulia in cowpea field. The average salinities during the study period varied from 4.75 dS m^{-1} in treatment T_6 to 9.97 dS m^{-1} in treatment T_9 during the crop season at Doulatpur. The highest fodder yield of 53 t ha^{-1} in T_6 and the lowest of 25.66 t ha^{-1} in T_9 were obtained. This indicates that quite an adequate amount of forage can be obtained from a maximum soil salinity of about 12 dS m^{-1} or so by using hosepipe irrigation with fresh water in raised bed at 7-day interval. In a similar initial soil salinity of 4.55 dS m^{-1} in Kulia, the same crop produced almost identical highest yield of 50.66 t ha^{-1} under the same treatment, T_6, when saline water (5.0–6.5 dS m^{-1}) was used. As usual, the treatment, T_9, which is farmer's practice, produced the lowest yield of cowpea in Kulia.

The performance of barley was found to follow the same sequence as of cowpea. Like cowpea, the hosepipe irrigation in raised bed at 7-day interval (T_{10}) also produced the highest yield of barley in Doulatpur and Kulia (Table 34.15).

Table 34.15 Yield of barley under different soil and irrigation management treatments

Sequence	Doulatpur		Kulia	
	Maximum soil salinity – EC_e (dS m^{-1})	Yield (green fodder) (t ha^{-1})	Maximum soil salinity – EC_e (dS m^{-1})	Yield (green fodder) (t ha^{-1})
*T*10	4.98	74.33	5.30	61.66
*T*11	6.00	66.66	7.50	54.00
*T*12	6.18	63.33	8.00	52.66
*T*13	10.25	43.33	11.10	33.66
CV (%)	–	5.58	–	7.09
LSD (0.05)	–	6.89	–	7.14

Table 34.16 Economic return from tomato under different management treatments

	Management treatments				
Indicator	*T*1	*T*2	*T*3	*T*4	*T*5
Doulatpur					
Yield (t ha^{-1})	66.00	53.33	59.66	42.33	19.66
Return from yield (US$ ha^{-1})	5,577	4,507	4,970	3,577	1,661
Total cost (US$ ha^{-1})	2,018	1,840	1,360	1,343	1,043
Net return (US$ ha^{-1})	3,559	2,667	3,610	2,234	618
Benefit-cost ratio	2.76	2.45	3.71	2.66	1.59
Kulia					
Yield (t ha^{-1})	55.33	41.66	48.00	38.88	17.66
Return from yield (US$ ha^{-1})	4,676	3,521	4,056	3,267	1,492
Total cost (US$ ha^{-1})	2,018	1,840	1,360	1,343	1,043
Net return (US$ ha^{-1})	2,658	1,681	2,696	1,924	449
Benefit-cost ratio	2.32	1.91	2.99	2.43	1.43

From Tables 34.13, 34.14, and 34.15, it is found that there were significant differences among the yields of the selected soil and irrigation management treatments. For tomato, drip irrigation in raised bed with mulch (T_1) and for cowpea and barley, hosepipe irrigation with saline and nonsaline water in raised bed at 7-day interval was found to produce the respective highest yields in the selected sites at Kulia and Doulatpur. Thus, the tested management practices were found feasible for growing tomato and forage crops in the saline soils of the coastal areas of Bangladesh.

34.3.3 Profitability Analysis

To evaluate the economic performances of the tested management practices for the selected cash and forage crops, the data were analyzed. The cost of all inputs for crop production was calculated based on prevailing market prices during the study period and treated as cash cost. Interest on operating capital basis was calculated based on cash costs for the period of 2 months at the rate of 7% a year. Opportunity cost of land, cost of irrigation equipment, and interest on operating capital were

Table 34.17 Economic return from cowpea under different managements

	Management treatments			
Indicator	*T*6	*T*7	*T*8	*T*9
Doulatpur				
Yield (t ha^{-1})	53.00	45.00	44.00	25.66
Return from yield (US$ ha^{-1})	1,120	951	930	542
Total cost (US$ ha^{-1})	427	419	376	369
Net return (US$ ha^{-1})	693	532	554	173
Benefit-cost ratio	2.62	2.27	2.47	1.47
Kulia				
Yield (t ha^{-1})	50.66	43.00	42.50	24.66
Return from yield (US$ ha^{-1})	1,070	908	898	521
Total cost (US$ ha^{-1})	427	419	376	369
Net return (US$ ha^{-1})	643	490	522	152
Benefit-cost ratio	2.51	2.17	2.39	1.41

treated as fixed costs. Simple costs, returns, and benefit-cost ratios were analyzed and are presented in Tables 34.16 and 34.17.

The net benefits from the tested technologies were found to vary considerably for tomato and forages over locations and mode of production processes. The traditional practice, i.e., flatland crop production, always produced the lowest net return because of very low yields compared to those of improved practices. In tomato crop, the net return was the highest for the treatment hosepipe irrigation in raised bed with mulch (T_3) followed by drip irrigation in raised bed with mulch (T_1) (Table 34.16). Though the yield was higher in drip irrigation, the establishment cost of this method was much higher than that of pipe irrigation and thus the yield advantage of drip irrigation could not compensate its additional fixed cost and resulted in higher net return in pipe irrigation. The benefit-cost ratios were 3.71 and 2.99 for pipe irrigation in raised bed followed by 2.76 and 2.32 by drip irrigation in raised bed at Doulatpur and Kulia, respectively. The traditional practice produced the lowest benefit-cost ratios of 1.59 and 1.43, respectively, for Doulatpur and Kulia.

Cowpea yield was found the highest (53 t ha^{-1}) in hosepipe irrigation with fresh water in raised bed, and it also gave the highest net benefit of US$ 693 ha^{-1} at 7-day interval (T_6) with benefit-cost ratio of 2.62 in Doulatpur. The traditional practice of hosepipe irrigation in flatland (cowpea) with fresh water at 15-day interval (T_9) produced the lowest net return of US$ 173 ha^{-1} having the benefit-cost ratio of 1.47 in the same site. The other management sequences had intermediate net benefits and benefit-cost ratios (Table 34.17). In Kulia, similar results were obtained for the management sequences with the corresponding yields and benefit-cost ratios but somewhat low compared to those in Doulatpur. The highest and the lowest net benefits were US$ 643 ha^{-1} (benefit-cost ratio of 2.51) for hosepipe irrigation with fresh water in raised bed at 7-day interval and US$ 152 ha^{-1} (benefit-cost ratio of 1.41) for hosepipe irrigation with fresh water in flatland at 15-day interval, respectively (Table 34.17).

Table 34.18 Economic return from barley under different managements

Indicator	Management treatments T_{10}	T_{11}	T_{12}	T_{13}
Doulatpur				
Yield (t ha^{-1})	74.33	66.66	63.33	43.33
Return from yield (US$ ha^{-1})	2,094	1,878	1,784	1,221
Total cost (US$ ha^{-1})	549	540	497	490
Net return (US$ ha^{-1})	1,545	1,338	1,287	731
Benefit-cost ratio	3.82	3.48	3.59	2.49
Kulia				
Yield (t ha^{-1})	61.66	54.00	52.66	33.66
Return from yield (US$ ha^{-1})	1,740	1,521	1,483	948
Total cost (US$ ha^{-1})	549	540	497	490
Net return (US$ ha^{-1})	1,191	981	986	458
Benefit-cost ratio	3.17	2.82	2.98	1.93

Barley, as fodder, was found highly profitable as it produced net returns of as high as US$ 1,545 ha^{-1} with hosepipe saline water irrigation in raised bed at 7-day interval (T_{10}) in Doulatpur and US$ 1,191 ha^{-1} with hosepipe saline water irrigation in raised bed at 7-day interval (T_{10}) in Kulia (Table 34.18). The benefit-cost ratios were 3.82 in Doulatpur and 3.17 in Kulia for the treatment T_{10}. The lowest net benefit (cowpea) was obtained from hosepipe irrigation in flatland with fresh water (T_9) and saline water irrigation (barley) with hosepipe in flatland at 15-day interval (T_{13}) as 2.49 and 1.93 for Doulatpur and Kulia, respectively. Compared to cowpea, barley produced higher forages and it was also more profitable than cowpea. This is due to higher fodder yield potential and salinity-tolerant characteristics of barley.

34.3.4 Water Productivity

The water productivities of the tested sequences for tomato, cowpea, and barley were calculated on the basis of fruit yield of tomato and fresh fodder yields of cowpea and barley and volume of water used by the treatments (Tables 34.19, 34.20, and 34.21).

For tomato, the highest water productivities of 17.37 kg m^{-3} in Doulatpur and 14.19 kg m^{-3} in Kulia were found in treatment T_1 (i.e., drip irrigation in raised bed with mulch) followed by the treatment T_2 (i.e., drip irrigation in raised bed without mulch) (Table 34.19). The traditional practice T_5 (i.e., can irrigation in flatland without mulch) produced the lowest water productivity (3.64 kg m^{-3} in Doulatpur and 3.21 kg m^{-3} in Kulia). This indicates that drip irrigation with mulch is an efficient water application and management method than any other selected water application techniques.

Table 34.19 Water productivity (kg m^{-3}) of different treatments of tomato

	Management treatments				
Sites	T_1	T_2	T_3	T_4	T_5
Doulatpur	17.37	14.03	12.38	8.91	3.64
Kulia	14.19	10.68	9.66	7.82	3.21

Table 34.20 Water productivity (kg m^{-3}) of different treatments of cowpea

Sites	Management treatments			
Doulatpur	10.29 (T6)	10.09 (T7)	9.17 (T8)	5.76 (T9)
Kulia	9.84 (T10)	9.64 (T11)	8.91 (T12)	5.74 (T13)

Table 34.21 Water productivity (kg m^{-3}) of different treatments of barley

Sites	Management treatments			
Doulatpur	14.58 (T6)	13.89 (T7)	11.62 (T8)	9.85 (T9)
Kulia	13.56 (T10)	13.17 (T11)	11.20 (T12)	8.11 (T13)

Table 34.20 shows that hosepipe irrigation with and without saline water in raised bed at 7-day interval produced the highest water productivities of 9.84 kg m^{-3} in Kulia and 10.29 kg m^{-3} in Doulatpur for cowpea. The traditional flatland production practice produced the lowest water productivity (5.76 kg m^{-3} in Doulatpur and 5.74 kg m^{-3} in Kulia).

A similar trend was also obtained in water productivity of barley in both Doulatpur and Kulia sites. The hosepipe irrigation in raised bed at 7-day interval produced the highest water productivity and that in flatland at 15-day interval produced the lowest water productivity as usual (Table 34.21).

34.3.5 Seasonal Water Use

The water used in different treatments in a season by different crops at different locations is presented in Fig. 34.2. The seasonal water included applied water, effective rainfall and residual soil moisture. For tomato, cowpea, and barley, the water use varied, respectively, from 380–580 mm, 445–515 mm and 440–510 mm in Doulatpur and from 390–550 mm, 430–515 mm, and 410–470 mm in Kulia. Islam

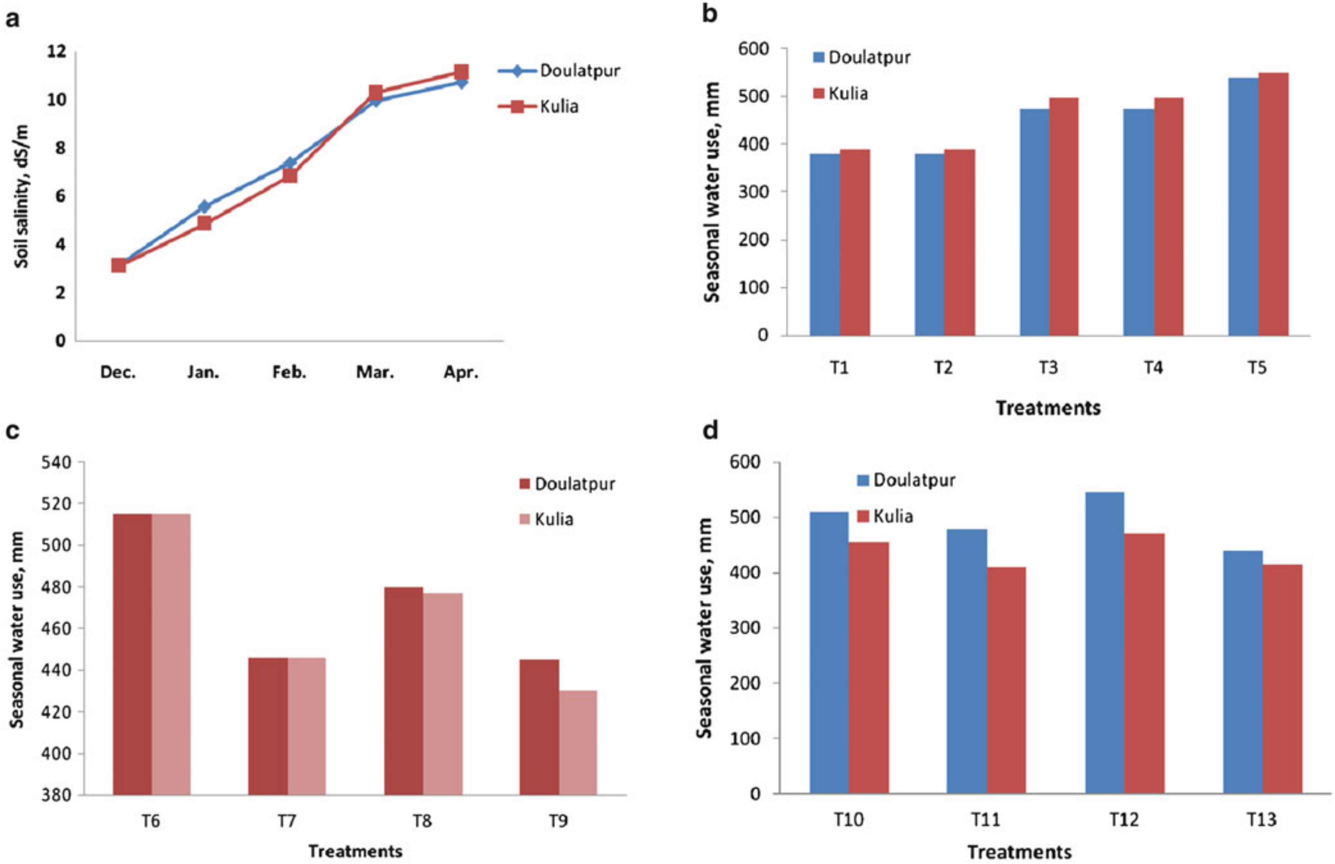

Fig. 34.2 (**a**) Soil salinity during the dry months of the year at two sites, (**b**) seasonal crop water use of tomato, (**c**) seasonal crop water use of cowpea, (**d**) seasonal crop water use of barley

et al. (2008) reported that seasonal water requirement of tomato in nonsaline soil of Bangladesh is around 320 mm and those of cowpea and barley for two cuttings as green fodder are 450 and 400 mm, respectively. Leaching requirement was not applicable in this case.

34.4 Conclusions

From the study, it is concluded that both the cash and fodder crops can be grown in lands having EC_e<12 dS m^{-1} covering about 770,000 ha in the coastal areas of Bangladesh. Soil and water management practices such as drip irrigation in raised bed with mulch and hosepipe irrigation in raised bed with mulch were more profitable than traditional practice for tomato production. For fodder (cowpea and barley) production, hosepipe irrigation in raised bed using fresh (<2.0 dS m^{-1}) and saline (<6.5 dS m^{-1}) waters was also found profitable (benefit-cost ratios: 2.51–2.62 for cowpea and 3.17–3.82 for barley). Since the management technologies had been tested in small areas, these should also be evaluated with regard to scaling-up of such technologies in the greater coastal belt.

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References

Abedin MZ (2010) Global warming, climate change and impact on agriculture of Bangladesh. In: Fourth national convention, Krishibid Institution, Bangladesh, Farmgate, Dhaka, 4–5 May 2010

BLRI (2007) Annual reports 2005 and 2006. Bangladesh Livestock Research Institute, Savar

Haque SA (2006) Salinity problems and crop production in coastal regions of Bangladesh. Review article. Pak J Bot 38(5):1359–1365

Islam MS, Akanda MAR, Islam MN, Islam ATMA, Akhand NA (2007) Development of integrated salinity management techniques for the coastal eco-system of Bangladesh. Report of Irrigation and Water Management Division, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur

Islam MS, Akanda MAR, Islam MN, Islam ATMA, Akhand NA (2008) Development of integrated salinity management techniques for the coastal ecosystem of Bangladesh. Annual report, ICBA Project, IWM Division

Maas MV, Hoffman GJ (1977) Crop salt tolerance, current assessment. J Irrig Drain Div ASCE 103:115–134

Mondal MK, Bhuiyan SI, Franco DT (2001) Soil salinity reduction and prediction of salt dynamics in the coastal rice lands of Bangladesh. Agric Water Manage 47(1):9–23, Elsevier, Dordrecht

MPO (Master Plan Organization) (1986) National water plan. Bangladesh Water Development Board, Dhaka, pp 43–44

Rahman SM, Khalil MI, Ahmed MF (1995) Yield-water relations and nitrogen utilization by wheat in salt affected soils of Bangladesh. Agric Water Manage 28(1):49–56

SRDI (Soil Resources Development Institute) (2000) Soil salinity in Bangladesh. Report of Ministry of Agriculture, People's Republic of Bangladesh

Rhoades JD (1974) Drainage for salinity control. *cf*. FAO. 1985. Water quality for agriculture by Ayers RS, Westcot DW. FAO Irrigation and Drainage Paper No.29 (Rev.1), Rome

Rhoades JD, Merrill SD (1976) Assessing the suitability of water for irrigation: Theoretical and empirical approaches. *cf*. FAO. 1985. Water quality for agriculture by Ayers RS, Westcot DW. FAO Irrigation and Drainage paper no. 29 (Rev.1), Rome

Soil Survey Division Staff (1993) Soil survey manual. USDA handbook no. 18

Part IV
Salt-Tolerance Mechanisms in Plants

Chapter 35
Salt Response of Some Halophytes with Potential Interest in Reclamation of Saline Soils: Gas Exchange, Water Use Efficiency and Defence Mechanism

Hans-Werner Koyro, Salma Daoud, and M. Cherif Harrouni

Abstract Most models about global changes predict the development of salt deserts with strongly degraded vegetation, unhealthy living conditions and negative impact on economic goods. The reservoir of freshwater on earth (especially in arid zones) is not sufficient to ensure the feeding of manhood in future. Furthermore, the substitution of freshwater against saline sources in combination with unprofessional artificial irrigation systems leads to an increasing destruction of useful areas and to strong economic damages. The consecutive increase of soil salinity is a threat for the productive land because most crops have only a low degree of salt resistance. In future, halophytes, plants with a natural high salt resistance, can play a major role for the rehabilitation and economic use of salt-affected habitats. Halophytic ecosystems present a high productivity and can be the base for a sustainable agriculture on saline soils.

A precondition is the extension of the up to now incoherent knowledge about the ecology of halophytes, their economic potential and – for the warranty of a sustainable use – also about their individual mechanisms of resistance. The physiological studies with the sea water irrigation system shown in this chapter have the potential to provide highly valuable means of detecting individual mechanisms of species against NaCl toxicity and may also provide opportunities for the comparison and screening of different varieties for their adaptation to salinity

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(QCS for cash crop halophytes). After the selection of halophytic species suited for a particular climate and for a particular utilisation, greenhouse experiments at the local substrates (and climatic conditions) to select and propagate promising sites have to be started.

Worldwide, initiatives are being undertaken to develop saline vegetable crops, as well as crops for fuel and fibre, but the use of halophytes is still in the early stages of development.

Keywords Gas exchange • Halophytes • Salt injury • Salt tolerance • Water relations

35.1 Introduction

Seven percent of the land's surface and 5% of cultivated lands are affected by salinity (Ghassemi et al. 1995; Szabolcs 1994), with salt stress being one of the most serious environmental factors limiting the productivity of crop plants. When soils in arid regions of the world are irrigated, solutes from the irrigation water can accumulate and eventually reach levels that have an adverse affect on plant growth. Of the current 230 million ha of irrigated land, 45 million ha are salt-affected (19.6%) and of the 1,500 million ha under dryland agriculture, 32 million ha are salt-affected to varying degrees (2.1%). There are often no sufficient reservoirs of freshwater available, and most of the agronomically used irrigation systems are leading to a permanent increase in the soil salinity and step by step to growth conditions inacceptable for most of the conventional crops. Significant areas are becoming unusable each year. It is a worldwide problem, but most acute in Australasia (3.1 million ha), the Near East (1,802 million ha) and Africa (1,899 million ha), North and Latin America (3.963 million ha) and to an increasing degree also in Europe (2.011 million ha) of salt-affected soils (FAO 2008). Despite advances in increasing plant productivity and resistance to a number of pests and diseases, improving salt tolerance in crop plants remains elusive, mainly because salinity simultaneously affects several aspects of plant physiology.

In contrast to crop plants, there exist specialised plants that thrive in the saline environments along the seashore, in estuaries and saline deserts. These plants, called halophytes, have distinct physiological and anatomical adaptations to counter the dual hazards of water deficit and ion toxicity. Salinity can affect any process in the plant's life cycle, so that tolerance will involve a complex interplay of characters. New insights into the mechanisms by which plants achieve this have emerged from research projects investigating details of the physiology and biochemistry of salt tolerance. Unfortunately, there are few investigations which combine studies of growth and other measurements on both biophysical and biochemical plant characteristics. Such joint investigations will be particularly important in the discovery of traits which present the ability to maintain high plant productivity in saline environments.

The sustainable use of halophytic plants is a promising approach to valorise strongly salinised zones unsuitable for conventional agriculture and mediocre waters (Boer and Gliddon 1998; Lieth et al. 1999). There are already many halophytic species used for economic interests (human food, fodder) or ecological reasons (soil desalinisation, dune fixation, CO_2-sequestration). However, the wide span of halophyte utilisation is not yet explored even to a small degree.

35.1.1 Halophytes: Plants Able to Complete Their Life Cycle on Saline Substrates

Saline conditions reduce the ability of plants to absorb water, causing rapid reductions in growth rate, and induce many metabolic changes similar to those caused by water stress (Epstein 1980).

Halophytes are plants, able to complete their life cycle in a substrate rich in NaCl (Schimper 1891). One of the most important properties of halophytes is their salinity tolerance (Lieth 1999). This substrate offers for obligate halophytes advantages for the competition with salt-sensitive plants (glycophytes). There is a wide range of tolerance among the 2,600 known halophytes (Pasternak 1990; Lieth and Menzel 1999). However, information about these halophytes needs partially careful checking. A precondition for a sustainable utilisation of suitable halophytes is the precise knowledge about their salinity tolerance and the various mechanisms enabling a plant to grow at (their natural) saline habitats (Marcum 1999; Warne et al. 1999; Weber and D'Antonio 1999; Winter et al. 1999). This chapter concentrates on the eco-physiological mechanisms of salt tolerance.

35.1.2 Complexity of Salt Tolerance

Most crop plants do not fully express their original genetic potential for growth, development and yield under salt stress, and their economic value declines as salinity levels increase (Läuchli and Epstein 1990; Maas 1990). Numerous attempts have been made to improve the salt tolerance of crops by traditional breeding programmes. However, commercial success has been very limited due to the complexity of the trait: salt resistance is genetically and physiologically complex (Flowers 2004). At present, major efforts are being directed towards the genetic transformation of plants in order to raise their tolerance (Borsani et al. 2003).

Improving salt resistance of crop plants is of major concern in agricultural research. A potent genetic source for the improvement of salt resistance in crop plants resides among wild populations of halophytes (Glenn et al. 1999; Serrano et al. 1999). These can be either domesticated into new, salt-resistant crops or used as a source of genes to be introduced into crop species by classical breeding or molecular methods.

35.1.3 State of the Art in Sustainable Utilisation with Saline Irrigation Waters

There are already several examples known for the utilisation of halophytes for industrial, ecological or agricultural purposes (Lieth et al. 1999). Because of their diversity, halophytes have been tested as vegetable, forage and oilseed crops in agronomic field trials (Koyro et al. 2006; Hoek 2008). The most productive species yield 10–20 t ha^{-1} of biomass on sea water irrigation, equivalent to conventional crops. The oilseed halophyte, *Salicornia bigelovii*, yields 2 t ha^{-1} of seeds containing 28% oil and 31% protein, similar to soybean yield (Glenn et al. 1999).

In several countries, specific plant species are used for waste water treatment. Some halophytes can be used for bioremediation of salt-contaminated soils, and even pharmaceutical values of their plant products are described (Lieth et al. 1999; Hoek 2008; Rozema and Flowers 2008). Halophyte forage and seed products already replaced conventional ingredients in animal feeding systems, with some restrictions on their use due to high salt content and anti-nutritional compounds present in some species.

35.2 The Quick Check System

It is – without doubt – necessary to develop sustainable biological production systems which can tolerate higher water salinity because freshwater resources will become limited in near future (Lieth 1999). A precondition is the identification and/or development of salinity tolerant crops. An interesting system approach lines out that after halophytes are studied in their natural habitat and a determination of all environmental demands has been completed, the selection of potentially useful plants should be started (Lieth 1999). The first step of this identification list contains the characterisation and classification of the soil and climate, under high potentially useful halophytes grow. Only artificial conditions in sea water irrigation systems in a growth cabinet under photoperiodic conditions offer the possibility to study potentially useful halophytes under reproducible experimental growth and substrate conditions. The supply of different degrees of sea water salinity (0, 25, 50, 75, and 100% (and if necessary higher) sea water salinity) to the roots in separate systems under otherwise identical or/and close to natural conditions gives the necessary preconditions for a comparative study in a quick check system (QCS) for potential cash crop halophytes (US Salinity Laboratory Staff 1954). The experiments of the QCS started off at steady state conditions in a gravel/hydroponic system imitating the climatic conditions of subtropical dry regions (Fig. 35.1, Koyro and Huchzermeyer 1999a). It is well known that salinity tolerance depends on the stage of development and period of time over which the plants have grown in saline conditions (Munns 2002). Plants were exposed to salinity in the juvenile state of development and were studied until achieving the steady state of adult plants. Variable applicable QCS seems to be valuable for the selection of useful plants, and it suggests itself as a first

Fig. 35.1 Quick check systems of several halophytes under photoperiodic conditions in a growth cabinet; (**a**) *Chenopodium quinoa*, (**b**) *Beta vulgaris ssp. Maritime*, (**c**) *Spartina townsendii*, (**d**) *Inula critmoides*, (**a**, **b**, and **d**) Gravel/hydroponic quick check system with automatic drip irrigation. (**c**) Intertidal irrigation (alternating water level) quick check system

step for the controlled establishment of cash crop halophytes because it provides detailed information about three major goals as they are the threshold of salinity tolerance at idealised growth conditions, how to uncover the individual mechanisms for salt tolerance and about the potential of utilisation for the pre-selected halophytic species (cash crop halophytes).

35.3 Threshold of Salinity Tolerance

In correspondence with the definition for the threshold of salinity tolerance according to Kinzel (1982), the growth reaction and the gas exchange are used during the screening of halophytes as objective parameters for the description of the actual condition of a plant (Ashraf and O'Leary 1996). There are now reliable information available about studies with several halophytic species from different families such as *Chenopodium quinoa* (Figs. 35.1a and 35.2a), *Aster tripolium*, *Plantago* cf. *coronopus*, *Beta vulgaris* ssp. *maritima* (Figs. 35.1b and 35.2b), *Batis maritima*, *Puccinellia maritima*, *Spartina townsendii* (Figs. 35.1c and 35.2c), *Atriplex nummularia*,

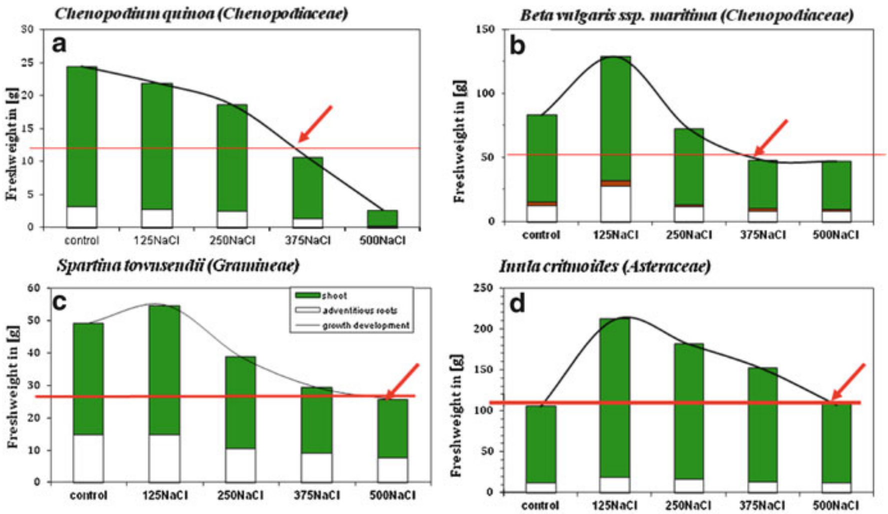


Fig. 35.2 Development of the plant freshweight at treatments with different percentages of sea water salinity. The crossover of the red and the black lines reflects the NaCl salinity where the growth depression falls down to 50% of the control plant (threshold of NaCl salinity according to Kinzel, 1982). (**a**) *Chenopodium quinoa* (*Chenopodiaceae*) 75% sea water salinity; (**b**) *Beta vulgaris* ssp. *maritima* (*Chenopodiaceae*): 75% sea water salinity; (**c**) *Spartina townsendii* (*Gramineae*): 100% sea water salinity; (**d**) *Inula critmoides* (*Asteraceae*): 100% sea water salinity. 0% sea water salinity = control, 25% = 125NaCl, 50% = 250NaCl, 75% = 375NaCl and 100% = 500NaCl

Atriplex leucoclada, *Atriplex halimus*, *Laguncularia racemosa*, *Limoneastrum articulatum*, *Sesuvium portulacastrum* and *Inula critmoides* (Figs. 35.1d and 35.2d) (Pasternak 1990; Koyro and Huchzermeyer 1997, 1999a, 2004b; Koyro et al. 1999; Lieth and Menzel 1999; Koyro 2000). The substrate concentration leading to a growth depression of 50% (refer to freshweight, in comparison to plants without salinity) is easy to calculate with the QCS (by extrapolation of the data), and it leads to a precise specification of a comparative value for the threshold of salinity tolerance (Fig. 35.2a–d). Dramatic differences are found between halophytic plant species. The threshold of salinity tolerance amounts to 350 mol*m^{-3} NaCl in *Chenopodium quinoa* and *Beta vulgaris* ssp. *maritima* and 500 mol*m^{-3} in *Spartina townsendii* and in *Inula critmoides* (Fig. 35.2). These results prove that it is essential to quantify differences in salinity tolerance between halophytic species as one basis for assessment of their potential of utilisation.

35.4 Morphological Structures to Reduce Salt Concentrations

In many cases various mechanisms and special morphological structures are advantageous for halophytes since they help to reduce the salt concentrations especially in photosynthetic or storage tissue and seeds. Salt glands may eliminate large quantities of

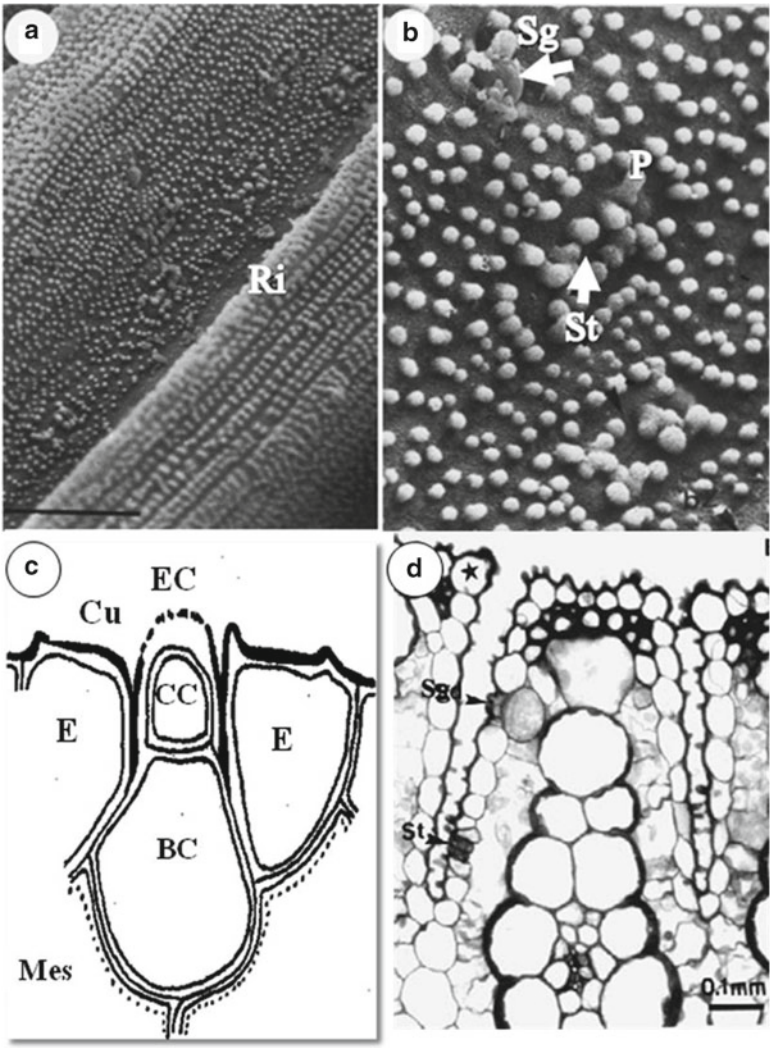


Fig. 35.3 Salt glands on a leaf of *Spartina townsendii*. The adaxial surface of the blade is increased enormously by ridges running from just above the pulvinus to the apex (**a**). These provide an increased assimilatory surface in addition to protection of the stomata (**a**, **b** and **d**). Latter one is also reached by papillae and waxy coating on the surface (**b**). Salt glands (**c** and **d**) take the place of the water pores found in many submerged plants. Scheme of a salt gland of *Spartina townsendii* (**c**). *Sg* salt gland, *St* stomata, *CC* capcell, *Ec* extracellular channel, *BC* basal cell, *P* papillae and waxy coating, *E* Epidermis, *M* mesophyll

salt by secretion to the leaf surface. This secretion appears in complex multicellular organs, for example, in *Avicennia marina* or by simple two cellular salt glands, for example, in *Spartina townsendii* (Fig. 35.3, Sutherland and Eastwood 1916; Walsh 1974; Koyro and Stelzer 1988; Koyro et al. 1997; Marcum et al. 1998). Several halophytes can reduce the salt concentrations in vital organs by accumulation in bladder hairs (*Atriplex halimus*, *Leptochloa fusca* (L.), *Halimione portulacoides*), enhancing the LMA (leaf mass to area ratio, e.g. by *Suaeda fruticosa*, *Salicornia europaea*, *Salsola kali*, *Sesuvium portulacastrum*), establishing apoplastic barriers (Freitas and Breckle 1992, 1993a, b; Hose et al. 2001), translocating NaCl into special organs (z.B. *Kandelia candel* L.), using of ultrafiltration at the root level to exclude salt (*Avicennia marina*, *Sonneratia alba*) or shedding of old leaves (*Beta vulgaris* ssp. *maritima*, see literature in Marschner 1995; Schroeder 1998; Glaubrecht 1999; Koyro 2002).

35.5 Screening Procedure

However, many halophytic species can tolerate high sea water salinity without possessing special morphological structures. To achieve salt tolerance, three interconnected aspects of plant activity are important for plants with or without salt glands. Damage must be prevented, homeostatic conditions must be re-established and growth must resume. Growth and survival of vascular plants at high salinity depends on adaptation to both low water potentials and high sodium concentrations, with high salinity in the external solution of plant cells producing a variety of negative consequences. It is the exception that a single parameter is of major importance for the ability to survive at high NaCl salinity. A comprehensive study with the analysis of at least a combination of several parameters is a necessity to get a survey about mechanisms constitution leading at the end to the salinity tolerance of individual species. These mechanisms are connected to the four major constraints of plant growth on saline substrates:

(a) Water deficit
(b) Restriction of CO_2 uptake
(c) Ion toxicity
(d) Nutrient imbalance

Plants growing in saline habitats face the problem of having low water potential in the soil solution and high concentrations of potentially toxic ions such as chloride and sodium. Salt exclusion minimises ion toxicity but accelerates water deficit and diminishes indirectly the CO_2 uptake. Salt absorption facilitates osmotic adjustment but can lead to toxicity and nutritional imbalance.

The presence of soluble salts can affect growth in several ways (Mengel and Kirkby 2001). In the first place plants may suffer from water stress, secondly high concentrations of specific ions can be toxic and induce physiological disorders and thirdly intracellular imbalances can be caused by high salt concentration.

Terrestrial plants at saline habitats are often surrounded by low water potentials in the soil solution and atmosphere. Plant water loss has to be minimised under these circumstances, since biomass production depends mainly on the ability to keep a high net photosynthesis by low water loss rates. Therefore, one crucial aspect of the screening procedure is the study of growth reduction and leaf (plant) water

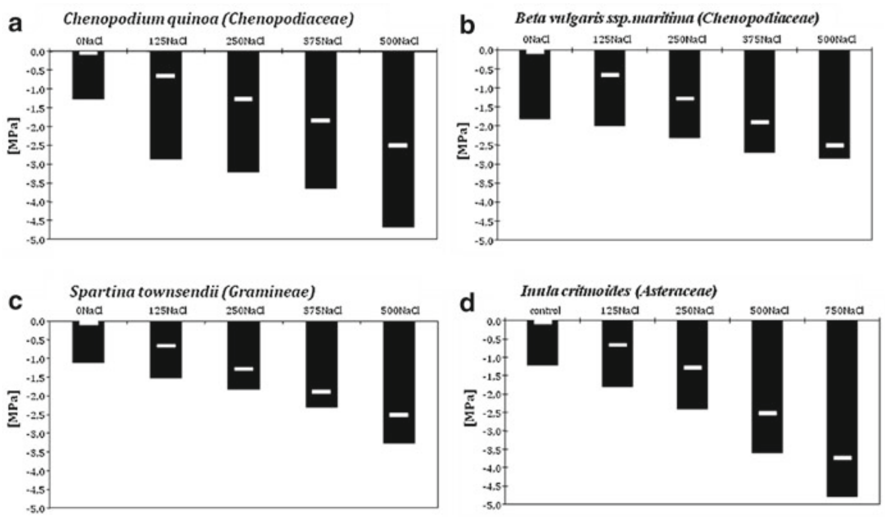


Fig. 35.4 Leaf water potentials (MPa) of (**a**) *Chenopodium quinoa* (*Chenopodiaceae*), (**b**) *Beta vulgaris* ssp. *maritima* (*Chenopodiaceae*) (**c**) *Spartina townsendii* (*Gramineae*) and (**d**) *Inula critmoides* (*Asteraceae*). The white lines in the bars mark the water potentials in the nutrient solutions. Leaf water potentials were always lower than the assigned nutrient solution potential. The difference between water potentials in the leaves and in the nutrient solutions decreased with increasing NaCl salinity. 0% sea water salinity = control, 100% sea water salinity = sea water salinity

potential especially at the threshold of salinity tolerance (Fig. 35.4). Water deficit is one major constraint at high salinity and can lead to a restriction of CO_2 uptake. The balance between water loss and CO_2 uptake is another basis for assessment of their potential of utilisation. Additionally, it helps to find weak spot in the mechanisms of adjustment (of photosynthesis) to high salinity.

35.6 Balance of Water Loss and CO_2 Uptake

Salt tolerance is not exclusively correlated with adaptations to Na^+ toxicity per se but also reflects adaptations to secondary effects of salinity such as water deficit and impaired nutrient acquisition (Maathuis and Amtmann 1999). Terrestrial plants at saline habitats are often surrounded by low water potentials in the soil solution and atmosphere. It is important to prevent water loss by transpiration from being higher than the influx rate. This is only possible if the water potential is lower in the plant than in the soil.

Data of leaf water potentials demonstrate clearly that leaf water potential of halophytes does not correlate alone as a single factor with salinity tolerance (Koyro 2006). They do not correlate at all with the respectively existing salt resistance in species such as *Chenopodium quinoa*, *Beta vulgaris* ssp. *maritima*, *Spartina townsendii* and

Sesuvium portulacastrum. All these species have a sufficiently low water potential even at high salinity although their salt resistance (definition see above) varies between 0.5 times (*Chenopodium quinoa*) and 1.5 times sea water salinity (*Sesuvium portulacastrum*). Furthermore, the osmotic potentials of all four halophytes (and many other) were sufficiently low to explain the full turgescence of the leaves at all salinity levels.

However, plant water loss has to be minimised at low soil water potentials, since biomass production depends mainly on the ability to keep a high net photosynthesis by low water loss rates. In this field of tension, biomass production of a plant has always to be seen in connection to the CO_2/H_2O-gas exchange which can be estimated based on water use efficiency (WUE) of photosynthesis. A critical point for the plant is reached if the CO_2-fixation (apparent photosynthesis) falls below the CO_2-production (compensation point). Therefore, one crucial aspect of the screening procedure is the study of growth reduction, water consumption and net photosynthesis especially at the threshold of salinity tolerance (Fig. 35.5).

Many plants such as *Chenopodium quinoa*, *Aster tripolium*, *Beta vulgaris* ssp. *maritima* or *Spartina townsendii* reveal a combination of low (but positive) net photosynthesis, minimum transpiration, high stomatal resistance and minimum internal CO_2-concentration at their threshold salinity tolerance (Koyro and Huchzermeyer 2004a). However, there is a big bandwidth between halophytes. Especially, succulent halophytes such as *Sesuvium portulacastrum* and *Avicennia marina* have alternatives if the water balance is still positive (water uptake minus water loss) and not the limiting factor for photosynthesis. In case of *Sesuvium* net photosynthesis and WUE increase but stomatal resistance decrease. These results show that it is quite important to describe the regulation of gas exchange at high salinity in strong reliance with other parameters (such as water relations).

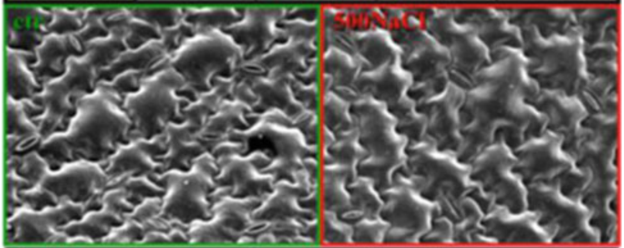
35.7 Ion Excess, Deficiency and Imbalance

In principle, salinity tolerance can be achieved by salt exclusion or salt inclusion. Several physiological mechanisms are described in literature which avoid salt injury (and to protect the symplast) are known as major plant responses to high NaCl salinity (Marschner 1995; Flowers et al. 1997; Mengel and Kirkby 2001; Munns 2002).

Useful parameters for screening halophytes should base on the major plant responses to high NaCl salinity (Volkmar et al. 1998). It seems to be essential that such a screening system should include salt-induced morphological changes such as succulence and LAR (leaf mass to area ratio, Koyro 2002), growth, water relations, gas exchange and composition of minerals (and compatible solutes) at different parts of the root system and in younger and older leaf tissues. The measurement of such general scientific data at plant, organ or tissue level reveals general trends – but since these represent a mean behaviour of several cell types, much information on single-cell adjustment are lost. They cannot give sufficient information about the compartmentation inside a cell or along a diffusion zone in a root apoplast or about

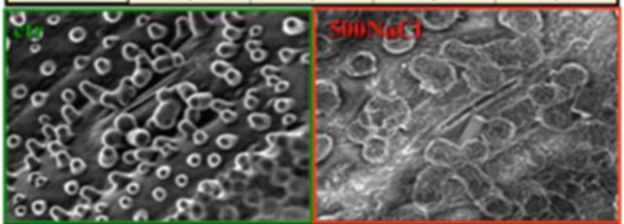
a

Beta vulgaris ssp. *maritima*	A $(\mu mol^*m^{-2}s^{-1})$	E $(mmol^*m^{-2}s^{-1})$	WUE (A/E)	rs $(m^{2}*s*mol^{-1})$
control	2,79	1,82	1,53	6,44
	+0,22	+1,30	+0,69	+2,90
125NaCl	3,13	1,87	1,68	4,53
	+0,20	+0,64	+0,56	+1,24
375NaCl	2,90	1,17	2,47	9,67
	+0,10	+0,11	+0,17	+1,23
500NaCl	1,58	0,44	3,62	31,45
	+1,01	+0,27	+2,44	+16,73



b

Spartina townsendii	A $(\mu mol^*m^{-2}s^{-1})$	E $(mmol^*m^{-2}s^{-1})$	WUE (A/E)	rs $(m^{2}*s*mol^{-1})$
control	6,25	3,30	1,90	0,82
	±1,04	±0,20	±0,45	±0,20
125NaCl	8,17	3,17	2,57	1,46
	±1,01	±0,34	±2,34	±0,59
375NaCl	7,25	2,29	3,17	2,49
	±2,26	±0,20	±1,31	±0,74
500NaCl	7,52	1,25	6,01	5,06
	±1,54	±0,26	±1,92	±1,99



c

Sesuvium portulacastrum	A $(\mu mol^*m^{-2}s^{-1})$	E $(mmol^*m^{-2}s^{-1})$	WUE (A/E)	rs $(m^{2}*s*mol^{-1})$
control	5,47	1,46	3,76	28,45
	+1,06	+0,20	+0,22	+4,88
125NaCl	6,53	1,67	3,90	26,40
	+0,25	+0,34	+0,34	+4,28
375NaCl	6,95	1,42	4,87	24,36
	+0,57	+0,02	+0,50	+0,28
500NaCl	7,44	1,51	4,98	22,60
	+0,81	+0,26	+0,36	+2,32

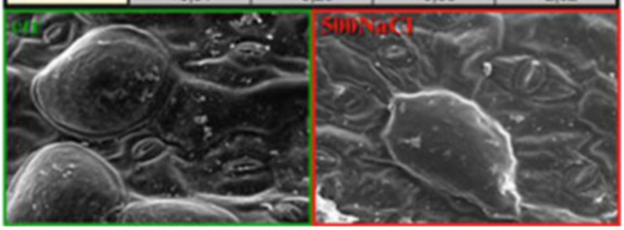


Fig. 35.5 Influence of NaCl salinity on the apparent photosynthesis (*A*), the adaxial transpiration (*E*), the water use efficiency (WUE) and the stomatal conductance (rs) of *Beta vulgaris* ssp. *maritima* (**a**), *Spartina townsendii* (**b**) and *Sesuvium portulacastrum*. The ultrastructures (SEM-micrograph) of the stomata on the leaf surfaces (*left side* controls, *right side* sea water salinity treatments) are presented next to the responding table

ultrastructural changes such as apoplastic barriers (Hose et al. 2001). The collection of scientific data should be completed if necessary (to uncover the individual mechanisms for salt tolerance) by a special physiological research at single-cell level supplemented optionally by methods such as the analysis of the gene expression and its genetic basis (genomics and proteomics, Winicov and Bastola 1997, 1999; Winicov 1998).

The general scientific data give an impression of various mechanisms of adaptation to high NaCl salinity. Besides water stress and ion-specific toxic physiological disorders on tissue level, intracellular ionic imbalances (K^+, Ca^{2+} and Mg^{2+}) can be caused by high salt concentrations (Mengel and Kirkby 2001). The capacity of plants to maintain K^+-homeostasis and low Na^+ concentrations in the cytoplasm appears to be one important determinant of plant salt tolerance (Yeo 1998; Läuchli 1999). A possibility to find such limiting factors is the study of the relations inside single cells such as the compartmentation between cytoplasm and vacuole, the distribution of elements in different cell types or along a diffusion zone in a root apoplast and ultrastructural changes.

Beta vulgaris ssp. *maritima* and *Spartina townsendii* keep Na and Cl concentrations low (Fig. 35.6) in their young growing tissues (such as juvenile leaves) and in their storage organs (such as taproot or rhizome). However, *Beta vulgaris* ssp. *maritima* is a typical Cl-includer and *Spartina townsendii* a typical Cl-excluder with high Na-accumulation in the leaves. Both species seem to react similar to salinity with changes of leaf water potential, gas exchange and nutrients (Koyro and Huchzermeyer 2004a). However, this number of partially congruent or complementary results does not allow concluding analogical intracellular relations. The comparison of their intracellular ionic balance will be used to demonstrate the necessity of special physiological investigations.

In contrast to water stress effects, occurring in the meristematic region of younger leaves, salt toxicity predominantly occurs in adventitious roots and mature leaves (Mengel and Kirkby 2001). Furthermore, most of the Na and Cl are stored mainly in the shoot of halophytes such as *Beta vulgaris* ssp. *maritima* and *Spartina townsendii* leading to a growth reduction of the above ground parts much higher than of the root (Koyro 2000; Koyro and Huchzermeyer 2004b). These changes can be interpreted as signs of a critical load. Therefore, to distinguish between the individual mechanisms of salinity tolerance, further investigations of the intracellular ionic balance were performed first of all at epidermal leaf cells (the end of the transpiration stream) of these both species.

The single cell data of the vacuolar and cytoplasmatic composition in cells of the upper leaf epidermis are summarised for the controls and the high-salinity treatments (at sea water salinity) in Table 35.1. The intracellular composition of the leaf epidermal cytoplasm and vacuoles of controls of *Beta vulgaris* ssp. *maritima* and *Spartina townsendii* show some more congruities of both species. The epidermal vacuoles of controls of both species contain most of the elements (with the exception of P) in higher concentrations as the cytoplasm indicating the overall picture of a vacuolar buffer. The leaf vacuoles in its entirety can be described as a voluminous potassium pool with high storage capacity for sodium and chloride. This pool is

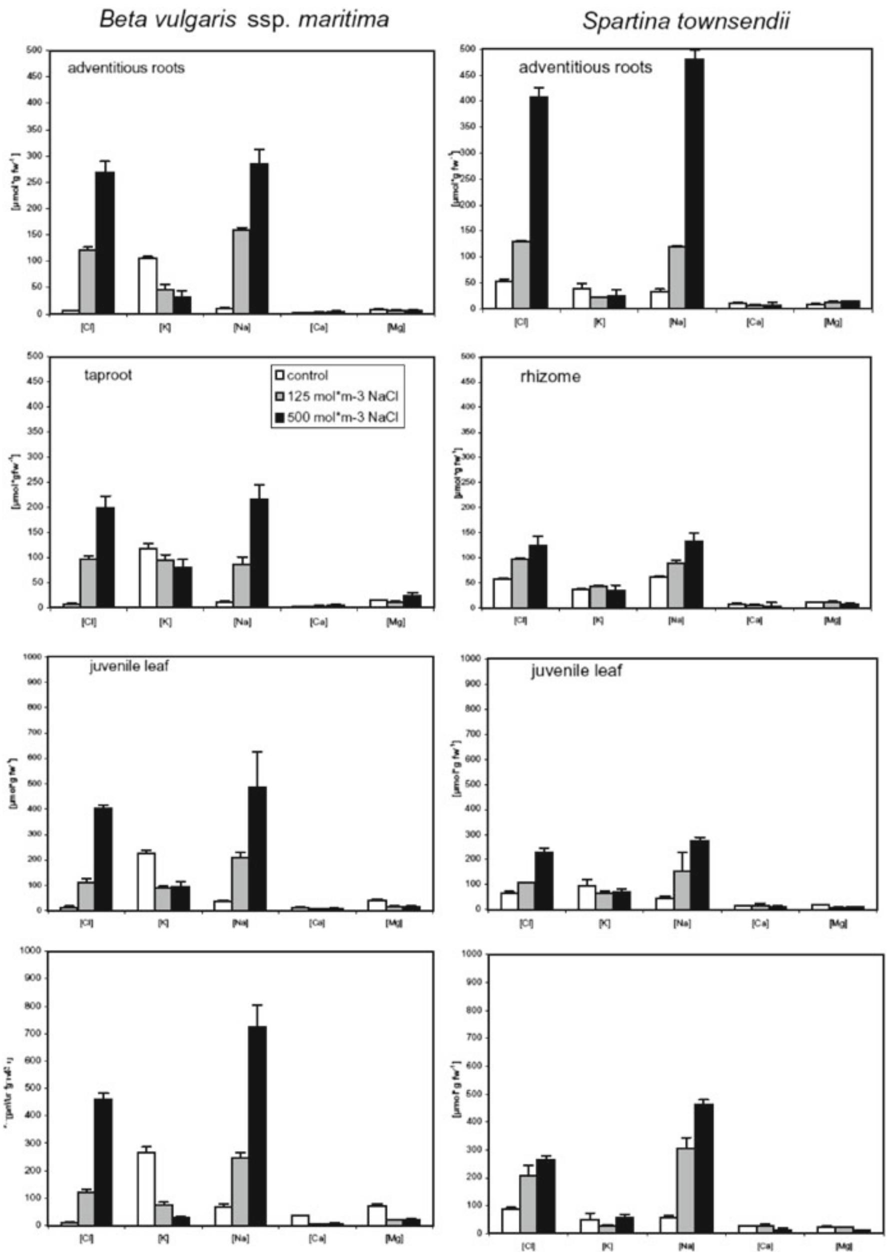


Fig. 35.6 Chlorine, potassium, sodium, calcium and magnesium concentrations in mol m^{-3} in different tissues of *Beta vulgaris* ssp. *maritima* and *Spartina townsendii*

Table 35.1 Chlorine, phosphorus, sulphur, sodium, magnesium, potassium and calcium concentrations in mol * m^{-3} (measured with EDX-analysis in bulk frozen tissues) in the vacuoles and in the cytoplasm of adaxial epidermis cells of *Beta vulgaris* ssp. *maritima* and *Spartina townsendii*

Adaxial leaf epidermis	Vacuole				Cytoplasm			
	Control		480 NaCl		Control		480 NaCl	
Beta vulgaris ssp. maritima								
Cl	22.6	±4.7	654.3	±54.8	0.0		<5	
P	22.2	±4.6	6.4	±4.2	58.2	±8.4	28.1	±6.7
S	40.4	±7.9	2.7	±1.9	10.5	±4.0	<5	
Na	12.2	±3.1	724.9	±65.1	<5		<5	
Mg	24.0	±1.2	4.3	±1.7	<5		<5	
K	282.5	±14.7	9.3	±6.1	88.9	±9.5	66.7	±7.2
Ca	<5		<5		<5		<5	
Spartina townsendii								
Cl	21.2	±3.2	324.3	±64.8	<5		<5	
P	11.1	±1.1	5.3	±2.1	81.5	±6.8	71.6	±10.8
S	24.4	±6.9	20.8	±2.6	8.8	±3.0	<5	
Na	16.4	±3.1	521.0	±54.9	<5		15.3	±3.2
Mg	29.6	±2.1	18.8	±1.6	<5		<5	
K	212.5	±34.8	71.5	±6.9	92.7	±12.7	78.4	±6.9
Ca	<5		<5	±2.1	<5		<5	

needed in case of high NaCl salinity for the maintenance of the K-homeostasis in the cytoplasm. The dominant elements in the cytoplasm were P and K. The K-concentrations were in the epidermal cytoplasm of control plants in an ideal range for enzymatic reactions (Wyn Jones et al. 1979; Wyn Jones and Pollard 1983; Koyro and Stelzer 1988).

It is obvious that sea water salinity leads to a decrease of P, S, Mg and K in the epidermal vacuoles of both species. The remaining K, S and Mg concentrations were only in *Spartina* two-digit and especially for K much higher as in *Beta*. The vacuolar buffer of the latter one seems to be exhausted.

NaCl salinity led to a significant decrease of the K and P concentrations especially in the cytoplasm of *Beta* and to a breakdown of the homeostasis (Koyro and Huchzermeyer 1997). This result points at a deficiency for both elements in the cytoplasm. Additionally, the concentrations of sodium and chlorine were at high NaCl salinity below 5 mol m^{-3} in the cytoplasm of the epidermal cytoplasm, and the gradients between cytoplasm and vacuole were higher in comparison with the results of *Spartina*. In summary these results support the hypothesis that the sea beet does not sustain ion toxicity but ion deficiency! It is hypothesised that such low K^{+} levels in the cytoplasm can lead to a reduction of protein synthesis which is of utmost importance in the process of leaf expansion (Mengel and Kirkby 2001). One possible consequence is the supply of sufficient fertilisers (especially K and P) at high NaCl salinity to reduce the symptoms of K- and P-deficiency in Beta.

The salt-induced reductions of the cytoplasmic K and P concentrations were much less pronounced in Spartina as in Beta. The results of Spartina point at a working system to keep ionic homeostasis. However, there was one important exception: The sodium concentration increased significantly in the epidermal cytoplasm. Sodium could (try to) substitute potassium in its cytoplasmic functions or it could be the first sign of intoxication.

The results and interpretations are in agreement with the hypothesis that plant growth is affected by ion imbalance and toxicity and probably leads to the long-term growth differences between the salt-tolerant and salt-sensitive species.

However, Beta and Spartina are also two excellent examples how important it can be to validate intracellular ionic imbalances (K^+, Ca^{2+} and Mg^{2+}) at high salt concentrations to uncover the individual mechanisms for salt tolerance and to understand the threshold levels of individual species.

35.8 Compatible Solutes

A metabolic response to salt stress especially in salt excluding species is the synthesis of compatible osmolytes. These mediate osmotic adjustment and therefore achieve a low water potential and/or a charge balance, protect subcellular structures and reduce oxidative damage caused by free radicals, produced in response to high salinity (Hong et al. 1992; Hare et al. 1998). The solute potential in these species is decreased by the synthesis of organic solutes such as sugar alcohols (e.g. mannitol in leaves of L*aguncularia racemosa*), soluble carbohydrates (e.g. sucrose in the taproots of *Beta vulgaris* ssp. *maritima*) and organic acids (including amino acids) or by reducing the matrical potential (e.g. with soluble proteins in leaves of *Beta vulgaris* ssp. *maritima*; results not shown). However, the synthesis of organic solutes is energy demanding (s.a. also includers), and the formation of these solutes decreases the energy status of the plant (Yeo 1983). Thus, for plant survival, growth depression in excluder species can be a necessary compromise in Na^+ and /or Cl^- excluding species and not a sign of toxicity or nutrient imbalance (Koyro and Huchzermeyer 1999b).

35.9 Protection of Metabolism

Mechanisms for tolerance of the salt-specific effects of salinity are of two main types: those minimising the entry of salt into the plant and those minimising the concentration of salt in the cytoplasm (Fig. 35.4). Root and leaf cytosolic Na^+ and Cl^- concentrations are in the order of 10–30 mM (Tester and Davenport 2003; Wyn Jones and Gorham 2002; Koyro and Huchzermeyer 2004b).

The destruction of metabolism by Na^+ or Cl^- has to be avoided if plants have to grow on saline habitats. Therefore, the protection of the responsible enzymes is of major importance. The ability of plant cells to maintain low cytosolic sodium concentrations is an essential process for halophytes (Borsani et al. 2003). Leaves being fed by the transpiration stream receive large quantities of sodium, which must be regulated. Plant cells respond to salt stress by increasing sodium efflux at the plasma membrane and sodium accumulation in the vacuole. Thus, the proteins, and ultimately genes, involved in these processes can be considered as salt tolerance determinants. The cloning experiments of Na^+/H^+ antiporter have demonstrated the role of intracellular sodium (Ohta 2002) compartmentalisation in plant salt resistance. Such compartmentalisation of sodium and chloride in leaf vacuoles can only be attained by an active transport into the vacuole and low tonoplast permeability to these ions.

The transport of ions across the plasma membrane and tonoplast requires energy, which is provided by vacuolar and plasma membrane ATPase (Gordon-Weeks et al. 1997; Koyro and Huchzermeyer 1997; Leigh 1997; Leigh and Sanders 1997). Sodium ions exchanged for hydrogen ions across membrane Na^+/H^+ antiporter take advantage of a proton gradient formed by these pumps. Salt stress was shown to increase Na^+/H^+ activity in glycophytes and halophytes (Apse and Blumwald 2002). The activation of such antiporter is likely to be operating to reduce sodium toxicity in salt-tolerant plants under saline conditions.

35.10 Overview of Results Presented

The results presented in this chapter contain a lot of information about the essential eco-physiological needs of several halophytes at high salinity. The very variable screening of individual species enables to study the characteristic combination of mechanisms against salt injury and the threshold of salinity tolerance. The so-called QCS can be modified to the special characteristics and needs of other species and is therefore useful to study a wide range of suitable halophytes. This screening procedure is a practical first step on the selection of economically important cash crop halophytes.

For future studies on utilisation potentials of halophytes, precise data about the ecological demands of halophytic species are required. Comparative physiological studies about salinity tolerance are essential. A precondition for this demand is a precise specification of a comparative value for halophytic species as shown in this chapter. The literature has to be screened prior to the selection of priority species (potentially useful species) in order to get first-order information about their natural occurrence in dry or saline habitats, existing utilisation (because of their structure, chemical content or other useful properties), natural climatic and substrate conditions, water requirement and salinity tolerance. Soon after the selection of a priority species, the threshold of salinity should be determined according to Kinzel (1982) and Munns (2002). The characteristic major plant response has to be evaluated for precise information of eco-physiological demands. The data can build up a well-founded basis for the improvement of the utilisation potential. Additionally, research about the genetic composition of chromosomes mastering saline environment is also needed and bases on quantitative precise determination (Winicov and Bastola 1997, 1999; Winicov 1998).

35.11 Development of Cash Crop Halophytes

The physiological studies with the sea water irrigation system have the potential to provide highly valuable means of detecting individual mechanisms of species against NaCl stress and may also provide opportunities for the comparison and screening of different varieties for their adaptation to salinity (QCS for cash crop halophytes). After the selection of halophytic species suited for a particular climate and for a particular utilisation, greenhouse experiments at the local substrates (and climatic conditions) to select and propagate promising sites (Isla et al. 1997) have to be started. This must be followed by studies with Lysimeters on field site to study the water consumption and ion movements. Last but not the least: A design for a sustainable production system in plantations at coastal areas or at inland sites (e.g. for economical use) needs to be developed.

35.12 Future Perspective

Time is running fast and the last decade has witnessed, especially in the arid and semi-arid regions, a sharp increase in losses of arable land due to salinisation. As shown above, salinity is an ever-present threat to crop yield, especially in countries where irrigation is an essential aid to agriculture (Flowers 2004). Irrigation farming is expanding fast, and many fields have reached a soil salinity level which prevents farmers from raising common crops. If we are not reacting soon, there is no further necessity to study salt-resistant genes because soil salinity worldwide will reach levels where no halophyte can grow at all.

References

Apse MP, Blumwald E (2002) Engineering salt tolerance in plants. Curr Opin Biotech 13:146–150

Ashraf M, O'Leary JW (1996) Effect of drought stress on growth, water relations, and gas exchange of two lines of sunflower differing in degree of salt tolerance. Int J Plant Sci 157:729–732

Boer B, Gliddon D (1998) Mapping of coastal ecosystems and halophytes (case study of Abu Dhabi, United Arab Emirates). Mar Freshw Res 49:297–301

Borsani O, Valpuesta V, Botella MA (2003) Developing salt tolerant plants in a new century: a molecular biology approach. Plant Cell Tiss Organ Culture 73:101–115

Epstein E (1980) Responses of plants to saline environments. In: Rains DW, Valentine RC, Hollaender A (eds) Genetic engineering of osmoregulation. Plenum Press, New York, pp 7–21. darter.ocps

FAO (2008) FAO Land and Plant Nutrition Management Service (www.fao.org/nr/land/en/)

Flowers TJ (2004) Improving crop salt tolerance. J Exp Bot 55:07–319

Flowers TJ, Troke PF, Yeo AR (1977) The mechanisms of salt tolerance in halophytes. Annu Rev Plant Physiol 28:89–121

Freitas H, Breckle SW (1992) Importance of bladder hairs for salt tolerance of field-grown Atriplex-species from a Portuguese salt marsh. Flora 187:283–297

Freitas H, Breckle SW (1993a) Progressive cutinization in Atriplex bladder stalk cells. Flora 188:287–290

Freitas H, Breckle SW (1993b) Accumulation of nitrate in bladder hairs of Atriplex species. Plant Physiol Biochem 31(6):887–892

Ghassemi F, Jakeman AJ, Nix HA (1995) Salinisation of land and water resources: human causes, extent, management and case studies. USNW Press, Sydney

Glaubrecht M (1999) Mangrove der tropischen Gezeitenwälder; Naturw Rdsch 52

Glenn E, Brown JJ, Blumwald E (1999) Salt tolerance and crop potential of halophytes. Critic Rev Plant Sci 18:227–255

Gordon-Weeks R, Koren'kov VD, Steele SH, Leigh RA (1997) Tris is a competitive inhibitor of K^+ activation of the vacuolar H^+-pumping pyrophosphatase. Plant Physiol 114:901–905

Hare PD, Cress WA, Van Staden J (1998) Dissecting the roles of osmolyte accumulation during stress. Plant Cell Environ 21:535–554

Hoek J (2008) Biosaline biomass for energy, a solution for saline wastelands. In: Lieth H, Sucre MG, Herzog B (eds) Mangroves and halophytes: restoration and utilisation. Springer, Dordrecht, pp 147–153

Hong B, Barg R, Ho TH (1992) Developmental and organ specific expression of an ABA- and stress-induced protein in barley. Plant Mol Biol 18:663–674

Hose E, Clarkson DT, Steudle E, Schreiber I, Hartung W (2001) The exodermis: a variable apoplastic barrier. J Exp Bot 52:2245–2264

Isla R, Royo A, Aragues R (1997) Field screening of barley cultivars to soil salinity using a sprinkler and a drip irrigation. Plant Soil 197:105–117

Kinzel H (1982) Pflanzenökologie und Mineralstoffwechsel. Eugen Ulmer, Stuttgart

Koyro H-W (2000) Untersuchungen zur Anpassung der Wildrübe (*Beta vulgaris* ssp. *maritima*) an Trockenstreß oder NaCl-Salinität. Habilitation, Justus-Liebig-University Giessen, Germany

Koyro H-W (2002) Ultrastructural effects of salinity in higher plants. In: Läuchli A, Lüttge U (eds) Salinity: environment-plants-molecules. Kluwer Academic, Dordrecht, pp 139–158

Koyro H-W (2006) Effect of salinity on growth, photosynthesis, water relations and solute composition of the potential cash crop halophyte *Plantago coronopus* (L.). Environ Exp Bot 56(2):136–146

Koyro H-W, Huchzermeyer B (1997) The physiological response of *Beta vulgaris* ssp. *maritima* to sea water irrigation. In: Lieth H, Hamdy A, Koyro H-W (eds) Water management, salinity and pollution control towards sustainable irrigation in the mediterranean region, Salinity problems and halophyte use. Tecnomack, Bari, pp 29–50

Koyro H-W, Huchzermeyer B (1999a) Influence of high NaCl-salinity on growth, water and osmotic relations of the halophyte *Beta vulgaris* ssp. *maritima*. Development of a quick check. In: Lieth H, Moschenko M, Lohmann M, Koyro H-W, Hamdy A (eds) Progress in biometeorology, vol 13. Backhuys Publishers, Leiden, pp 87–101

Koyro H-W, Huchzermeyer B (1999b) Salt and drought stress effects on metabolic regulation in maize. In: Pessarakli M (ed) Handbook of plant and crop stress, 2nd edn. Marcel Dekker, New York, pp 843–878

Koyro H-W, Huchzermeyer B (2004a) Ecophysiological mechanisms leading to salinity tolerance – screening of cashcrop halophytes. Rec Res Dev Plant Sci 1:187–207

Koyro H-W, Huchzermeyer B (2004b) Ecophysiological needs of the potential biomass crop *Spartina townsendii* Grov. Trop Ecol 45:123–139

Koyro H-W, Stelzer R (1988) Ion concentrations in the cytoplasm and vacuoles of rhizodermal cells from NaCl treated *Sorghum*, *Spartina* and *Puccinellia* plants. J Plant Physiol 133:441–446

Koyro H-W, Wegmann L, Lehmann H, Lieth H (1997) Physiological mechanisms and morphological adaptation of *Laguncularia racemosa* to high salinity. In: Lieth H, Hamdy A, Koyro H-W (eds) Water management, salinity and pollution control towards sustainable irrigation in the mediterranean region: salinity problems and halophyte use. Tecnomack, Bari, pp 51–78. http://www.usf.uos.de/~hlieth/publications.html

Koyro H-W, Wegmann L, Lehmann H, Lieth H (1999) Adaptation of the mangrove *Laguncularia racemosa* to high NaCl salinity. In: Lieth H, Moschenko M, Lohmann M, Koyro HW, Hamdy A (eds) Progress in biometeorology, vol 13. Backhuys Publishers, Leiden, pp 41–62

Koyro H-W, Geissler N, Hussin S, Huchzermeyer B (2006) Mechanisms of cash crop halophytes to maintain yield and reclaim soils in arid areas. In: Khan MA, Weber DJ (eds) Ecophysiology of high salinity tolerant plants, vol 40, Task for vegetation science. Springer, Dordrecht, pp 345–366. ISBN ISBN-10 1-4020-4017-2(HB)

Läuchli A (1999) Potassium interactions in crop plants. In: Oosterhuis DM, Berkowitz GA (eds) Frontiers in Potassium Nutrition: new perspectives on the effects of potassium on physiology of plants. Marcel Dekker, New York, pp 71–76

Läuchli A, Epstein E (1990) Plant responses to saline and sodic conditions. In: Tanji KK (ed) Agricultural salinity assessment and management, ASCE Manual No. 71. ASCE, New York, pp 113–137

Leigh RA (1997) The solute composition of the vacuoles. Adv Bot Res 25:253–295

Leigh RA, Sanders D (1997) The plant vacuole: advances in botanical research, vol 25. Academic, London, p 463. ISBN ISBN 0 12 441870 8

Lieth H (1999) Development of crops and other useful plants from halophytes. In: Lieth H, Moschenko M, Lohmann M, Koyro H-W, Hamdy A (eds) Halophytes uses in different climates, ecological and ecophysiological studies. Backhuys Publishers, Leiden, pp 1–18

Lieth U, Menzel U (1999) Halophyte database Vers 2. In: Lieth H, Moschenko M, Lohmann M, Koyro H-W, Hamdy A (eds) Halophytes uses in different climates, ecological and ecophysiological studies. Backhuys Publishers, Leiden, pp 159–258

Lieth H, Moschenko M, Lohmann M, Koyro H-W, Hamdy A (1999) Progress in biometeorology, vol 13. Halophyte uses in different climates I. Ecological and ecophysiological studies. Backhuys Publishers, Leiden, p 258

Maas EV (1990) Crop salt tolerance. In: Tanji KK (ed) Agricultural salinity assessment and management, ASCE Manual No. 71. ASCE, New York, pp 262–304

Maathuis FJM, Amtmann A (1999) K^+ nutrition and Na^+ toxicity: the basis of cellular K^+/Na^+ ratios. Ann Bot 84:123–133

Marcum KB (1999) Salinity tolerance mechanisms of grasses in the subfamily *Chloridoideae*. Crop Sci 39:1153–1160

Marcum KB, Anderson SJ, Engelke MC (1998) Salt gland ion secretion: a salinity tolerance mechanism among five zoysiagrass species. Crop Sci 38:806–810

Marschner H (1995) Mineral nutrition of higher plants. Academic, London/New York/San Diego/Boston/Sydney/Tokyo/Toronto, p 889

Mengel K, Kirkby EA (2001) Principles of plant nutrition. Kluwer Academic, Dordrecht/Boston/London, p 849

Munns R (2002) Comparative physiology of salt and water stress. Plant Cell Environ 25:239–250

Ohta H (2002) Introduction of a Na^+/H^+ antiporter gene from *Atriplex gmelini* confers salt tolerance to rice. FEBS Lett 532:279–282

Pasternak D (1990) Fodder production with saline water. The institute for applied research, Ben Gurion University of the Negev. Project report BGUN-ARI-35-90. Beer-Sheva/Israel. p 173

Rozema J, Flowers T (2008) Crops for a salinized world. Science 322(5907):1478–1480

Schimper AFW (1891) Pflanzengeographie auf physiologischer Grundlage. Fischer Publisher, Jena

Schroeder FG (1998) Lehrbuch der Pflanzengeographie. Quelle & Meyer, Wiesbaden

Serrano R, Mulet JM, Rios G, Marquez JA, de Larrinoa IF, Leube MP, Mendizabal I, Pascual-Ahuir A, Proft M, Ros R, Montesinos C (1999) A glimpse of the mechanisms of ion homeostasis during salt stress. J Exp Bot 50:1023–1036

Sutherland GK, Eastwood A (1916) The physiological anatomy of Spartina townsendii. Ann Bot 30:333–351

Szabolcs I (1994) Soils and salinisation. In: Pessarakli M (ed) Handbook of plant and crop stress. Marcel Dekker, New York, pp 3–11

Tester M, Davenport R (2003) Na^+ tolerance and Na^+ transport in higher plants. Ann Bot 91:503–527

US Salinity Laboratory Staff (1954) Diagnosis and improvement of saline and alkali soils. In: Richards LA (ed) Agricultural handbook, vol 60. U.S. Department of Agriculture, Riverside

Volkmar KM, Hu Y, Steppuhn H (1998) Physiological responses of plants to salinity: a review. Can J Plant Sci 78:19–27

Walsh GE (1974) Mangroves: a review. In: Reimold RJ, Queen WH (eds) Ecology of halophytes. Academic, New York/London, pp 51–174

Warne TR, Hickok LG, Sams CE, Vogelien DL (1999) Sodium/potassium selectivity and pleiotropy in stl2, a highly salt-tolerant mutation of *Ceratopteris richardii*. Plant Cell Environ 22:1027–1034

Weber E, D'Antonio CM (1999) Germination and growth responses of hybridizing *Carpobrotus* species (*Aizoaceae*) from coastal California to soil salinity. Am J Bot 86:1257–1263

Winicov I (1998) New molecular approaches to improving salt tolerance in crop plants. Ann Bot 82:703–710

Winicov I, Bastola DR (1997) Salt tolerance in crop plants: New approaches through tissue culture and gene regulation. Acta Physiol Plant 19:435–449

Winicov I, Bastola DR (1999) Transgenic overexpression of the transcription factor Alfin1 enhances expression of the endogenous MsPRP2 gene in alfalfa and improves salinity tolerance of the plants. Plant Physiol 120:473–480

Winter U, Kirst GO, Grabowski V, Heinemann U, Plettner I, Wiese S (1999) Salinity tolerance in *Nitellopsis obtusa*. Aust J Bot 47:337–346

Wyn Jones RG, Gorham J (2002) Intra- and inter-cellular compartmentation of ions. In: Läuchli A, Lüttge U (eds) Salinity: environment – plants – molecules. Kluwer, Dordrecht, pp 159–180

Wyn Jones RG, Pollard A (1983) Proteins, enzymes and inorganic ions. In: Läuchli A, Bieleski RL (eds) Encyclopaedia of plant physiology, vol 15. Inorganic plant nutrition. Springer, New York, pp 528–555

Wyn Jones RG, Brady CJ, Speirs J (1979) Ionic and osmotic relations in plant cells. In: Laidman DL, Wyn Jones RG (eds) Recent advances in the biochemistry of cereals. Academic, New York

Yeo AR (1983) Salinity resistance: physiologies and prices. Physiol Plant 58:1399–3054

Yeo A (1998) Molecular biology of salt tolerance in the context of whole-plant physiology. J Exp Bot 49:915–929

Chapter 36
Salt Response of Halophytes with Potential Interest in Food Crops and Reclamation of Saline Soils: Growth, Water Relations, Mineral Content and Anatomical Adaptations

Salma Daoud, Hans-Werner Koyro, and M. Cherif Harrouni

Abstract Considering the interest for arid and semi-arid regions to improve biosaline agriculture by domestication and sustainable use of halophytic plants in salt-affected regions, present work was accomplished by studying diverse ecophysiological mechanisms of several promising candidates such as *Batis maritima*, *Sporobolus spicatus*, *Spartina alterniflora*, *Sesuvium portulacastrum*, *Beta vulgaris* ssp. *maritima* and *vulgaris* and *Aster tripolium*. They all share high economic potential, the ability for reclamation of salt-affected lands and to survive at high salinities. Seawater was used as the source of saline water at different dilutions with fresh water: 0% (control: fresh water), 25, 50, 75 and 100% seawater. Plants were cultivated in an automated irrigation and drainage system, in coastal sand as substrate, under highly reproducible greenhouse conditions (*quick check system*). The salt-tolerant species survived at all salinity treatments, and maximum growth occurred in low and moderate salinities (25 and 50% seawater). Beyond the optimal growth treatment, a progressive growth decrease took place. Threshold of salinity tolerance differed from one species to another which is related to osmotic adjustment by the regulation of minerals and water uptake from culture medium. To avoid toxicity of excess ion accumulation, halophytic plants have developed morphological and anatomical adaptations at the scale of the whole plant. The Na^+ and Cl^- were the dominant ions, and their concentrations increased with the increase of seawater

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concentrations while K^+ concentration decreased. However, the degree of NaCl – and the maintenance of K^+ content – accumulation differed between species. One similarity of all halophytes was the unaffected Ca^{2+} uptake and transport through the plants when plants are irrigated with seawater which is rich in Ca^{2+}.

Keywords Anatomic adaptations • Halophytes • Salinity tolerance • Seawater • Water relations

36.1 Introduction

The rapid global warming leads to increase drought and salinisation of water and arable lands especially in arid and semiarid regions. In these regions, the succession of drought years, the scarcity of water for irrigation and high evaporation rate cause secondary salinisation of agricultural lands, which limit productivity and causes physical, chemical and biological degradation of lands on extended areas (Lahlou 1999). Irrigation of salt-tolerant plants (halophytes) with saline water can produce useful biomass and can offer the opportunity to cultivate salt-affected lands in a form of productive agriculture (O'Leary and Glenn 1984; Glenn et al. 1982).

Present study is conducted to evaluate the potential of local halophytic species to be widely and economically used in arid and semi-arid regions. Major research topics are to identify and select promising halophytic plant species with adequate salt and drought tolerance, to study their potential in the field of human or animal nutrition and to evaluate the possible use of nonconventional waters, such as seawater, brackish water and pretreated wastewater (Koyro et al. 2008). Salinity is a multifactorial problem, and the use or the breeding of salt-resistant crop varieties will require a clear understanding to the complex mechanisms of salt-stress resistance, which is still lacking despite intensive research during the last decades (Apse and Blamwald 2002; Sosa et al. 2005).

The objective of this study is to determine the limit of salt tolerance, on the basis of growth reaction, and to investigate the mechanisms involved by some halophytic plant species to grow naturally in saline environments. Experiments were conducted in an automated irrigation and drainage quick check system (Koyro 1999) under artificial culture conditions, which offers the possibility to study the response of the plants to increasing seawater concentrations under reproducible experimental conditions. This is a necessary step prior to their cultivation under land conditions, which permits to have data about the optimal salt concentration for growth of each species and its potential of utilisation. The study correlated basic parameters such as growth and the threshold of salinity tolerance with special investigations of the water relations and morphological/anatomical adjustment to get a network of information determining the salt tolerance of these plants.

36.2 Materials and Methods

36.2.1 Culture System

Halophyte species with high economic potential and belonging to different families – *Sporobolus spicatus* (Poaceae), *Spartina alterniflora* (Poaceae), *Batis maritima* (Batidaceae), *Sesuvium portulacastrum* (Aizoaceae), *Beta vulgaris* ssp. *maritima* and *vulgaris* (Chenopodiaceae) and *Aster tripolium* (Asteraceae) – were studied with the aim to determine ecophysiological mechanisms allowing them to survive at highly saline environments. Sea beet and sugar beet plants were grown from seeds. *S. spicatus* and *S. alterniflora* seedlings were obtained from rhizome propagation, and those of *Aster tripolium*; *B. maritima* and *S. portulacastrum* were propagated by cuttings. All seedlings were grown in a mixture (50%, 50%) of sand and peat. At the beginning of the experiment, plants were transplanted in black plastic pots with coastal sand as substrate; the surface of the pots was covered with fine gravel to avoid crust formation. Pots were transferred in an automated irrigation and drainage system (*quick check system*; Koyro and Huchzermeyer 1999) constituted by 100-L containers regularly flooded for 15 min with irrigation water. Small pumps were used to recycle water four times per day starting at 8 am. This system has the advantage of good drainage and aeration of plant root system which promotes high productivity of plants for a short period. Seawater, at different dilutions with fresh water, was used for irrigation as the source of saline water: 0% (control: fresh water), 25, 50, 75 and 100% seawater. To ovoid osmotic shock, seawater was added progressively to tap water at the step of 1/8th every 2 days until the required concentration was achieved. Since seawater is poor in nitrogen and phosphorus, a nutrient solution containing 60 mg L^{-1} nitrogen, 6.5 mg L^{-1} phosphorus, 40 mg L^{-1} potassium and trace elements was used in order to fertilise the five treatments. Experiments were conducted under greenhouse and natural light conditions. Temperature was monitored daily with a “mini-maxi” thermometer. To ovoid impoverishment of nutrients for plants, irrigation water was changed fortnightly.

36.2.2 Growth Parameters and Chemical Analysis

After 6 weeks growth in the five treatments, four plants of each species were harvested, washed with cool distilled water (0°C) and drained off water in absorbing paper. Refrigerated water was used to prevent absorption of water by roots during washing procedure. Shoots and roots were weighed individually to determine fresh weight and oven dried at 65–70°C for at least 48 h. Growth was estimated on the basis of dry weight. Ash content was determined after burning 500 mg of dry samples of shoots and roots of each species overnight at 500°C. Mineral contents of each sample (Na^+, K^+, Ca^{2+} and Mg^{2+}) were measured after dissolving the ash in 2 N

HCl by Munter methods (Munter 1980), Na^+ and K^+ concentrations were determined by flame photometer 410 (FLM3b, radiometer Copenhagen) and those of Ca^{2+} and Mg^{2+} were measured in the same solution by atomic absorption spectrophotometer (PE 3110, Perkin Elmer). Mineral content in plant tissues was expressed on dry weight basis. Osmotic potential of the leaves of each species was measured in sap extract by measuring freezing point depression with an osmometer (Osmomat 030, GONOTEC) which is proportional to that of distilled water (Gonzalez et al. 1996). Three replicates per sample were measured. The values given by the apparatus correspond to the number of mosmols kg^{-1}.

36.3 Results and Discussion

Seawater used for irrigation of studied species had beneficial effects for plant's productivity since it contained high proportions of major ions such as K^+, Ca^{2+} and Mg^{2+} (Table 36.1). These elements are important for a number of physiological processes in plant cells (Kramer 1984; Goodin et al. 1990). However, nitrogen and phosphorus contents were very low; thus, it was necessary to ameliorate nutritive value of seawater treatments by the addition of nitrogen and phosphorus fertilisers.

Coastal sand used as substrate had a light texture (Table 36.2) allowing a good drainage of irrigation water and a good root aeration quality (Goodin et al. 1990; O'Leary et al. 1985). Munns (2002) reported that root system immersion induces lack of oxygen which inhibits oxidative phosphorylation. These conditions reduce the energy needed by pumps and carriers to control Na^+ absorption which affects the response of plants to salinity.

Table 36.1 Characteristics of seawater use for irrigation

pH	EC at 25°C ($dS\ m^{-1}$)	Dry residue ($g\ L^{-1}$)	Cl^- ($g\ L^{-1}$)	Na^+ ($g\ L^{-1}$)	K^+ ($g\ L^{-1}$)	Mg^{2+} ($g\ L^{-1}$)	Ca^{2+} ($g\ L^{-1}$)	SO_4^{2-} ($g\ L^{-1}$)	HCO_3^-	N (Total)
7.85	53.10	43.62	20.50	12.19	0.33	1.10	0.40	3.50	0.17	Trace

Table 36.2 Physical and chemical characteristics of sand used as substrate

Physical characteristics						
Coarse sand (0.2–2 mm)	Fine sand (50–200 μm)	Coarse silt (20–50 μm)	Fine silt (2–20 μm)	Clay (<2 μm)	EC ($dS\ m^{-1}$)	pH (water)
24.82%	74.43%	0.75%	0.00%	0.00%	0.19	8.9

Chemical characteristics									
CaO	N (Total)	Na_2O	MgO	K_2O	P_2O_5	Fe	Zn	Mn	Cu
($mg\ kg^{-1}$)									
984	980	227	111	48	14	14.1	0.7	0.5	0.3

36.3.1 Growth Parameters

The use of the automated irrigation and drainage quick check system (Koyro 1999) combined with sand as substrate and seawater irrigation gave remarkable results of plants tested during a short period. The survival of all species was 100% in all saline treatments, and no sign of chlorosis or deficiency was registered during the period of the experimentation (6 weeks). The response of the studied plants to different levels of salinity was traduced at the scale of the whole plants by the stimulation of biomass, expressed by production of dry matter (or fresh matter in the case of the sea beet and sugar beet), at low and moderate salinities and a progressive decrease of biomass weight in high salinity treatments. It is a typical reaction of halophytes to saline stress (Kelley et al. 1982; Glenn and O'Leary 1984; Munns and Termatt 1986; Maas 1987; Gorham 1996; Munns 2002). However, the limit of salt tolerance differed from one species to another (Fig. 36.1). The most salt-tolerant species, *Batis maritima*, *Spartina alterniflora* and *Sporobolus spicatus*, had their limit of salt tolerance exceed full-strength seawater concentration, whereas the limit of salt tolerance of *Sesuvium portulacastrum* and *Aster tripolium* was between 75 and 100% seawater salinity. *Beta maritima* and *Beta vulgaris* had a moderate salinity tolerance since their limit of salt tolerance was respectively at 40 and 30% seawater salinity (Fig. 36.1). These results show a high variability in the response of different species to increasing salinity which is in accordance with Munns (2002) and Pitman and Läuchli (2002).

Relatively to biomass curves established by Greenway and Munns (1980) and by Munns (2002) for a variety of halophytic and glycophytic plants having different degrees of salinity tolerance and growing for a period of 4 weeks in increasing salinity conditions, we can classify studied plants in three categories (Figs. 36.1 and 36.2).

Species presenting halophytic plant's characteristics expressed maximum growth in treatments with low and moderate salinities (Kelley et al. 1982; Glenn and O'Leary 1984; Gorham 1996; Breckle 2002; Munns 2002). In this category, there are species like *Sporobolus spicatus* and *Batis maritima* for which biomass was stimulated by 50% seawater salinity and those stimulated 25% seawater salinity: *Spartina alterniflora*, *Sesuvium portulacastrum* and *Beta maritima* (Fig. 36.2). Marschner (1995) explained growth stimulation by the effect of Na^+ on cellular expansion and water balance. Nevertheless, beyond optimal salinity treatment of each species, biomass of all species was reduced relatively to increasing seawater concentration in irrigation water. For the species of this category, biomass reduction was not very important at the whole plant level. It was, in 100% seawater, 1.5 and 2 times higher than that in control treatment respectively for *Batis maritima* and *Sporobolus spicatus*. These plants are considered very tolerant to salinity since their limit of salinity tolerance exceeded that of seawater (Fig. 36.1). However, 100% seawater salinity induced a significant biomass decrease for species which had their optimum growth at 25% seawater salinity. It was 35, 56 and 77% compared to optimum growth salinity respectively for *Spartina alterniflora*, *Sesuvium portulacastrum* and *Beta maritima*.

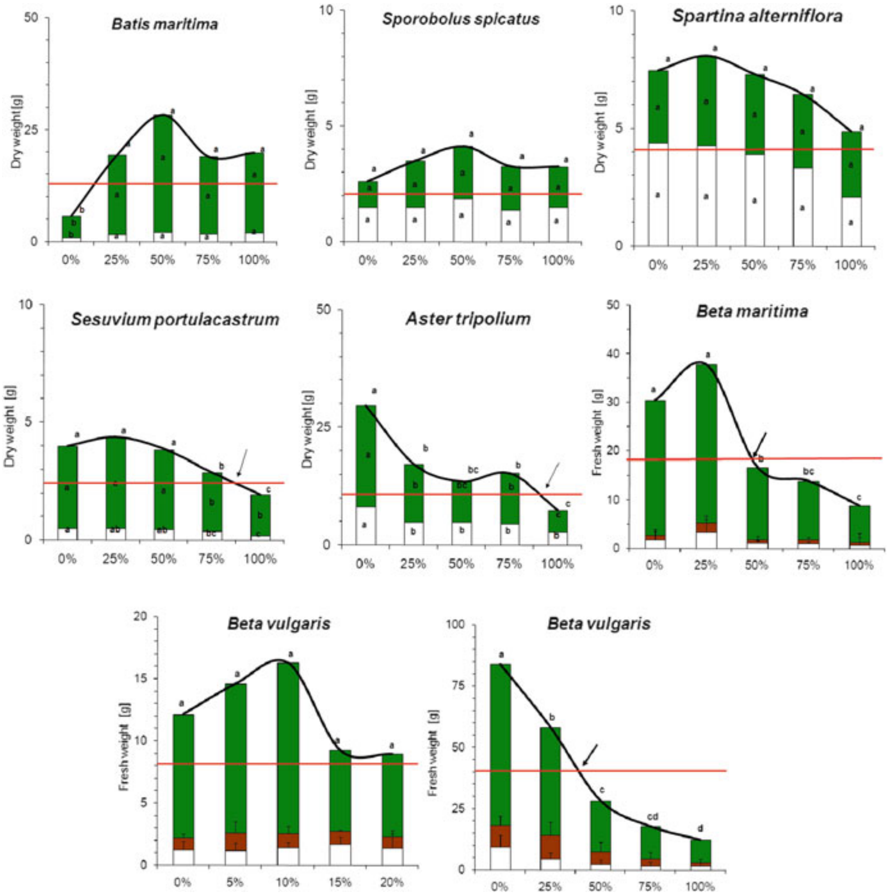

Fig. 36.1 Growth expressed as dry or fresh biomass of plants grown in several seawater degrees compared to the control (tap water). Horizontal line indicates 50% of maximal growth. Curve indicates growth trend with increasing salinity. *Arrow* corresponds to the limit of salt tolerance (50% growth reduction). Histograms with the same letter are not significantly different at 5% threshold Newman-Keuls test

The second category of plants includes *Aster tripolium* in which maximal biomass was in control treatment (Fig. 36.1). The 100% seawater treatment induced 52% biomass reduction, where shoot was more affected than roots. Since the limit of salt tolerance of this specie was registered in high salinities (between 75 and 100% seawater), its maximum growth is probably between control and 25% seawater. Indeed, Flowers et al. (1986) reported that most halophytes require at least 1 mM NaCl for optimum growth, many of them reach their maximum growth between 10 and 50 mM NaCl, and some succulent dicotyledonous improve their growth at salinities around 200 mM NaCl.

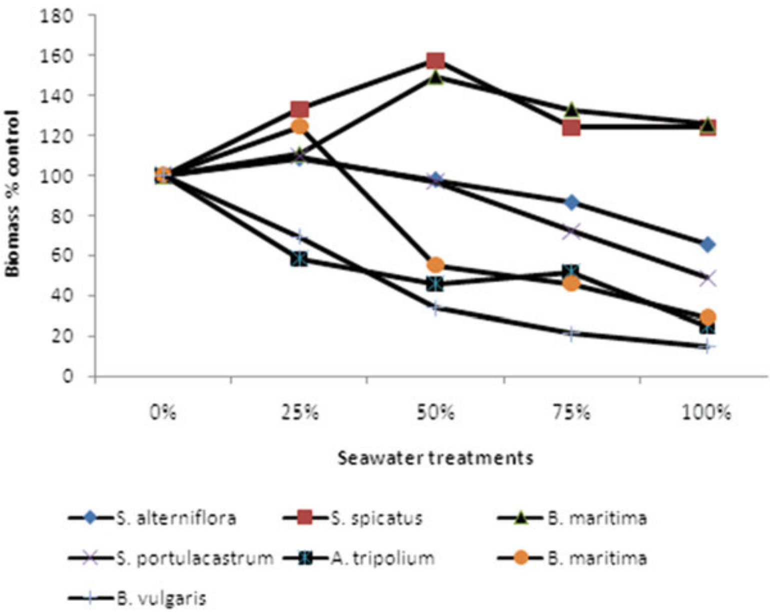

Fig. 36.2 Biomass production (% control) of plants irrigated with increasing sea water salinity for a period of 6 weeks

The response of *Beta vulgaris* to increasing salinity is typical to that of tolerant glycophytes (third category of plants), where biomass was reduced to 85% in highest salinity treatment compared to control treatment. Its limit of salt tolerance was in 34% seawater salinity. The growth analysis of *B. vulgaris* in salinities between 0 and 20% seawater showed that optimum growth occurred at 10% seawater salinity (Fig. 36.1).

In general, the difference in the response of halophytes and glycophytes to saline conditions is question of degree. Indeed, dicotyledonous halophytes biomass is stimulated to higher degree by higher salt concentrations than that of dicotyledonous glycophytes (Munns 2002). By another way, most used criteria to separate the two groups are the aptitude of halophytes to complete their life cycle at salt concentrations between 100 and 200 mM NaCl (Koyro and Huchzermeyer 1999b).

36.3.2 Water Relations

Osmolality measurements of sap extracted from leaves of most studied species increased significantly with increasing seawater salinity in the culture medium (Table 36.3) which indicates a progressive decrease of osmotic potential.

Table 36.3 Adult leaves osmolality (mosmol kg^{-1}) of some halophytes irrigated with tap water (control) and four seawater (SW) concentrations: 25, 50, 75 and 100%

Mosmol kg^{-1}	*Batis maritima*	*Aster tripolium*	*Beta maritima*	*Beta vulgaris*	*Sesuvium portulacastrum*	*Spartina alterniflora*	*Sporobolus spicatus*
0% SW	–	590 d	549.17 e	374 e	610.33 e	670.33	233 e
25% SW	1,130 b	1,210 c	836.38 d	721.83 d	1,012.54 d	847.33 d	340 d
50% SW	1,270 b	1,320 c	1,013.67 c	996.17 c	1,412.67 c	1,011.67 c	532 c
75% SW	2,180 a	2,000 b	1,398.17 b	1,145.17 b	1,710.101 b	1,202.00 b	770 b
100% SW	2,110 a	2,250 a	1,588.33 a	1,736 a	2,160.137 a	1,364.67 a	1,010 a

Values with the same letter does not differ significantly at $p=0.05$

This reaction is essential for the absorption of water by plants in saline conditions since increasing salinity is associated with reduction of water potential of irrigation solution. Nevertheless, growth and survival of plants in saline conditions depend on their adaptation to low water potential and high Na^+ and Cl^- concentration (Munns 2002; Lüttge 2002; Breckle 2002). Pitman and Läuchli (2002), Gorham and Wyn Jones (2002) and Breckle (2002) reported that salt tolerance of halophytes is a response at the scale of the whole plant, and it is a multigenic regulated process. It depends on the capacity of different species to maintain turgescence of their leaves at all salinity levels (Koyro et al. 2008) and to generate osmotic adjustment by regulating water and ion absorption from culture medium (Breckle 2002; Munns 2002). The necessity to regulate internal concentrations of ions consists the following: to maintain low water potentials of different tissues more negative than that of culture medium and to maintain cellular water content while avoiding ion accumulation at the cytoplasm level which could inhibit enzyme activity (Flowers 1985; Flowers et al. 1986; Weber 1995; Reinhold and Guy 2002; Koyro et al. 2008) or might build up in the cell wall and dehydrate the cell (Koyro et al. 2008).

36.3.3 NaCl Excess and Anatomical Adaptations

Mineral content in shoots and roots of different species increased with increasing salinity in irrigation water (Table 36.4). However, the distribution of mineral matter in different parts of the plants permitted to classify studied species on two groups: a group which accumulated high amounts of minerals in the shoots compared to roots and proportionally with increasing salinity in the culture medium (*Batis maritima*, *Sesuvium portulacastrum*, *Aster tripolium*; *Beta maritime* and *Beta vulgaris*) and a group which shoots concentrated very low minerals with increasing salinity (*Spartina alterniflora* and *Sporobolus spicatus*) in contrast to roots which concentrate higher amounts of minerals with increasing salinity and compared to shoots (Table 36.4).

Chemical analysis of mineral matter (ash) of different species revealed a considerable selectivity in the absorption of ions. For all studied species, Na^+ was the most absorbed ion by plants in comparison with other ions, and its concentration increased simultaneously with increasing seawater salinity. Its distribution between different parts of the plants differed from studied plants (Table 36.5).

Batis maritima, *Sesuvium portulacastrum*, *Aster tripolium*, *Beta maritima* and *Beta vulgaris* (salt includer species) concentrated high amounts of Na^+ in their shoots in different seawater salinity treatments, compared to their roots. The accumulation rate of Na^+ in shoot's includers increased in parallel with increasing salinity in culture medium; this rate varied from one species to another (Table 36.5). Flowers et al. (1977) and Greenway and Munns (1980) (in Koyro et al. 2008) reported that includer halophytes need an excess of salt for maximum growth and for maintaining low solute potentials. The accumulation of NaCl consumes much less energy than needed for the osmotic adjustment with compatible organic solutes (Yeo 1983).

Table 36.4 Mineral content (% dry weight) in shoots and roots of plants grown in the four seawater treatment compared to control

	Control (tap water)		25% seawater		50% seawater		75% seawater		100% seawater	
Species	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
Salt includers										
A. Aster tripolium	22.6	13.48	28.13	14.40	31.11	12.90	32.00	16.88	34.59	18.02
Batis maritima	39.33	11.73	55.60	19.47	57.25	19.38	60.54	18.52	61.99	19.90
S. portulacastrum	29.34	22.52	38.88	21.36	39.56	20.86	40.00	14.58	34.48	13.98
Beta maritima	25.63	22.46	26.33	25.56	26.80	19.29	28.15	16.59	28.92	13.58
Beta vulgaris	28.77	29.75	29.12	28.73	28.17	23.08	29.83	17.50	35.31	17.36
Salt excluders										
S. spicatus	10.00	21.14	11.60	25.52	11.70	33.82	12.14	31.42	14.02	28.16
S. alterniflora	08.84	13.34	10.58	12.12	11.08	13.00	12.50	16.08	15.08	17.72

Table 36.5 Effect of seawater salinity on Na^+ and K^+ content (mmol g^{-1} DW) of shoots and roots of some halophytic species

Ions (mmol g^{-1} DW)	*Batis maritima*		*Aster tripolium*		*Sesuvium portulacastrum*		*Beta maritima*		*Beta vulgaris*		*Spartina alterniflora*		*Sporobolus spicatus*	
Seawater treatments	Shoot	Roots	Shoot	Roots	Shoot	Roots	Shoot	Roots	Shoot	Roots	Shoot	Roots	Shoot	Roots
Na^+														
Control	1.66a	0.24 b	1.53 b	1.13 a	3.27	0.57	1.20a	0.45a	1.04b	0.24c	0.98	0.64	0.79	0.52
25%	1.73ab	1.96 a	3.42 a	1.50 a	3.94	0.84	1.92a	0.98a	1 .65ab	0.74b	1.37	0.64	1.02	0.68
50%	2.41bc	2.29 a	3.56 a	1.04 a	4.4	0.84	2.34a	0.74a	1.96ab	1.05a	1.89	0.96	1.09	0.76
75%	3.50 c	2.35 a	3.68 a	–	4.81	0.98	2.48a	0.79a	2.69a	1.06a	1.36	0.91	1.12	0.85
100%	4.48 c	2.48 a	3.69 a	1.45a	4.55	0.96	2.16a	0.82a	2.81a	0.95a	1.89	1.83	1.38	1.09
K^+														
Control	0.83 a	0.58 a	1.21 a	0.36 b	0.86	0.65	1.44 a	0.81 a	1.52 a	0.81 a	0.24	0.34	0.49	0.32
25%	0.62 b	0.57 a	1.11 a	0.72 a	0.64	0.83	0.97ab	1.27 a	0.82 b	1.11 a	0.23	0.28	0.49	0.39
50%	0.51 b	0.73 a	0.96 a	0.34 b	0.41	1.14	0.66 b	0.94 a	0.31 c	0.78 a	0.20	0.28	0.49	0.51
75%	0.50 b	0.65 a	0.70 b	0.45 b	0.37	0.91	0.53 b	0.65 a	0.48 c	0.67 a	0.20	0.27	0.42	0.47
100%	0.48 b	0.56 a	0.53 b	0.36 b	0.31	1.14	0.48 b	0.42 a	0.53 c	0.34 a	0.14	0.23	0.47	0.55

Values with the same letter does not differ significantly at $p = 0.05$

The accumulation of NaCl allows these halophytes to absorb water from soil solution, but ionic excess can generate toxicity in adult leaves and nutritional imbalance if plants are exposed for a long period to high salinities (Munns et al. 1983; Marschner 1995; Koyro and Huchzermeyer 1999a, b). These halophytes are adapted to saline conditions by compartmentation of toxic ions (Na^+ and Cl^-) in leaf cell's vacuoles to protect essential metabolic functions in the cytoplasm (Koyro and Huchzermeyer 1997; 1999b). Indeed, includer halophytes have large vacuoles in their shoot cells allowing the storage of Na^+ and Cl^- and their dilution by osmotic absorption of water which permits plants to maintain their foliar cells turgescence and succulence (Lüttge 2002). The degree of succulence varies in relation of external salinity (Breckle 2002) and among species. The Na concentration in the roots did not vary significantly except for *Batis maritima* roots in which a significant increase of Na amount was in saline treatments compared to control (Table 36.5).

The *Spartina alterniflora* and *Sporobolus spicatus* (salt excluder halophytes) (Table 36.5) accumulated rising Na^+ and Cl^- concentrations in their shoots relatively to increasing seawater salinity in culture medium, but to a low degree than that of includer halophytic species. Indeed, these species excluded salts from their leaves through salt glands or bladders. Salts in the surface of leaves formed crystals during the day and was washed by dew when relative humidity was high especially early in the morning. For this reason, the rate of mineral matter varied little (between 9 and 10%) for the two species. Similar low Na^+ and Cl^- concentrations were found in their shoots and roots. *S. spicatus* and *S. alterniflora* belong to Gramineae, and for these species, salt exclusion can also be done from roots (Table 36.5). Salt exclusion minimises ion toxicity but accelerates water deficit which reduces growth at high salinity conditions (Koyro 1997).

In order to mediate osmotic adjustment, achieve low water potential gradient from substrate to different parts of the plants, protect subcellular structures and reduce oxidative damage caused by free radicals that are produced in response to high salinity, compatible solutes, especially in salt excluding species, and at lower degree for salt including ones, are synthesises by plants as a metabolic response to salt stress (Hong et al. 1992; Hare et al. 1998). The synthesis of organic solutes, which can be alcohols; soluble carbohydrates or organic acids, is energy demanding (Lüttge 2002; Koyro et al. 2008) and the formation of these solutes decreases the energy status of the plant and can lead to decreases of growth in high saline condition (Koyro 1997; Koyro and Huchzermeyer 1999a)

36.3.4 Mineral Nutrition Regulation

Mineral nutrition of studied plants was highly influenced by high NaCl concentrations in the culture medium which interfere with the uptake and the transport of K^+ thus disturbing K^+/Na^+ selectivity and ion homeostasis. Indeed, in the salt includer species, internal leaves K^+ content decreased substantially with increasing salinity, but the decreases in K^+ are more than compensated for by increases in Na^+

(Table 36.5). In contrast, salt excluder species often have similar internal K^+ in all treatments (Table 36.5). In saline treatments, K^+ rates were kept ± similar in shoots of the two species group, what let suppose that the decreased K^+ rate in saline treatments for salt includer plants concerned K^+ which ensured osmotic functions in vacuoles in the absence of NaCl in culture medium, and was replaced by Na^+ under saline treatments. Nevertheless, K^+ content measured in includer and excluder species in different saline treatments was maintained in adequate concentrations to ensure physiological functions in the cytoplasm (Table 36.5) that explain the absence of the K^+ deficiency symptoms in studied species. Flowers et al. (1986); Cheeseman and Wikens (1986); Blumwald et al. (2000) estimated that the rate of K^+ favourable for enzymatic reactions in the cytoplasm are between 100 and 200 mM.

At the roots level, for most species growing in saline treatments, K^+ concentrations was higher in roots than that of shoots. Pitman (1984) who reported similar results, concluded that K^+ absorption in root's cells showed a high selectivity for K^+ compared to Na^+, whereas, there is a low selectivity for K^+ during its transport from roots to shoot. Blumwald et al. (2000) reported that Na^+ assimilation in the roots is due to the similarity between hydrated radicals of Na^+ and K^+ in these conditions it is difficult for transport proteins to distinguish between the two ions. This problem is the basis of Na^+ toxicity for metabolic processes. Indeed, Flowers et al. (1977) reported that cytoplasmic enzymes of halophytic plants have the same sensitivity to salt toxicity than glycophytes. Thus, the survival of halophytes in high Na^+ concentrations conditions depends on their capacity to maintain low Na^+ concentrations and high K^+/Na^+ in the cytoplasm level (Blumwald et al. 2000).

The maintenance of adequate net uptake of K^+ at high Na^+ concentrations is important, since the physiological functions of K^+ in plants cannot be substituted by Na^+, except for the osmotic role of Na^+ in the vacuoles. Exclusion of Na^+ (in salt excluders) and/or its compartmentation in the vacuole for osmotic role (in salt includers) are strategies to maintain a high K^+/Na^+ (Greenway and Munns 1980; Blumwald et al. 2000).

The Ca^{2+} and Mg^{2+} contents of salt treated plants did not show a big difference compared to the control plant, the exception was for *S. alterniflora* shoots in which Ca^{2+} content decreased in high salinity treatments (Table 36.6). In the conditions of our experiment, increasing seawater concentrations was accompanied with the increase of Na^+, Ca^{2+} and Mg^{2+} concentrations.

In high salinity treatments (50, 75 and 100%), Ca^{2+}content ranged from 5.8 to 10 mM L^{-1} which led to a good Ca^{2+}/Na^+ ratio. Cramer (2002) reported that Ca^{2+} rate necessary for maximal growth of glycophytic plants in saline conditions is ranged from 5 to 10 mM Ca^{2+} and it depends on salinity degree and on species. These conditions prevent Ca^{2+} deficiency induced by Na^+ and improve growth stimulation of plants (Marschner 1995). Indeed, studied species did not show any Ca^{2+} deficiency symptoms.

In most species, Ca^{2+} content varied slightly in shoots with increasing salinity compared to the control. However in some species which has the highest limit of salt tolerance has high amounts of Ca^{2+} in the shoots and roots (*Batis maritima*; *S. portulacastrum*). For these species the limit of salt tolerance was high (exceeded

Table 36.6 Effect of seawater salinity on Ca^{2+} and Mg^{2+} content (mmol g^{-1} dry weight) of shoots and roots of some halophytic species

Ions (mmol g^{-1} DW)	*Batis maritima*		*Aster tripolium*		*Sesuvium portulacastrum*		*Beta maritima*		*Beta vulgaris*		*Spartina alterniflora*		*Sporobolus spicatus*	
Seawater treatments	Shoot	Roots	Shoot	Roots	Shoot	Roots	Shoot	Roots	Shoot	Roots	Shoot	Roots	Shoot	Roots
Ca^{2+}														
Control	2.26a	0.58a	0.43a	0.16c	0.17	0.37	0.30 b	0.60 a	0.36	0.36 b	0.09	0.18	0.07	0.52
25%	1.39a	0.46a	0.26bc	0.11c	0.12	0.27	0.24 b	0.68 a	0.30	0.87 a	0.09	0.15	1.06	0.59
50%	0.24b	0.23b	0.16bc	0.13c	0.14	0.33	0.25 b	0.88 a	0.27	0.76 a	0.10	0.14	1.07	0.95
75%	0.26b	0.22b	0.20c	0.58a	0.13	0.27	0.31 b	0.70 a	0.31	0.23 b	0.12	0.12	1.07	0.65
100%	0.25b	0.20b	0.27bc	0.43b	0.10	0.21	0.63 a	0.79 a	0.33	0.40 b	0.13	0.19	1.05	0.46
Mg^{2+}														
Control	0.12a	0.04a	0.04a	0.04a	0.25	0.18	0.40 a	0.81 c	0.69 a	0.33 b	0.14	0.17	0.10	0.15
25%	0.05b	0.04a	0.03b	0.02a	0.19	0.23	0.85 a	1.27 c	0.70 a	1.23 a	0.16	0.16	0.11	0.15
50%	0.03b	0.23a	0.02b	0.40b	0.17	0.25	0.52 b	0.94 a	0.70 a	1.64 a	0.16	0.16	0.11	0.19
75%	0.04b	0.38a	0.02b	0.05b	0.14	0.32	0.27 b	0.65 b	0.89 a	0.27 b	0.14	0.20	0.11	0.17
100%	0.03c	0.34a	0.05a	0.10b	0.15	0.21	0.18 b	0.42 c	0.72 a	0.22 b	0.15	0.21	0.13	0.16

Values with the same letter do not differ significantly at $p = 0.05$

seawater salinity of some). It was reported in literature for a wide range of species that increasing the external level of Ca^{2+} alleviated the toxic effect of high NaCl concentrations on plant growth (Greenway and Munns 1980; Zhong and Läuchli 1994; Cramer 2002). The Ca^{2+} increased salt tolerance of plants (Munns et al. 1983; Epstein 1998) by its function in maintaining membrane integrity and controlling the selectivity of plant ion uptake and transport under saline conditions (Laüchli and Wieneke 1979; Lynch and Läuchli 1985; Marschner 1995) especially K^+ versus Na^+ (Koyro 1997; Cramer 2002).

For most species, Mg^{2+} concentrations was lower than Ca^{2+}, and did not varied slightly with increasing salinity (Table 36.6). The Mg^{2+} is an essential constituent of chlorophyll and some glycolyse enzymes, its concentration increased with increasing seawater concentration in the culture medium, for this reason plants did not show any chlorosis symptoms due to Mg^{2+} deficiency.

36.4 Conclusion

Diversity between studied species on their degree of salt tolerance was observed. Their growth was stimulated by low and/or moderate seawater salinities. However, in high salinity concentrations, plants were confronted to the combination of low water potential in soil solution and high concentrations of potentially toxic ions such as Cl^- and Na^+; these problems could potentially affect plant performance. Nevertheless, these plants can complete their reproductive life cycle in saline conditions since they constitute a part of halophytes collection in IAV Hassan II, Agadir, Morocco and are irrigated with 25% (125 mM NaCl) seawater salinity 10 years ago. The survival and growth of these species to saline conditions is related to the dominance of processes regulating salt transport and osmotic adjustment in plant organs to insure the water continuum, soil-plant-atmosphere. Dicotyledonous halophytes can avoid harmful effect of salt by accumulation and compartmentalisation of high amounts of salts in cell vacuoles, whereas monocotyledonous halophytes excrete salts (especially the Gramineae) from special structure of their leaves (salt gland and bladders) or from leaves. *Spartina alterniflora*, *Sporobolus spicatus* and *Batis maritima*, which have very developed rhizomes and root system, can be used for seaside dune stabilisation. Other halophytes like *Aster tripolium*, *Beta maritima* and *Beta vulgaris* can constitute an excellent fodder for sheep, goats and camels, whereas *Sesuvium portulacastrum* can be used for landscaping. The aptitude of these plants to produce reasonable biomass under high saline conditions demonstrates their economic potential to be used for the rehabilitation of lands affected by salinity with saline irrigation, with the condition to conceive a suitable irrigation and drainage systems. Experiments on salt tolerance of plants irrigated with seawater in a quick check system under greenhouse conditions are the first step to develop halophytic plants cultures in saline conditions.

References

Apse MP, Blamwald E (2002) Engineering salt tolerance in plants. Curr Opin Biotech 13:146–150

Blumwald EA, Gilads A, Maris PA (2000) Sodium transport in plant cells. Biochem Biophys Acta 1465:140–151

Breckle S-W (2002) Salinity, halophytes and salt affected natural ecosystems. In: Läuchli A, Lüttge U (eds) Salinity: environment – plants– molecules. Kluwer Academic, London, pp 53–77

Cheeseman JM, Wikens LK (1986) Control of Na^+ and K^+ transport in *spergularia marina*. III. Relationship between ion uptake and growth at moderate salinity. Plant Physiol 67:15–22

Cramer GR (2002) Sodium–calcium interactions under salinity stress. In: Läuchli A, Lüttge U (eds) Salinity: environment – plants – molecules. Kluwer Academic, London, pp 205–227

Epstein E (1998) How calcium enhances plant salt tolerance. Science 280:1906–1907

Flowers TJ (1985) Physiol of halophytes. Plant Soil 89:41–56

Flowers TJ, Troke PF, Yeo AR (1977) The mechanism of salt tolerance in halophytes. Annu Rev Plant Physiol 28:89–121

Flowers TJ, Hajibagheri MA, Clipson NJW (1986) Halophytes: the quaternary. Rev Biol 61(3):313–337

Glenn EP, O'Leary JW (1984) Relationship between salt accumulation and water content of dicotyledonous halophytes. Plant Cell Environ 7:253–261

Glenn EP, Fontes MR, Yensen NP (1982) Productivity of halophytes irrigated with hypersaline seawater in Sonoran Desert. In: San Pietro A (ed) Biosaline research: a look to the future. Plenum, New York, pp 491–494

Gonzalez E, Arrese-Igor C, Aparicio-Tejo PM, Koyro H-W (1996) Osmotic adjustment in different foliar structures of semileafless pea subjected to water stress. Plant Physiol and Biochem (Special Issue), pp 240–242

Goodin JR, McKell CM, O'Leary JW (1990) Introduction. In: Saline agriculture, salt-tolerant plants for developing countries. Report of a Panel of the Board on Science and Technology for International Development Office of International Affairs National Research Council, National Academy Press, Washington, DC, pp 1–9

Gorham J (1996) Mechanisms of salt tolerance of halophytes. In: Choukr-Allah R, Malcom CV, Hamdy A (eds) Halophytes and biosaline agriculture. Marcel Dekker, New York, pp 31–53

Gorham J, Wyn Jones G (2002) Genetics of salinity responses and plant breeding. In: Läuchli A, Lüttge U (eds) Salinity: environment – plants – molecules. Kluwer Academic, London, pp 451–490

Greenway H, Munns R (1980) Mechanisms of salt tolerance in non halophytes. Annu Rev Plant Physiol 31:149–190

Hare PD, Cress WA, Van Sraden J (1998) Dissecting the roles of osmolyte accumulation during stress. Plant Cell Environ 21:535–554

Hong B, Barg R, Ho TH (1992) Developmental and organ specific expression of an ABA-and stress-induced protein in barley. Plant Mol Biol 18:663–674

Kelley DB, Goodin JR, Miller DR (1982) Biology of atriplex, Chapter 5. In: Sen DN, Rajpurohit KST (eds) VS2 (Tasks for vegetative, Scinec 2) Contribution to the ecology of halophytes. Hagues, Netherlands: Dr. W. Junk Publishers, pp 79–107

Koyro H-W (1997) Ultrastructural and physiological changes in root cells of *Sorghum* plants (*Sorghum bicolor* X *S. sudanensis* cv. Sweet Sioux) induced by NaCl. J Exp Bot 48:693–706

Koyro H-W (1999) Protocol for the installation of an improved quick check system in the IAV Hassan II (Agadir, Morocco). In: Third annual report: sustainable halophyte utilisation in the Mediterranean and subtropical dry regions

Koyro H-W, Huchzermeyer B (1997) The physiological response of *Beta vulgaris ssp. maritima* to sea water irrigation. In: Lieth H, Hamdy A, Koyro H-W (eds) Water management, salinity and pollution control towards sustainable irrigation in the Mediterranean region. Special volume: salinity problems and halophyte use. Technomack, Bari, pp 29–50

Koyro H-W and Huchzermeyer, B (1999) Influence of high NaCl-salinity on growth, water and osmotic relations of the halophyte Beta vulgaris ssp. maritima. Development of a quick check. In: Progress in Biometeorology Volume 13. Halophyte uses in different climates I. Ecological and ecophysiological research. H. Lieth, M. Moschenko, M. Lohmann, H-W Koyro and A. Hamdy (eds) Backhuys Publ., leiden, pp 89–104

Koyro H-W, Huchzermeyer B (1999a) Salt and drought stress effects on metabolic regulation in maize. In: Pessarakli M (ed) Handbook of plant and crop stress. Marcel Dekker, New York, pp 843–878

Koyro H-W, Huchzermeyer B (1999b) Influence of high NaCl-salinity on growth, water and osmotic relations of the halophyte *Beta vulgaris* ssp. *maritima* – development of a quick check. In: Hamdy A, Lieth H, Todorovic M, Moschenko M (eds) Halophyte uses in different climates I. Backhuys Publishers, Leiden, pp 89–103

Koyro H-W, Geisler N, Hussain S, Huchzermeyer B (2008) Survival at extreme locations: life strategies of halophytes – the long way from system ecology, whole plant physiology, cell biochemistry and molecular aspects back to sustainable utilization at field sites. In Abdely C, Öztürk M, Achraf M, Grignon C (eds) Biosaline agriculture and high salinity tolerance, Birkhäuser, Basel, Boston, Berlin, pp 1–20

Kramer D (1984) Cytological aspects of salt tolerance in higher plants. In: Staples RC, Toenniessen GH (eds) Salinity tolerance in plants: strategies for crop improvement. Wiley, New York, pp 3–15

Lahlou A (1999) La production de récoltes au moyen de l'exploitation des eaux saumâtres. Publication de l'lSCESCO, Rabat, Maroc

Laüchli A, Wieneke J (1979) Studies on growth and distribution of Na, K and Cl in soybean varieties differing in salt tolerance. Z Pflanzenernahr Bodenkd 142:3–13

Lüttge U (2002) Mangroves. In: Läuchli A, Lüttge U (eds) Salinity: environment – plants – molecules. Kluwer Academic, London, pp 113–135

Lynch J, Läuchli V (1985) Salt stress disturbs the calcium nutrition of barley (*Hordeum vulgar* L.). New phytol 99:345–354

Maas EV (1987) Salt tolerance of plants. In: Christie BR (ed) CRC handbook of plant sciences in agriculture, vol II. CRC Press, Boca Raton, pp 57–75

Marschner H (1995) Mineral nutrition of higher plants. Academic, London/San Diego/New York/ Boston/Sydney/Tokyo/Toronto, p 889

Munns R (2002) Salinity, growth and phytohormones. In: Läuchli V, Lüttge U (eds) Salinity: environment – plants – molecules. Kluwer Academic, London, pp 271–290

Munns R, Termatt A (1986) Whole-plant responses to salinity. Aust J Plant Physiol 13:143–160

Munns R, Greenway H, Kirst GO (1983) Halotolerant eukaryotes. In: Lange OL, Nobel PS, Osmond CB, Ziegler H (eds) Physiological plant ecology II, Encyclopedia of Plant Physiology, New series 12 C. Springer, Berlin, pp 59–135

Munter CR (1980) Preparation of plant material. Research Analytical Laboratory, University of Minnesota, St. Paul

O'Leary JW, Glenn EP (1984) New crop opportunities from halophytes. University of Arizona, annual meeting, New York, 24–29 May 1984, pp 1–19

O'Leary JW, Glenn EP, Watson MC (1985) Agricultural production of halophytes irrigated with seawater. Plant Soil 89:311–321

Pitman MG (1984) Transport across the root and shoot/root interactions. In: Staples RC, Tnniessen GH (eds) Salinity tolerance in plants: strategies for crop improvement. Wiley, New York, pp 93–123

Pitman MG, Läuchli A (2002) Global impact of salinity and agricultural ecosystems. In: Läuchli A, Lüttge U (eds) Salinity: environment – plants – molecules. Kluwer Academic, London, pp 3–20

Reinhold L, Guy V (2002) Function of membrane transport systems under salinity: plasma membrane. In: Läuchli A, Lüttge U (eds) Salinity: environment – plants – molecules. Kluwer Academic, London, pp 397–421

Sosa L, Lilanese A, Reinoso H, Reginato M, Luna V (2005) Osmotic and specific ion effects on the germination of *Prosopis strombulifera*. Ann Bot 96:261–267

Weber DJ (1995) Mechanisms and reactions of halophytes to water and salt stress. In: Ajmal Khan M, Irwin Ungar A (eds) Biology of salt tolerant plants. Book Crafters, Michigan, USA

Yeo AR (1983) Salinity resistance: physiologies and prices. Physiol Plant 58:1399–3054

Zhong HL, Läuchli A (1994) Spatial distribution of solutes, K, Na, Ca and their deposition rates in the growth zone of primary cotton roots: effects of NaCl and $CaCl_2$. Planta 194:34–41

Chapter 37
Biology and Physiology of *Avicennia Marina* in the Coastal Conditions of Southern Morocco

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Abstract To introduce *Avicennia marina* in some bays of Morocco, a planting test has been carried out in the bay of Agadir. The plantation failed mainly due to human pressure and natural stress (wind); however, these effects could have been reduced through taking necessary measures during the first stages of plantation. As a follow-up to this failure, and to better understand the optimum conditions for the establishment of *A. marina* under Moroccan conditions, several experiments are carried out; one of these was the vegetative propagation of the species and growth under different salinity levels. It is observed that air layering showed encouraging results, when 30% of plants produced thick roots after 5 months. The performance of 6-month-old *Avicennia marina* plants was evaluated in quick check system (QCS) using five water salinity levels (0, 50, 75, 100 and 150% seawater) and by studying limit of salt tolerance, growth and some physiological parameters. The number of leaves, length and area, stem diameter, branching and biomass showed a similar trend, that is, maximum values were obtained in 50% seawater. The threshold of salt tolerance exceeded 150%. Ions concentration (K^+, Na^+, Ca^{2+} and Mg^{2+}), relative water content (RWC), protein content and osmotic potential of different parts of the plants showed that *Avicennia marina* adapts physiologically to survive under very high salt stress conditions. Ions concentration increased with increasing salinity (0.59 g/100 g and 2.35 g/100 g of Na^+ at 0 and 150% seawater, respectively, in leaves), and their content in the shoots was higher than in the roots. In consequence, osmotic potential was lower in plants grown in high salinity (−12.24 bars at 0% and −37.45 bars at 150% seawater in roots).

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Keywords *Avicennia marina* • Physiology • Propagation • Seawater salinity • Southern Morocco conditions

37.1 Introduction

Morocco holds along its coast diverse environments and most productive lagoons, estuaries and bays in the world. The most important bays and lagoons are Dakhla, Khnifiss, Imsouane, Oualidia and Agadir. They have a large biological and ecological interest due to their high biodiversity and their geographical location. The planting of these bays by halophytes species, which tolerate seawater salinity, presents an opportunity to create green spaces and biomass where only seawater is available. Mangroves are marine halophytic woody plants that serve as a nursing ground and a source of energy for detritus-based coastal food chain, in addition to its uses in medicinal products, dyes and tannins. Mangroves are derived from various families in which there are over 80 species of trees and shrubs inhabiting shorelines and estuaries in tropical and subtropical coastal regions (Al-Bahrany and Al-Khayri 2002). Grey mangrove, *Avicennia marina*, a member of the family Avicenniaceae, is highly tolerant to adverse environmental conditions with the broadest distribution worldwide (Tomlinson 1994).

The objective of the present study is to introduce *Avicennia marina* in some bays and estuaries of the Southern Morocco as ornamental plant. The investigations were accompanied with propagation by vegetative multiplication in greenhouse conditions. The underlying adaptive eco-physiological mechanism with special emphasis on the adjustment to high salinities is investigated.

37.2 Materials and Methods

37.2.1 Avicennia Marina Plantation on Agadir Bay

37.2.1.1 Plantation Site Characteristics

Plantation was initiated in Agadir on May 2009; the site was chosen after field investigations and laboratory testing of soil and water samples (Tables 37.1 and 37.2). The seawater shows very high salinity, among cations Na^+ and anions Cl^- being the dominant ions. The water pH is in the slightly alkaline range. The particle size distribution shows fine sand being the dominant fraction, with very low silt and clay fractions (Table 37.2). The soil texture is "*fine sand*" (Soil Survey Division Staff 1993). The soil is strongly calcareous, perhaps due to coastal shells, and total N is in traces (Table 37.3).

Table 37.1 Chemical composition of seawater

pH	EC (dS m^{-1})	K^+ (g L^{-1})	Na^+ (g L^{-1})	Ca^{2+} (g L^{-1})	Mg^{2+} (g L^{-1})	Cl^- (g L^{-1})	HCO_3^- (g L^{-1})	Total N (g L^{-1})
7.85	46.9	0.30	7.79	0.53	1.22	19.6	0.14	Traces

Table 37.2 Particle size distribution, pH and EC of soil

Sand fractions		Silt fractions		Clay		
Coarse 2–0.2 mm	Fine 0.2–0.05 mm	Coarse 0.05–0.02 mm	Fine 0.02–0.002 mm	Clay <0.002 mm	EC (dS m^{-1})	pH
15.67	81.34	0.74	0.25	2.00	2.16	8.3

Table 37.3 Chemical characteristics of soil

CaO (g kg^{-1})	Na_2O (g kg^{-1})	MgO (g kg^{-1})	K_2O (g kg^{-1})	P_2O_5 (g kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	Mo (mg kg^{-1})	$CaCO_3$ (%)	Total N (%)
2.52	2.81	0.81	0.13	0.007	3.74	6.92	0.55	0.72	0.16	42.84	Trace

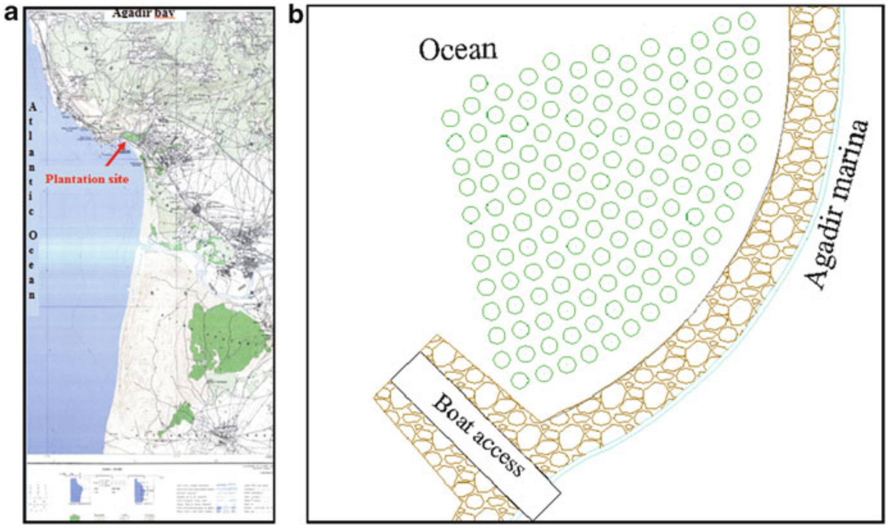

Fig. 37.1 (**a**) Map showing location of plantation site at Agadir bay and (**b**) Planting plan of *Avicennia marina* on the test site

The coast of Agadir (Fig. 37.1a) is characterised by semidiurnal tides, range from 0.69 m (low tides) to 3.76 m (high tides), winds west and west-south-west decrease temperatures maxima and increase the relative humidity in the coastal fringe. The average relative humidity is 68% recorded in March and 80% in November. The temperature varies between 17°C average minimum and 27°C average maximum.

37.2.1.2 Propagules Source

The mature propagules of *Avicennia marina* were collected from adult plants of halophytic collection at IAV Hassan II Horticulture Complex of Agadir (30° 20′ northern latitude, 9° 30′ western longitude, 32 m above sea level); parent plants are originating in Dubai, United Arab Emirates.

37.2.1.3 Plant Material Preparation

Propagules were soaked in tap water for 24 h to remove the pericarp and were germinated in benches filled with 50% sand and 50% peat. They were watered once a day in the morning. Roots and leaves were produced after 24 days, at 4-leaves stage, seedlings were placed in black plastic pots and watered with tap water for 2 months and then irrigation water salinity was raised progressively to 50% seawater. The experiment was conducted in noncontrolled greenhouse conditions. Survival percentage of plants was 50%. Measurements of plant height were taken weekly for all surviving plants.

37.2.1.4 Acclimation of Plants Before Their Plantation in the Bay

At 1.40 m mean height, seedlings were acclimated to seawater salinity level with raising salinity by addition of 50 mM NaCl twice a day (in the morning and in the evening). After reaching seawater salinity level, the irrigation solution was changed by seawater to which nitrate fertiliser was added. Seedlings were maintained in these conditions 1 month before their transfer to the bay.

37.2.1.5 Plantation in the Bay

On May 19, 2009, 137 seedlings (0.80–1.93 m in height) were transferred to the coastal field at low tide. The holes were prepared at a spacing 3 × 3 m on an area close to 200 m^2 according to the following plan (Fig. 37.1b).

37.2.1.6 *Avicennia Marina* Propagation by Layering

The layering is carried out in May 2009 on adult *Avicennia marina* plants without detaching from their parent plant; aerial shoots are prepared by raising slightly bark in three ways (incision in ring, vertical side incision and two sides vertical incision); the shoots are then coated with moist peat maintained by a canvas or black plastic bound of the two extremity to obtain temperature, humidity and darkness favourable for roots production. The layers were watered once a week by syringe to keep the peat moist.

37.2.1.7 Effect of High Salinity on Morphological and Physiological Parameters of *Avicennia Marina:* Culture Conditions

The plants were grown for 4 months on a quick check system (QCS). The QCS is an automated irrigation and drainage system, where plants were put in 100-l containers and regularly flooded with the required water. Small electric pumps were used to recycle water on the time basis of 6 h flooding and 18 h of total drainage. The treatments comprised of a control (tap water) and 4 seawater salinities (50, 75, 100 and 150% seawater), and each treatment was duplicated. Plants were adjusted to saline water irrigation by raising the salinity at 100 mM NaCl per day until the required concentration was reached. Irrigation solution was then changed by the fractions of seawater. The dilutions were obtained by tap water addition to seawater. For 150% seawater treatment (1,158 g), NaCl was added to Agadir seawater.

The NPK and oligo elements fertilisation was calculated on the basis of nutrient solution of Epstein (1972).

37.2.1.8 Determination of Plant Growth

During the period of the experiment, several growth parameters were measured (height of plants and internodes, stem diameter, number of leaves and branches diameter).

At the beginning of the experiment, 20 plants were harvested, washed and weighed to determine the relative growth rate (RGR). After 8 weeks in different treatments, four plants from each treatment were washed and shoot and roots of each plant were weighed to determine fresh water. The dry weight (DW) was obtained after oven drying the plants at 65–70 °C for 48 h. Relative growth rate (RGR) was calculated using the following equation (Botella et al. 1997):

$$\mathrm{RGR}\ (\mathrm{mg\,g^{-1}\,day^{-1}}) = \frac{\mathrm{Ln}W2 - \mathrm{Ln}W1}{t2 - t1},$$

where $W1$ and $W2$ represent shoot dry weight, respectively, at the beginning and at the end of the experiment and $t1$ (first treatment day) and $t2$ (final treatment day), time in days.

For the determination of leaf area, young and adult leaves of each plant are photocopied; the copies of each leaf were cut and weighed with a precision balance. A piece of paper of 2 cm^2 was cut and weighed. Leaf area of leaves was calculated in reference to the surface of this piece of paper.

37.2.1.9 Mineral Composition

Half gram of shoots and roots dry matter was incinerated at 485 °C for 7 h; the ash was dissolved in 3-mL hydrochloric acid (2 N) and filtered to obtain clear solution for further analyses. The Fe, Mn, Zn and Cu contents were determined by atomic absorption spectrophotometer and Na^+, K^+, Ca^{2+} and Mg^{2+} by flame emission spectrophotometer. The K^+ to Na^+ selectivity in roots level was determined according to Daoud et al. (2004) by using the formula

$$S_{\mathrm{K/Na}} = \left(\frac{\text{Na in irrigation solution}}{\text{K in irrigation solution}}\right) \times \left(\frac{\text{K in roots}}{\text{Na in roots}}\right).$$

Concentrations of these minerals in plant tissues are expressed on a dry weight (g) basis.

37.2.1.10 Relative Water Content Measurements

Before the harvest, relative water content (RWC) of the leaves was measured according to Yamasaki and Dillenburg (1999). Eight discs (0.5 cm diameter) were cut with a punch from fresh leaves (young and adults) and immediately weighed to determine fresh weight (FW). The leaf segments were then placed in Petri dishes in deionised water. After 4 h when the segments were totally turgid, they were gently dried with absorbent paper to measure the saturated weight (SW). Dry weight (DW) was measured after drying the discs for 48 h at 70 °C. The RWC was calculated using the following formula:

$$\mathrm{RWC}\,(\%) = \left(\frac{\mathrm{FW} - \mathrm{DW}}{\mathrm{SW} - \mathrm{DW}}\right) \times 100,$$

where weights are used in grams.

37.2.1.11 Ionic Composition of Leaves Excretion

Before harvest, the leaves of each plant were washed with 10 mL of deionised water to determine ionic composition for leaves excretions. Various ions (K^+, Na^+, Ca^{2+}, Mg^{2+}, Mn and Zn) were determined using atomic absorption spectrophotometer; Cl^- was determined by standard $AgNO_3$ (0.1 N) titration method.

37.2.1.12 Protein Contents

The protein contents were determined using Kjeldahl apparatus. One gram of digestion mixture (K_2SO_4, $CuSO_4$ and selenium) and 10-mL concentrated sulphuric acid was added to 0.2 g of dry plants matter (shoots and roots) and digested for 5–10 h, and ammonia distilled into acid in the receiver. The distillate containing ammonia is titrated in the presence of phenolphthalein indicator by sulphuric acid 0.1 N. The percent protein contents were then calculated by using standard equation.

37.2.1.13 Osmotic Potential (OP)

Leaves were excised and kept overnight in a deep freezer and then placed in a hot water bath (~80 °C) for around 5 min, crushed with a pistil and centrifuged (2,000 rpm) for 5 min. Freezing point depression was measured in the supernatant with an osmometer (Osmomat 030, GONOTEC). The osmotic potential was measured on the clear supernatant through using EC meter and converting EC to OP using standard relationship.

37.2.1.14 Statistical Analysis

Multiple comparisons of the means of ions concentrations, RWC, plant height, stems diameter, leaves area and number, internodes height and branches between different salinity treatments were performed using independent sample *t*-test at the 0.05 significance level (all tests were performed with SPSS Version 10 for Windows).

37.3 Results and Discussion

Avicennia marina plantation plan on the test site in Agadir is shown in Fig. 37.1, and the mangroves plantation on Agadir bay at low and high tides is shown in Fig. 37.2a, b. During the first month, 20% of the plants planted near the rocks were torn by the force of water on the rocks; 30% of the survived plants showed brown and black spots (necrosis) on their leaves (Fig. 37.2c).

During the second month, almost 20 plants have uprooted because of poor fixation in soil; some of the plants were either broken or they lost their foliage. The rest of the plants were clearly adapted, and the new leaves emerged (Fig. 37.2d); however, they were threatened by the frequent visitors to the Agadir coast where the plantation was made.

After this test, we have found that, as demonstrated by Chapman (1974, 1977), Pannier (1978) and Kiener (1973), the existence and the establishment of *Avicennia marina* depend on several factors, such as the high temperature of the air, ocean currents, the presence of protected areas, areas of shallow soil, water salinity, tidal range and presence of muddy substrate. Indeed, during the present study, the average temperature was between 13 and 27°C, with sudden fluctuations (42°C) during the day and almost mists all the morning; this could effect on the physiological processes of *Avicennia marina* causing loss of foliage and death. Similarly, the mists would drop light intensity that is detrimental for *Avicennia marina* growth and development; the optimal light intensity for mangrove growth is 3,000–3,800 kcal m^{-2} day^{-1} (Kato and Akosornkoae 1998).

The west and west-west-southward winds without vegetation protection decreased temperatures in the coastal fringe and caused physical damage. Best growth of *Avicennia marina* was in moderate salinities (Clough 1992). The acclimatation of the plants in nursery out of greenhouse conditions is essential before the transfer to the bay to avoid the sudden shocks which are certainly the cause of the black and brown spots on leaves.

37.3.1 *Avicennia Marina Propagation by Layering*

After 5 months, more than 30% of layers have delivered large roots between 2.5 and 9 cm (Fig. 37.2e). The layers were separated from the mother plants and potted with 50% of peat and 50% of sand. As several difficult woody plants were

Fig. 37.2 *Avicennia marina*: (**a**) at high tide, (**b**) at low tide, (**c**) showing black spots (necrosis), (**d**) plants showing new shoots and (**e**) propagation by layering showing root initiation and growth of thick roots on incision in ring

to be rooted by cuttings, the multiplication of *Avicennia marina* proves easier by layering. Indeed, Kathiresan and Bingham (2001) report that physiological mechanisms for adaptation of mangrove forests to salinity stress present a major obstacle in grey mangrove tissue culture which contributed to the limited success in plant regeneration.

37.3.2 Effect of High Salinity on Morphological and Physiological Parameters of Avicennia Marina

37.3.2.1 Effect of Salinity on Plant Development

Moderate salinity levels (50 and 75% seawater) stimulated significantly ($p<0.05$) *Avicennia marina* height (Fig. 37.3a) and internodes growth (Fig. 37.3b) compared to 0, 100 and 150% seawater salinities which reduced these parameters by 20.45 and 16.8%, respectively. These results are similar to those reported by Clough (1984), Najamuddin and de Soyza (2004) and Zhongzheng et al. (2007). These results for fresh weight were reduced by 100 and 150% seawater by 20 and 39.04%, respectively. Threshold of salt tolerance, which corresponds to the reduced salinity of 50% fresh weight compared with the control, exceeds 150% seawater; this indicates that *Avicennia marina* can live and tolerate salinity more than 150% seawater (Fig. 37.3c). Extreme salinities (100 and 150% seawater) also significantly affected the number of branches ($p<0.05$) (Fig. 37.3d). There were no significant differences in the increase of number of leaves (Fig. 37.3e) and stem diameter (Fig. 37.3f) between all salinity treatments ($p>0.05$). Thus, salinity has not shown adverse effect on stem diameter and the number of leaves; similar results were found by Najamuddin and de Soyza (2004).

37.3.2.2 Effect of Salinity on Plant Growth (Dry Weight)

At 50% seawater salinity, total dry weight of *Avicennia marina* increased more than control, whereas in other salinities, dry weight showed a similar response to salinity than control (Fig. 37.3g). The root/shoot ratio was unaffected by increasing salinity; instead, it increased mostly at 50% SW treatment (Fig. 37.3h), so adverse effects of increasing salinity were more pronounced on shoots than on roots. Similar results were also obtained by Zhongzheng et al. (2007). This was also found for shoot relative growth rate (Fig. 37.3i); indeed, at 75, 100 and 150% seawater salinities shoot, RGR decreased significantly ($p<0.05$) compared to 50% seawater treatment. The reduction in growth not only helps the plants to save the energy for defence purposes but also limits the risk of heritable damage (May et al. 1998).

Leaf area was significantly larger in plant grown at 50, 75 and 100% seawater than 0% seawater, and at 150% seawater, leaf area decreased significantly compared with 0% ($p<0.05$) (Fig. 37.3j). Clough (1984) found that the leaf development was inhibited (leaves were smaller and fewer) in *Avicennia marina* and *Rhizophora stylosa* when they were grown in fresh water, compared to that grown in 25, 50 and 75% seawater salinities. Similar results were also obtained by Najamuddin and de Soyza (2004). According to Ball (1988), the decline in rate of leaf area expansion with increasing salinity has been considered the major cause of growth reduction of several species. This partly explains why *Avicennia marina* grows better under moderate salinity than when salinity is high (150%).

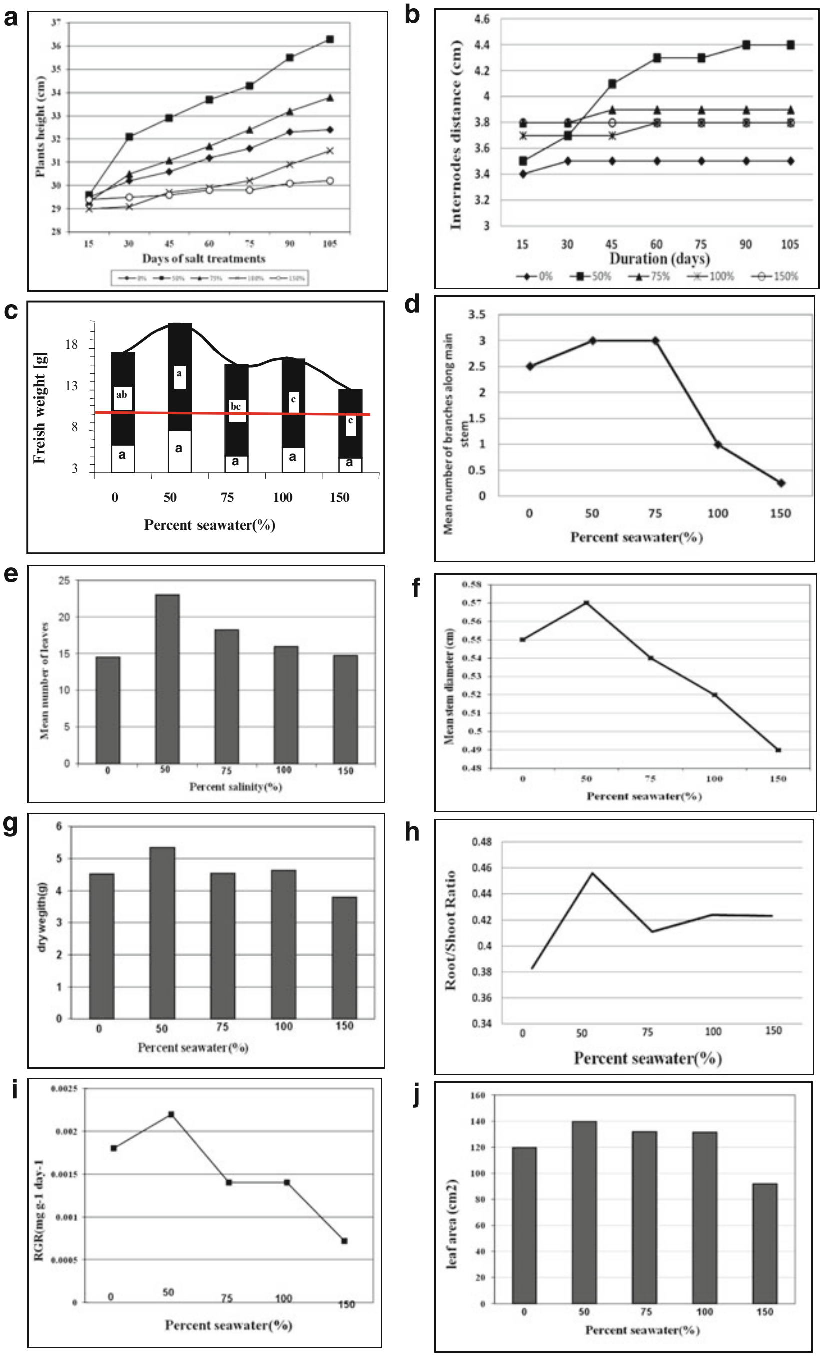

Fig. 37.3 *Avicennia marina* in five seawater salinity: (**a**) Mean plant height (cm), (**b**) mean internode height, (**c**) mean fresh weight (g), (**d**) mean number of branches along main stem, (**e**) mean number of leaves, (**f**) mean stem diameter, (**g**) mean dry weight (g), (**h**) root/shoot ratio, (**i**) relative growth rate and (**j**) mean leaf area

37.3.2.3 Effect of Salinity on Relative Water Content RWC

Young and adult leaves of *Avicennia marina* had similar values of relative water content (RWC) at 0% seawater. Up to 100% seawater salinity, there was no adverse effect on adult leaves RWC of plant ($p > 0.05$); exception is for 150% seawater salinity where RWC was significantly lower than that in other salinity treatments ($p < 0.05$) (Fig. 37.4a). Relative water content of young leaves (Fig. 37.4a) declined significantly at high salinities ($p < 0.05$). Thus, RWC was more affected by salinity in adult leaves than in young adult leaves. Leaf RWC is considered an alternative measurement of plant water status, reflecting the metabolic activity in tissues (Flower and Ludlow 1986). Its reduction in young leaves may result in the loss of turgor causing stomatal closure which leads to reduced CO_2 uptake, hence a decrease in metabolic activity. This explains reduction in plant growth and plant development at high salinity.

37.3.2.4 Effect of Salinity on Mineral Composition of the Plant

Na^+ and K^+ are dominant ions, but considerable differences were observed in the accumulation of Na^+ and K^+ in leaves and roots of *A. marina* with increasing salinity. Accumulation of sodium was higher in roots than in shoots; beyond 50% seawater, the sodium was significantly increased ($p < 0.05$) (Fig. 37.4b, c). The potassium was significantly more accumulated in roots compared to shoots. Its concentrations were similar in all salinity treatments (0.95%) ($p > 0.05$), but higher at 150% seawater salinity (1.28%). These rates are beneficial for plant survival and plant growth under saline stress. Potassium is considered as one of the primary osmotic substances which contribute to osmotic adjustment in many plant species (Ashraf et al. 2001). In 150% seawater treatments, the NaCl added to seawater to reach this level of salinity contained the iodine. The increases of potassium roots content in 150% seawater treatment were probably due to the mechanisms developed by plants to absorb K^+ in the presence of iodine. On the other hand, K^+ to Na^+ selectivity in roots was increased significantly with increasing salinity (Fig. 37.4d); higher potassium levels in plants are beneficial in achieving a better plant survival with improved plant growth under saline stress (Sangakkara et al. 2001; Umar 2002). The physiological functions of K^+ in plants cannot be substituted by Na^+, with the exception of its osmotic role in the vacuoles (Daoud et al. 2004). Sustained K^+/Na^+ selectivity is therefore proposed as a physiological marker for the ionic component of salt stress, providing ion homeostasis in growing roots (Mühling and Läuchli 2001).

Calcium and magnesium contents fluctuated with high salinity; the lowest values were measured in plants in the control treatment (Fig. 37.4b, c). The status of these two nutrients was not drastically affected by salt stress in *Avicennia marina* plants since their concentrations in seawater are high. Calcium plays a vital role

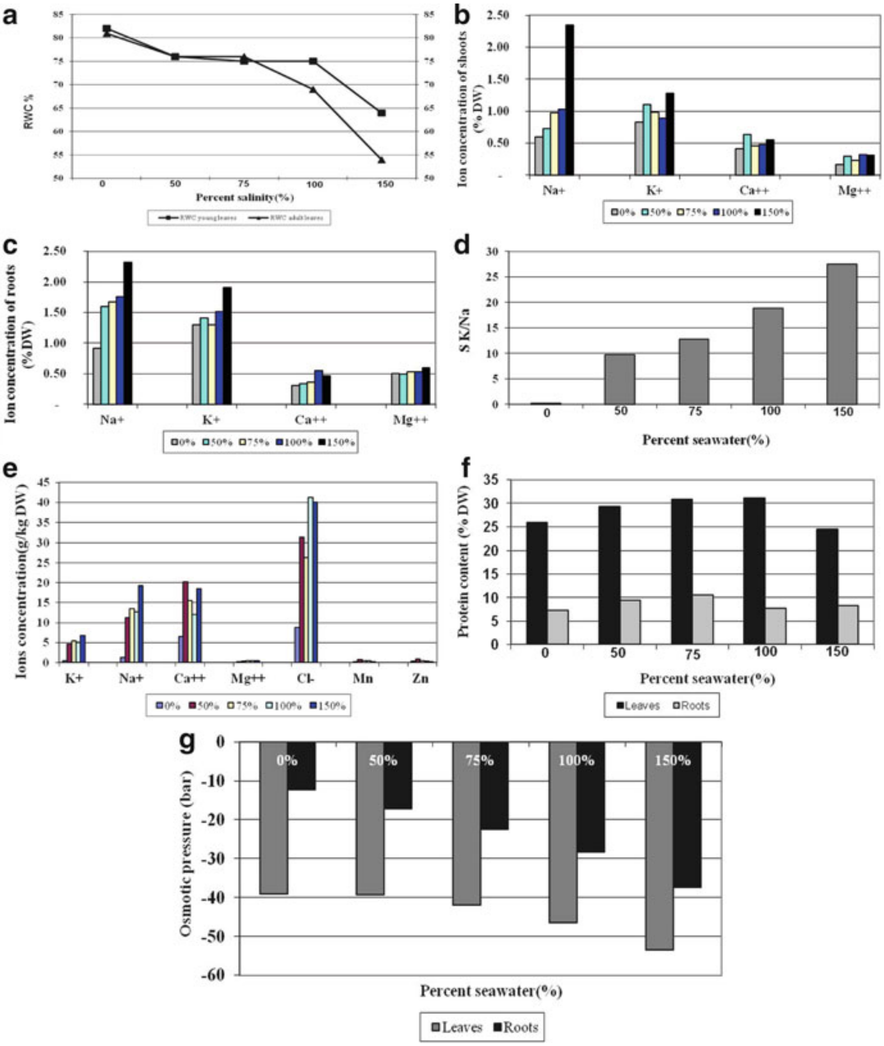

Fig. 37.4 *Avicennia marina* in five seawater salinities (0, 50%, 75%, 100% and 150%): (**a**) mean relative water content in young and adult leaved, (**b**) ion concentration of shoots (% dry weight), (**c**) ion concentration of roots (% dry weight), (**d**) K to Na (S K/Na) selectivity in roots, (**e**) ion concentration (g kg^{-1} DW) water rinsing of leaves, (**f**) protein content (% DW) of leaves and roots and (**g**) osmotic pressure (bar) of leaves and roots

in maintaining membrane stability and permeability (Mengel and Kirkby 1987). The Mg^{2+} is an important element occupying a central position in the chlorophyll molecule, thereby affecting the concentration of chlorophylls "a" and "b" in the green plant tissues (Yasseen and Al-Thani 2007).

37.3.3 Effect of Salinity on Ionic Composition of Leaves Excretion

Analysis of washing water of leaves of *Avicennia marina* from different seawater treatments showed that in addition to Na^+ and Cl^-, presence of other cations (Mg^{2+}, Ca^{2+}, K^+, Mn and Zn) with different proportions was confirmed (Fig. 37.4e). The Na^+, Cl^- and Ca^{2+} are the dominant ions; their concentrations increased with increasing salinity. The K^+ content was less than Na^+ and increased with increasing salinity, while proportions of Mg^{2+}, Mn and Zn were relatively low.

Salt glands are the main features of *Avicennia* that play vital role in ion regulation and homeostasis (Abdel-Bari et al. 2007). These salt glands are playing significant role in the extrusion of Na^+ and Cl^-. It is suggested that glands vacuoles may have a primary role in Cl^- secretion. This explains results achieved in the present study and the excretion of salt glands of other ions in varying proportions depending on their presence within cells. Indeed, the secreted quantities and the differences between the different ionic concentrations reflect ion content of leaves (Fig. 37.4e). *Avicennia marina* has adaptive characteristics to salt stress. Indeed, it has grey and hairy leaves at the lower surface where most secretion occurs, while the above surface is shiny green, glabrous with some salt glands (Yasseen and Abu-Al-Basal 2008). These adaptative mechanisms allow *A. marina* to grow normally under saline environment. It prefers saturated saline soils, but it can grow in less salty environment (Downton 1982).

37.3.4 Effect of Salinity on Protein Content

Protein accumulation in the roots was much lower than in the leaves (Fig. 37.4f). Proteins content increases insignificantly with increasing salinity. Indeed, similar to compatible solute production, plants synthesised some proteins that aid their survival and growth under dry or saline conditions (Razavi et al. 2004). At high concentration of salinity (150% seawater), protein concentration decreased but was similar to the control. This is explained by the decrease of leaf area with high salinity which is decisive of photosynthesis source of proteins.

37.3.5 Effect of Salinity on Osmotic Potential

Figure 37.4g shows that the osmotic pressure in leaves is lower than in roots; this allowed decreasing gradient to sink water from roots to leaves. Osmotic pressure in leaves and roots decreased significantly ($p < 0.05$) with increasing salinity (Fig. 37.4g). Mineral analysis shows excess Na^+ and Cl^- accumulation with increasing salinity, which compensates for the loss of K^+ and the osmotic stress imposed by salinity. At high salinity, the osmotic pressure (and hence the volume) of the cytoplasm was maintained by the accumulation of organic solutes which were compatible with enzyme activity (Gorham 1996). The formation of these solutes decreases the energy status of the plant (Yeo 1983). This can explain the regression of growth.

37.4 Conclusion

This study is focused on the behaviour of *Avicennia marina* plants in response to the salt stress. Its tolerance to very high salinities is manifested by the combination of morphological and physiological characteristics. Indeed, the osmotic adjustment and reduction of growth are observed when *Avicennia marina* is subjected to salt stress. These two phenomena are related to maintain the water needs of the plant for survival. The propagation by layering would achieve a large number of plants identical to their parent plant. Test plantation determined the ability of *Avicennia marina* to adapt diverse natural saline environments. The establishment of mangroves in bays and estuaries of Morocco is possible through selection of sites protected from biotic (human activity) and abiotic stress (such as protection from wind) conditions; by this way, the effect of wind and water waves can be reduced on plantation.

References

Abdel-Bari EM, Yasseen BT, Al-Thani RF (2007) Halophytes in the state of Qatar. Environmental Studies Center, University of Qatar, Doha

Al-Bahrany AM, Al-Khayri JM (2002) Micropropagation of grey mangrove *Avicennia marina*. Plant Cell Tiss Organ Cul 72:87–93 (Kluwer Academic, Dordrecht)

Ashraf M, Ahmad A, McNeilly T (2001) Growth and photosynthetic characteristics in pearl millet under water stress and different potassium supply. Photosynhetica 39:389–394

Ball MC (1988) Salinity tolerance in the mangroves, *Aegiceras corniculatum* and *Avicennia marina*. I. Water use in relation to growth, carbon partitioning and salt balance. Aust J Plant Physiol 15:447–464

Botella MA, Martinez V, Nieves M, Cerda A (1997) Effect of salinity on the growth and nitrogen uptake by wheat seedlings. J Plant Nutr 20:793–804

Chapman VJ (1974) Mangroves biogeography. In: Walsh G, Snedaker S, Teas H (eds) Proceedings of the international symposium on the biology and management of mangroves, Honolulu, Hawai, pp 3–22

Chapman VJ (ed) (1977) Ecosystems of the word. I. Wet coastal ecosystems. Elseiver, Amsterdam, p 359

Clough BF (1984) Growth and salt balance of the mangrove *Avicennia marina* (Forsk.) and *Rhizophora stylosa* Griff. in relation to salinity. Aust J Plant Physiol 11:419–443

Clough BF (1992) Primary productivity and growth of mangrove forest. In: Robertson AI, Alongi DM (eds) Coastal and estuarine studies. American Geophysical Union, Washington, DC, pp 225–250

Daoud S, Harrouni MC, Koyro H-W (2004) Comparison of salinity tolerance of two related subspecies of *Beta vulgaris*: the sea beet (*Beta vulgaris* ssp. maritima) and the sugar beet

(*Beta vulgaris* ssp. vulgaris). In: Abdelly C, Öztürk M, Ashraf M, Grignon C (eds) Biosaline agriculture and high salinity tolerance. Birkhäuser Verlag, Basel
Downton WJS (1982) Growth and osmotic relations of the mangrove (*Avicennia marina*) as influenced by salinity. Aust J Plant Physiol 9(5):519–528
Epstein E (1972) Mineral nutrition of plants: principles and perspectives. Wiley, New York
Flower DJ, Ludlow MM (1986) Contribution of osmotic adjustment to the de-hydration tolerance of water stressed pigeon pea (*Cajanus cajan* (L.) Milsp) leaves. Plant Cell Environ 9:33–40
Gorham J (1996) Mechanisms of salt tolerance of halophytes. In: Choukr-Allah R, Malcom CV, Hamdy A (eds) Halophytes and biosaline agriculture. Marcel Dekker, Inc., New York, pp 31–53
Kathiresan K, Bingham BL (2001) Biology of mangroves and mangrove ecosystems. Adv Mar Biol 40:81–251
Kato S, Akosornkoae S (1998) Physiology and ecology of mangroves. In: Bhat NR, Taha FK, Al-Nasser AY (eds) Mangroves ecosystems: natural distribution, biology and management. pp 137–158
Kiener A (1973) Les mangroves du globe: aspects écologiques, biocénotiques et physiologiques particuliers – mise en valeur. Bull Mus Nat Hist Nat (Sér 3) 164:317–331
May MJ, Vernoux T, Leaver C, Van Montagu M, Inze D (1998) Glutathione homeostasis in plants: implications for environmental sensing and plant development. J Exp Bot 49:649–667
Mengel K, Kirkby EA (1987) Principles of plant nutrition. International Potash Institute, Berne
Mühling KH, Läuchli A (2001) Physiological traits of sodium toxicity and salt tolerance. In: Horst WJ et al (eds) Plant nutrition-food security and sustainability of agroecosystems. Kluwer Academic, Dordrecht, pp 378–379
Najamuddin V, de Soyza AG (2004) Effect of water salinity on seedling survival, growth and physiology of grey mangrove (*Avicennia marina*) in the UAE. In: Taha FK, Ismail S, Jaradat A (eds) Prospects of saline agriculture in the Arabian Peninsula. Amherst Science Publications, Amherst, pp 247–253
Pannier F (1978) Interpretacion fisicoecologica de la distribution de manglares en las costas del continente sudamericano: memorias del Primer Seminario sobre el oceano Pacifico Suramericano. Universidad del Valle, Cali, pp 535–560
Razavi K, Mohsen-Zadeh S, Malboobi MA (2004) Molecular aspects of osmotic stresses. In: Taha FK, Ismail S, Jaradat A (eds) Prospects of saline agriculture in the Arabian Peninsula. Amherst Science Publications, Amherst, pp 175–188
Sangakkara UR, Frehner M, Nosberger J (2001) Influence of soil moisture and fertilizer potassium on the vegetative growth of mung bean (*Vigna radiata* L. Wilczek) and cow pea (*Vigna unguiculata* L. Walp). J Agron Crop Sci 186:73–81
Soil Survey Division Staff (1993) Soil survey manual. USDA handbook no. 18. US Government Printing Office, Washington, DC
Tomlinson PB (1994) The botany of mangroves. Cambridge University Press, Cambridge
Umar SM (2002) Genotypic differences in yield and quality of groundnut as affected by potassium nutrition under erratic rainfall conditions. J Plant Nutr 25:1549–1562
Yamasaki S, Dillenburg LC (1999) Measurements of leaf relative water content in Araucaria angustifolia. R Bras Fisiol Veg 11:69–75
Yasseen BT, Abu-Al-Basal MA (2008) Ecophysiology of *Limonium axillare* and *Avicennia marina* from the coastline of Arabian Gulf-Qatar. J Coast Conserv 12:35–42
Yasseen BT, Al-Thani RF (2007) Halophytes and associated properties of natural soils in the Doha area, Qatar. Aquat Ecosyst Health Manage 10:320–326
Yeo AR (1983) Salinity resistance: physiologies and prices. Physiol Plant 58:1399–3054
Zhongzheng Y, Wenqing W, Danling T (2007) Effect of different time of salt stress on growth and some physiological processes of *Avicennia marina* seedlings. Mar Biol 152:581–587

Part V
Biosaline Agriculture and Agroforestry for Marginal Lands

Chapter 38
Integrating Agroforestry and Pastures for Soil Salinity Management in Dryland Ecosystems in Aral Sea Basin

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Abstract Salt-affected lands in the Central Asian region demonstrate the most characteristic features of natural continental terrestrial salinization, sodication, and alkalinization. Low organic matter (<1.0%), high salt contents, and poor water-holding capacity render these soils unproductive. The predominant salinity type is sulfate-chloride. The Na^+ and SO_4^{2-} are dominant ions. Total nitrogen and phosphorus ranged between 0.7–5.5 mg kg^{-1} and 10.0–18.26 mg kg^{-1}, respectively. Available potassium is low or moderate. Vegetation richness, botanic species diversity, and plant biomass were well integrated with soil moisture and soil salinity. A linear regression equation between apparent soil electrical conductivity (EM38) and quantitative Na^+ accumulation for 0–75 cm ($r^2 = 0.88$) soil profiles allowed us to identify the proportional contribution and interactive effects of each plant community

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(calculated for C_3/C_4 species abundance) at fine desert landscape scale. Foliar $\delta^{13}C$ (carbon discrimination) indexes as an indicator of long-term water-use efficiency in plants in a restored forest – pastures ecosystem showed that $\delta^{13}C$ of C_3 species increased with a decrease in soil water availability, suggesting that water-use efficiency increased with decreasing soil moisture and salinity. The C_4 species' occurrences were observed to be absent and/or scarce within relatively lower soil moisture microhabitats, whereas they occurred and/or even had a high abundance within relatively higher soil moisture microhabitats and salinity, suggesting limited moisture available was a key factor of limiting C_4 distribution in arid region. The suitable coexistence of C3/C4 into an integrated agroforestry – farming system comprising 12–15% of tree cover, 58% of alfalfa, and 27–30% of annual forage crops provides satisfactory drainage – control of these salt affected marginal lands preventing salts accumulation at the root zone area. Trees/shrub plantations were deeply planting (sticks tap into the water table) through seedlings transplanting in early spring or late autumn seasons. A limited irrigation with low-quality water has been applied during the initial stage of growth before sole reliance on available drainage water (EC 4.5–12.3 dS m^{-1}) resource becomes possible. The most promising plants including stands of native rangeland halophytes grown alone, or mixed with various traditional salt-tolerant trees, and fodder crops are addressed in this chapter.

Keywords Agroforestry • Aral Sea Basin • Dryland salinity • Marginal resources • Pastures

38.1 Introduction

Dryland salinity and associated water quality are recognized to be among most severe natural resource degradation problems in the marginal desert belt of Aral Sea Basin. Access to irrigation water in this region has drastically decreased in the last years, which caused additional obstacles to rangelands productivity and agricultural production (Lamers et al. 2005).

Replacement of deep-rooted, perennial native vegetation with shallow-rooted, annual agricultural crops and halophytic pastures has resulted in increased recharge causing shallow saline water tables leading to dryland salinity and loss of plant diversity. These results in greater amounts of water entering a groundwater system, water table rise, and the concentration of naturally occurring salts near the soil surface.

Natural arid desert ecosystems, additionally, are particularly susceptible to climate change and desertification. Slight changes in temperature or soil moisture and dissolved salts regime could therefore substantially alter the composition, distribution and abundance of species. Increased frequency of climatic extremes and changes in soil salinity induce changes in plant functional group composition with invasion of nonnative annual plant, which significantly reduce productivity in arid ecosystems. Therefore, functioning of these arid systems depends to a high degree on plant diversity. Considerable research has been conducted on soil-vegetation relationship in coastal salt marshes saline soils (Toft and Elliot-Fisk 2002). However, investigations identifying the major environmental factors associated with vegetation patterns on inland saline desert areas are scarce and limited to the descriptive botanic documentation of species. Previous studies have shown that many wild halophytes grow well in association with a variety of salt-tolerant traditional crops and often provide severe competition to tree/shrubs species, in natural and improved pastures both on saline and disturbed mine sites (Toderich et al. 2007, 2008). Carbon isotope composition ($\delta^{13}C$) of plant material is related to intrinsic water-use efficiency in C_3 plants (Farquhar et al. 1989). The positive correlation was found between the salinity and the $\delta^{13}C$ of leaf organic matter both in salt-tolerant species (Guy et al. 1980; Farquhar et al. 1982) and salt-sensitive species (Seemann and Critchley 1985). These reports indicate that salt stress may decrease the CO_2 concentration inside the leaf via the stomata closure and consequently increase the intrinsic water-use efficiency. There was, however, no report that presented the response of the $\delta^{13}C$ of leaf organic matter to the salinity.

Afforestation has proved to be effective in revegetating saline landscapes, providing valuable products to local pastoral communities from marginal degraded land, and makes use of the otherwise low-quality water, unproductive lands and lowers the elevated groundwater table via biodrainage (Heuperman et al. 2002; Marcar and Craw-Ford 2004; Khamzina et al. 2006). However, to ensure effective and sustainable outcomes, afforestation of marginal lands must be preceded by a comprehensive evaluation of appropriate both native and introduced tree species (Toderich et al. 2009). Utilization of native vegetation and revegetation has a most important role in raising oasis agriculture under saline environments (Gupta et al. 2009).

The present study aims to describe the spatial distribution of desert plant communities along soil salinity and moisture gradients to understand the relationship between different ecological types of halophytic vegetation and soil properties. The $\delta^{13}C$ and $\delta^{18}O$ data were used to assess the responses of native plants to salinity and the effect of salinization on natural vegetation in Central Asian dryland ecosystem. Native vegetation such as *Artemisia diffusa* and *Salsola paulsenii* are dominated in the plot of the lowest salinity. In this study three dominant shrubs analyzed in this study are *Artemisia diffusa*, *Tamarix hispida* (C_3 species), and *Haloxylon aphyllum* (C_4 species). The *T. hispida* distributed in the plots with high salinity is found frequently after salinization. *H. aphyllum* is planted as a sand shield in all plots.

It was expected that introduction and adaptation of native halophytes and exotic salt-tolerant crops have the potential to provide a break for improving the livelihood of farmer's income at abandoned degraded marginal areas. It is known that the soil and irrigation water salinity limits crop production, especially in arid and semiarid regions. Therefore, experiments on evaluation of indigenous and introduced salt-tolerant plants and halophytes for increasing food, forage, and grain production under soil and irrigation water salinity through farmer's participatory work were conducted in 2007–2009.

This chapter presents an analysis of revegetation technique to mitigate secondary salinity and improve productivity of degraded drylands ecosystems in Aral Sea Basin.

38.2 Material and Methods

38.2.1 Description of the Study Sites

The studies on cover desert vegetation along a salinity gradient were conducted in Kanimekh district at the research station of the Uzbek Research Institute of Karakul Sheep Breeding and Desert Ecology at an altitude of 113 m. The Kyzylkesek site was selected – an area located between two hot springs (vertical drainage flow) in Central Kyzylkum Desert – in order to determine spatial changes of vegetation as from the xerophytes in sandy dunes toward typical halophytes in wet salt depression (Fig. 38.1). Our findings showed that each zone differs by its relief, total soluble salts, floristic composition, and botanic diversity. This region has a typical inland arid climate with a hot, dry summer and cold winter: annual mean temperature is 11.4°C, and annual mean precipitation is 120 mm, which distributes in the growing season from May to September.

Experimental plantations were established in early April 2007–2009 on gleyic-sandy solonchak soils (Central Kyzylkum Desert) and silt loam texture (Amudarya river delta, Dashauz district, Turkmenistan), both underlain by a thin gypsum layer (a hydrated calcium sulfate accumulation, which is most pronounced within upper 100 cm). Therefore, the root zone before planting needs to be leached.

An agro-silvicultural trial of trees intercropped with deep-rooted, early maturing, and frost-tolerant legume was established in the Yangiobod farm, northern Tajikistan, in order to determine appropriate tree species and silvicultural techniques for converting degraded, salt-affected land patches into small-scale tree plantations. The plantations measured an area of 0.14 ha each. The preselected nine deciduous native and exotic species represented a variety of life spans and tolerances to drought and salt stress. One-year-old tree saplings were randomly planted on the shoulder of a 40-cm-deep irrigation furrow. The spacing of 5.0 m × 5.0 m avoided mutual shading during the experiment and allowed to plant annual crops and grasses between rows. Due to an adequate availability of saline irrigation water in the region throughout the study period, the presence of intensively irrigated rice fields in the vicinity, and a high groundwater table (GWT), the trees at the loamy site (in northern Turkmenistan) were only occasionally irrigated. The soil moisture at the sandy site remained close to field capacity; hence, only one irrigation event was necessary at the onset of each vegetation season.

The area was instrumented with a network of observation wells. The texture analyses of the sandy-gleyic solonchak soil at each installation point showed in

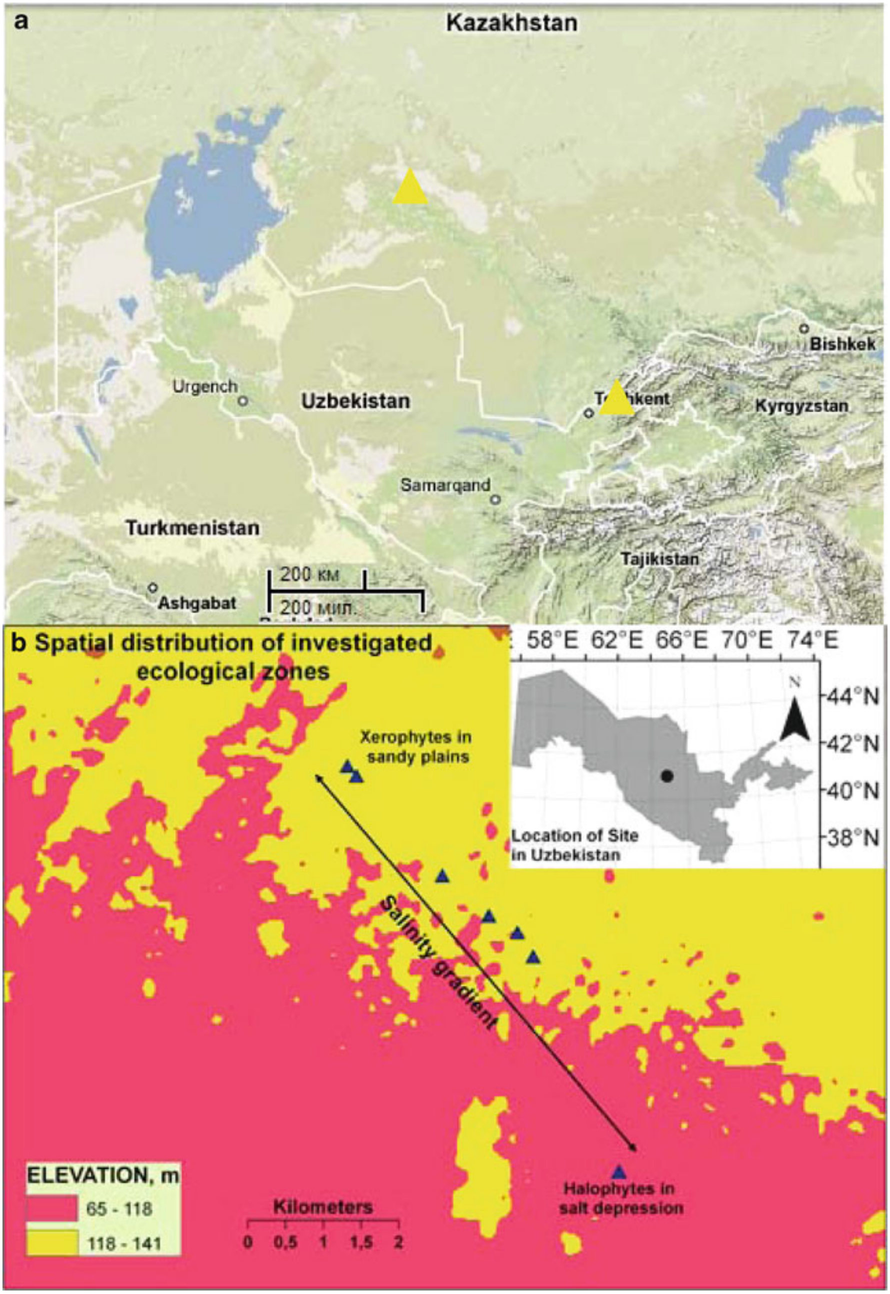

Fig. 38.1 Topographical landscape map of Central Asia. (**a**) Altitude maps in large and small scale (**b**). The circle in the large-scale map indicates the left figure area. Salinity gradient on microrelief level includes area between two artesian thermal springs (triangular showed the investigated plant community with the investigated area)

general a silt loam texture with a clay bank of varying thickness between 100 and 150 cm depth. Below this clay level, the profile typically consisted of fine sand.

The groundwater table (GWT) at the sandy site ranged between 0.7 and 1.3 m during the vegetation period, whereas the GW level at the loamy site varied from 1.0 to 1.3 m. The average GWT depth monitored at both sites was close to the long-term mean of 1.22 m for the region. During the observation seasons, the mean electrical conductivity (EC) of the GW was higher at the nonirrigated sandy site (4.3 dS m^{-1} vs. 3.3 dS m^{-1} at the silt loamy site). Both values exceeded the long-term mean salinity of 1.8 g L^{-1}. Spatial and temporal distribution of natural vegetation according to soil salinity level was studied based on plant vegetation type and soil salinity level.

38.2.2 Estimation of Dry Biomass

Aboveground biomass of investigated species was harvested at the end of October each year, and the harvested material was packed in paper bags in the field and then oven-dried at 65°C for 72 h in the laboratory. The dry weight of all the species was then combined to get the total biomass estimates.

38.2.3 Calibration of EM38

Electromagnetic induction conductivity device (EM38) was standardized at reference temperature of 25°C as EC increases at a rate of approximately 1.9% per 1 degree centigrade above 25°C. (Rhoades et al. 1999). The formula provided in Sheets and Hendrickx (1995) was used, that fits the curve to conversion table given in USDA (1954): $EC_{25} = EC_a \times [0.4470 + 1.4034\varepsilon^{(T/26.815)}]$, where EC_{25} is standardized EC_a and T-soil temperature (Akramkhanov et al. 2008; Hendrikx et al. 1992).

38.2.4 Soil Samples

Soil samples were collected from different depths (0–20, 20–40, 40–60, 60–90, 90–120 cm). Na^+ ions were analyzed by water extract from air-dry soil and plant samples (100 mg of sample) and detected on atomic adsorption spectrophotometer (Hitachi 2007, Japan). Salinity gradient was characterized by contents of Na^+ ions in the soil profiles. Modern techniques to predict trends of neo-halophylization process from soil and plant cover data were tested. The regression analysis was applied to investigate correlation between remote sensing data, Na^+ ion content, and EC values calculated from field data in order to predict soil salinity and vegetation changes.

38.2.5 Carbon Isotope Analysis of Desert Vegetation

The distribution and abundance of desert plant communities were examined. Plant species were collected along a sequence of increasing groundwater depths in eight transects. Isotope analysis, carbon, and oxygen isotope ratios were expressed by the following equation:

$$\delta^{13}\mathrm{C} \text{ or } \delta^{18}\mathrm{O} = \left(\frac{R_{\mathrm{sam}} - R_{\mathrm{std}}}{R_{\mathrm{std}}}\right) \times 1{,}000\ (‰)$$

where R_{sam} and R_{std} represent the $^{13}C/^{12}C$ or $^{18}O/^{16}O$ of the samples and standard, respectively. The PDB and VSMOW were used for standards of $\delta^{13}C$ and $\delta^{18}O$, respectively.

The photosynthetic organ samples (leaves and short pieces of stems at case of aphyllous species) were oven-dried at 70 °C for 48 h and finely ground. The $\delta^{13}C$ in the organic samples was analyzed using a continuous flow system of an elemental analyzer and an isotope ratio mass spectrometer (Flash 2000 and Delta S, Thermo Fisher Scientific) at Field Science Education and Research Center, Kyoto University, Japan.

38.3 Results and Discussion

Groundwater salinity varies in the range of 2,000–8,200 mg L^{-1}. Groundwater table fluctuates from 0.5 to 2.5 m during May–July at the dry solonchaks and experimental agricultural plots and up to 8.0 to 20.0 m in the virgin desert degraded rangelands area. The GW table under the plantations ranged during the observation period from 1.2 to 2.2 m below the soil surface. The EC of the GW under plantations varied between 0.4 and 4.2 dS m^{-1} while the range of EC values under the open field was 0.4–2.8 dS m^{-1}. Measurements of soil EC in the beginning and the end of the vegetation season indicated that the soil was of slight to medium salinity, although at the upper 40-cm horizon at some points, EC reached values of over 25 dS m^{-1}. Soil EC at the open field was in average about twice as low as that at the plantation area.

The organic matter of soil in the surveyed soils is less than 1%, while the cation-exchange capacity varies between 10 meq/100 g and 35 meq/100 g soil. Total nitrogen (N) and phosphorus (P) contents in salt-affected soils are low, usually ranging between 0.7–5.5 mg kg^{-1} and 10.0–18.26 mg kg^{-1}, respectively. Available potassium (K) content is classified as low or moderate (Fig. 38.2). The dominant cation is Na and the dominant anion is SO_4. Soil fertility of the desert saline soils is characterized as low; therefore, the cultivation of agricultural crops requires high inputs of chemical fertilizers and costly leaching practice to free root zone from salinity.

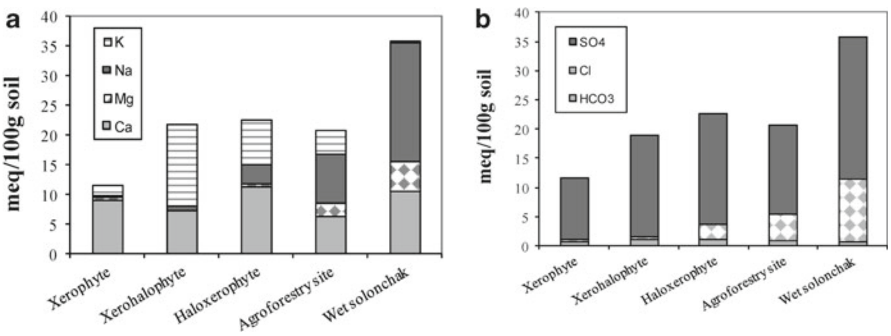

Fig. 38.2 Content of different cations (**a**) and anions (**b**) under different dominant plant communities along a salinity gradient

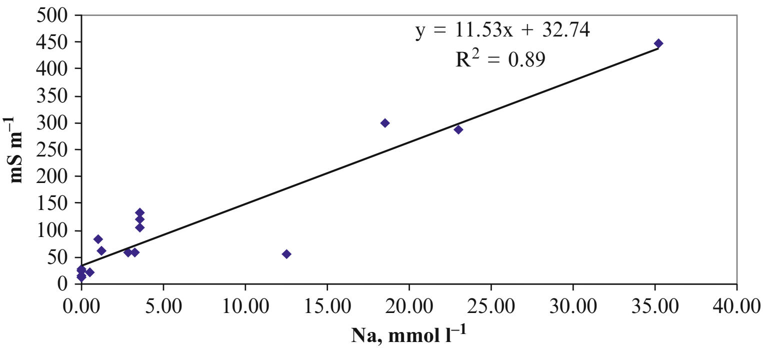

Fig. 38.3 Linear regression between apparent electrical conductivity (EM38) and Na^+ content across salinity gradient at the fine landscape level (Source: Shuyskaya et al. (2008))

Analysis of soil samples from five hot spot areas separately demonstrated significant differences of cations and anions content, strongly interrelated with the halophytic plant spectrum composition (Fig. 38.2).

Chemical analysis of soil showed that main type of mineralization is calcium-sodium and sulfate from anions. The virgin Artemisia rangeland and gray-brown stabilized sands with predominance xerophytes and xerohalophytes with the least content of salinity in soil solution is characterized by significant amount of Ca^{2+}, HCO_3^- ions, and the least content of Na^+, Mg^{2+}, and Cl^- compared with other tested sites.

The ability of up-taking and/or accumulation of sodium ion in the upper soils profile and electric conductivity value detected by EM38 were gradually raising according to floristic composition, spatial halophytic vegetation distribution, and relief characteristics. Electrical conductivity values were graphed, and the linear regression was fitted. In general, there is a good fit of the regression line that is demonstrated by high r^2 (Fig. 38.3).

It is evident from Fig. 38.3 that there is a positive correlation between sodium ion content and electric conductivity ($r^2 = 0.881$) at 0–75 cm of soil profiles. Results generally indicated that the salinity gradient, moisture, and available nutrient in soil are the important factors in controlling the temporal and spatial distribution of vegetation.

The salt-affected marginal lands in the plains and studied saline depression were classified into three habitat types: *A*-with shallow water table and moderate salinity (marginal old agricultural lands), *B*-with relatively deep water table and high salinity, and *C*-transitional habitats in which salinity and water table are not controlling factors (virgin Artemisia perennial pastures). The most important factors of zonal vegetation were soil salinity and the salt-tolerance limits of species. In general, the distinction of each ecological vegetation group differs according to relief, floristic composition, and ion concentration (halo accumulation plant ability) in the aboveground dry biomass. It was found that the most important direct source of soil salinization, as is seen in the Table 38.1, was shallow groundwater level calculated through the soil moisture content and soil salinity based on the content of Na^+ ions in the upper soil profiles. A very intensive process of soil salinization occurs in the areas located in the vicinity of settlements, animal drinking points, and artesian freely flowing wells along drainage channels and on small saline depressions (wet solonchaks-ecotype 5 in this research).

Plant composition, soil salinity, water table level, and pasture yield were quantified in five main ecological zones. Afforestation program was performed to test the importance of farming practice in the mitigation of salinity and decreasing water table. On the high end of the gradient, soil salinity and sodicity (a measure of exchangeable sodium) were high in the *Climacoptera lanata* zone [(EC = 5.3 dS m^{-1}), sodium adsorption ratio-SAR = 44.0 (mmoles $L^{-1})^{0.5}$] and extreme in the *Tamarix hispida* zone [(EC = 21 dS m^{-1}), SAR = 274 (mmoles $L^{-1})^{0.5}$]. Natural species produced maximum biomass in the zone where they originated, not in any other higher or lower vegetation zone. The *Tamarix* species, H. *apphyllum*, and annual halophytes, which were distributed across nearly all sites, had low frequency of occurrence. Based on this, we have distinguished common growth forms into distinct groups corresponding to different groundwater levels. Three clearly defined groups of growth forms were strongly associated with three distinct groundwater zones, ranging from <3, 3–5 to >5 m, respectively. Four taxa groups were found to correspond to the three groundwater zones and to several other environmental factors that suggest a major botanical gradient exists relating to groundwater depth than to the secondary gradients like soil moisture and pH and to a lesser extent, alkalinity and mineralization.

As seen from Table 38.1, the dominating life forms are halophytes (chamaephytes) in sites of high salinity and xerophytes (therophytes) in sites of low salinity. Spatial and temporal variations in the standing crop biomass were pronounced. The accumulation of green biomass started during spring and reached a maximum in autumn, when photosynthetic activity was maintained to account for transpiration losses. There was a general trend of increasing salinity and concentration of different ions along the salinity gradient. The periodical variation in the water table was

Table 38.1 Description of halophytic plant communities in the Karakata salt depression, Central Kyzylkum

	Biotope/ecological groups	Description of plant communities	Water table depth (m)	Improvement practice	Soil salinity level as per sodium content (Na^+, meq/100 g)	Halophytic pasture yield (t ha^{-1})[a]	Moisture (%)
1.	Sandy and gray-brown desert soils/aboriginal psammophytic pastures (xerophyte)	*Ferula assa-foetida*, *Aellenia subaphylla*, *Ammothamnus lehmannii*, *Astragalus villosissimus*, *Artemisia diffusa*, *Salsola praecox*, *Turnefortia* sp., *Calligonum leocacladum*, *Stipa* sp., *Ammodendron connolly*	20–28	No	Low (0.3–0.5)	0.7	2.8
2.	Sagebrush with ephemers (Artemisia spp.) sandy desert (xerohalophyte)	*Artemisia diffusa*, *Haloxylon aphyllum*, *Peganum harmala*, *Salsola* sp., *Climacoptera lanata*	20–18	No	Low (0.2–1.2)	2.48	3.3
3.	Haloxylon forest (haloxerophyte)	*Peganum harmala*, *Haloxylon aphyllum*, *Alhagi pseudalhagi*, *Salsola* sp., *Sueda* sp., *Climacoptera lanata*	4–6	No	Low-moderate (3.5–7.0)	1.5	7.9
4.	Desert salt-affected soil improved through an agro-silvi-pastoral model	Aboriginal strips of halophytes with *Climacoptera lanata* mixed with moderately salt-tolerant tree-shrubs-traditional crops (*Sorghum*, *Pennisetum-Amaranthus* etc., crops)	1.5–2.8	Without irrigation and fertilizers (control)	Moderate (7.9–12.0)	4.7	8.1

5.	Desert salt-affected soil improved through an agro-silvi-pastoral model	Aboriginal strips of halophytes with *Climacoptera lanata* mixed with moderately salt-tolerant tree-shrubs-traditional crops (*Sorghum*, *Pennisetum-Amaranthus* etc. crops)	0.9–2.0	Irrigation with saline water, without fertilizers	Moderate (7.9–12.0)	21.8	8.1
6.	Desert salt-affected soil improved through an agro-silvi-pastoral model	Aboriginal strips of halophytes with *Climacoptera lanata* mixed with moderately salt-tolerant tree/shrubs traditional crops (*Sorghum*, *Pennisetum-Amaranthus* etc., crops)	0.9–2.0	Irrigation with saline water and fertilizers	Moderate (7.9–12.0)	43.6	8.1
7.	Wet solonchak/hyperhalo-phytes (pure stands)	*Tamarix hispida*, *Salicornia europea*, *Sueda* sp., *Climacoptera lanata*, *Aeluropus littoralis*, *Halostachys caspia*, *Halimochnemis strobilaceum (belangeriana)*	0.5–0.9	No	High (17.5–34.0)	11.5	8.9

[a]Calculated for *Climacoptera lanata* under different agropastoral management practices

insignificant, while a significant drop in salinity and the concentration of different ions were detected in spring, which was attributed to the diluting effect of rainwater during that season.

As indicated in Fig. 38.2, we used five halophytic vegetation types to build a species-area curve by calculating the cumulative number of species according to soil anions/cations changes, which correspond with habitats heterogeneity and species diversity at fine landscape scale, like Karakata flat salt depression. In this situation, rangelands productivity sharply declined, and it was mostly determined by development of monospecific dominant vegetation stands. During extension of the process of neo-halophylization, previously high productive rangelands became converted into saline pastures covered by halophytes, which differed by their salt-tolerance limit and vegetation composition, as seen on Fig. 38.2 and Table 38.1. Based on accumulation of Na^+ in the soil profile over the entire studied area, the key halophytic plant communities were distributed as strong ecological groups starting from nonsaline (psammophytes and xerophytes) through moderate saline (xerohalophytes and haloxerophytes) to highly saline habitats or salt marshes (hyperhalophytes) habitats. Thus, patterns at Karakata saline depression arise from counter-directional stress gradients: a gradient from low salinity to extremely high soil salinity and shallow water table, which strictly dominate the vegetation zonation. Therefore, we assume that the restoration of the salt-affected/waterlogged regime of these lands to a natural desert regime through afforestation farming system may be sufficient to reestablish many of the natural biodiversity/ecosystem functions.

The distribution of halophytic vegetation is related to interspecific and intraspecific plant species competition, grazing capacity, and land management. Desert topographical features and salinity gradient are of primary importance in determining the contribution of species with different photosynthetic pathways or taxonomic relations in forming of core ecological plant community types or vegetation units.

38.3.1 Plant Density of C_3*- and* C_4 *Species Related to Na and K Accumulation and Biomass Productivity*

The C_3 species such as *A. lehmannii*, *A. diffusa*, and *Alhagi. pseudalhagi*, which occurred mostly on 1–3 ecological zones (Table 38.1), and some of tree species accumulate insignificant amount of sodium in leaves (0.63–7.34 g kg^{-1} of dry matter). Considerably high content of sodium (about ten times higher) was found in the leaves of *P. harmala* (52.33 g kg^{-1}) which is one of the plant components of haloxerophyte vegetation association. Such C_4 species as *H. aphyllum*, *S. paulsenii*, *and T. hispida* accumulate 20–90 g kg^{-1} of sodium in green aboveground part. The representatives of C_4 species (*C. lanata*, *Suaeda* sp.) of haloxerophyte plant association are capable to accumulate up to 300 g kg^{-1} of sodium.

Potassium was accumulated approximately in the same amount (6.9–28.11 g kg^{-1}) in both C_3 and C_4 studied plants. In the green part of C_3 species, the content of potassium has increased twice than the content of sodium (2.0 and 0.8 kg ha^{-1}) in xero-

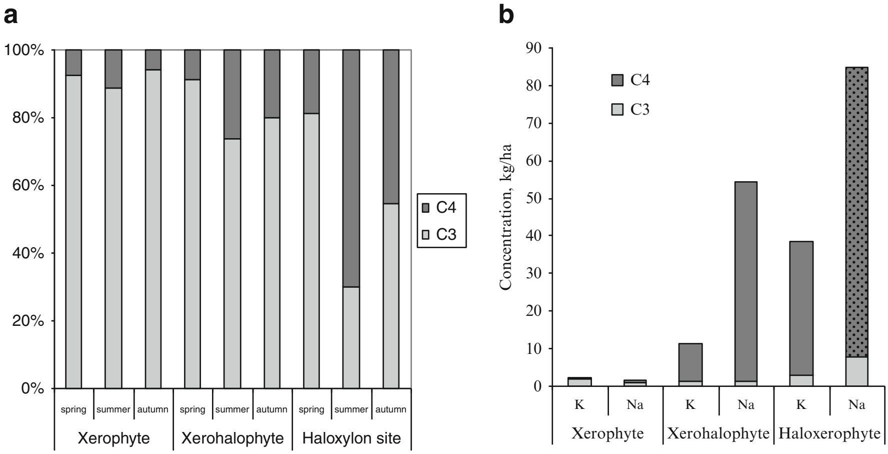

Fig. 38.4 Ratio of species with C_3 and C_4 types of photosynthesis (**a**) and contribution of C_3 and C_4 species in accumulation of sodium and potassium in plant communities (**b**)

phyte plant community. Slightly increased content of potassium (1.3 kg ha^{-1}) over the sodium (1.1 kg ha^{-1}) was also observed in xerohalophyte plant community. The opposite trend was observed in haloxerophyte plant community being 2.8 times higher content of sodium than potassium representing the values of 7.9 and 2.8 kg ha^{-1}, respectively. Accumulation of high amount of sodium was detected in C_4 plants. In green part of C_4 species, the content of sodium has considerably increased from 2 to 8.6 times over the content of potassium for all plants (Fig. 38.4).

Proportion of species with C_3 and C_4 types of photosynthesis at the three plant communities considerably differentiated along the spatial and temporal scales (Fig. 38.4a, b). The highest density of xerophyte and xerohalophyte plant communities belongs to C_3 species consisting of 89–94% and 74–91%, respectively. The ratio of C_4 plants showed smaller values than C_3 plants for both plant communities. As its name implies, the plant density of haloxerophyte community represented considerably rapid changes during the seasons in terms of the ratio of C_3 and C_4 plants. In spite of the dominancy character of C_3 species in haloxerophyte community, the proportion of C_4 species is noticeably increased than in other plant communities. The contribution of C_4 species showed 19–70, and 45% during spring, summer, and autumn seasons, respectively. However, during the summer season, relatively increased values of C_4 species are observed for all plant communities.

Results showed that ratio of C_3 and C_4 plants in vegetation communities differs both along the salinity gradient and on seasons of the year. Along the salinity gradient, the ratio of C_3:C_4 species (in average by all seasons) is represented as 10:1, 10:2, and 10:9 for xero-, xerohalo-, and haloxerophyte plant communities, respectively. Regular prevalence of C_3 species is observed, as proportion of C_4 species in the flora of desert vegetation of Uzbekistan does not exceed than 4% (Pyankov et al. 2001; Toderich et al. 2007; Shuyskaya et al. 2012). Nevertheless, proportion of C_4 species

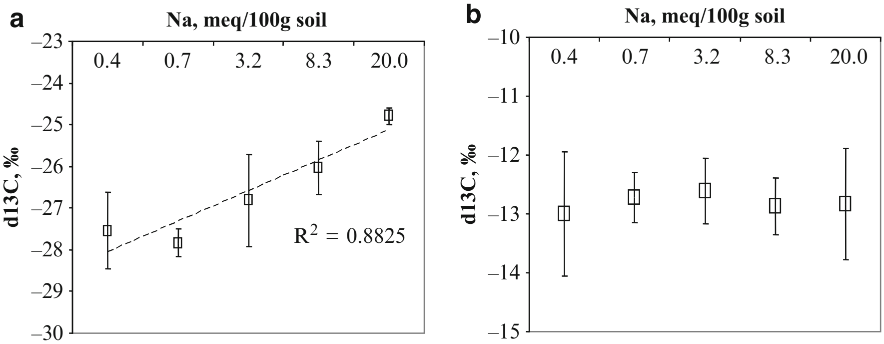

Fig. 38.5 Leaf carbon isotope ratio of (**a**) C_3 and (**b**) C_4 species along salinity gradient

is increased along the salinity gradient, and in haloxerophyte plant community, its amount becomes comparable to the proportion of C_3 species. The C_4 species are mostly dated to the salt-affected soils, and Na^+ is essential for C_4 species (for the translocation of pyruvate across the chloroplast envelope) where it functions as a micronutrient, and to some extent, all Chenopodiaceae species (studied C_4 chenopods) are halophytes (Akhani et al. 1997; Toderich et al. 2007) from one side. From other side, in case of vegetation cover of Karakum desert (Pyankov et al. 2002) and grasslands of Argentina (Feldman et al. 2008), the increased amount of C_4 species comparatively to C_3 species has shown along the gradient of deterioration of soil condition and soil salinization. Significant dependence of C_3 species on soil salinization indicates about the reduction of carbon isotope discrimination (d13C value) of studied C_3 species along the salinity gradient (from −27.39 to −24.79‰). A 2% difference in d13C value of C_3 plants indicates a difference in water-use efficiency of about 30% (Ehleringer and Cooper 1988). In this case, C_4 species demonstrates independence of d13C value along the salinity gradient (Fig. 38.5b). All studied C_4 species are halophytes and accumulate sodium ten times more than C_3 species. In most species, Na^+ does not act as a nutrient in the sense that it is strictly required for growth, but its addition to the growth medium may promote growth of many plants when the K^+ supply is limited (Flowers and Lauchli 1983) and in particular, the growth of salt-tolerant and halophytic plants by contributing to turgor formation. Although the availability of Na^+ as a "cheap" osmoticum is generally beneficial, a large excess of Na^+ ions over K^+ is not. As has been pointed out by Yeo (1998), one of the key elements in salinity tolerance is the capacity to maintain a high cytosolic K^+/Na^+ ratio. In the present study, potassium has been accumulated in a comparative amount. In connection with this evidence, the ratio of K^+ to Na^+ in C_3 species is more than in C_4 species, particularly in xerophytes and xerohalophytes plant communities. From other side, the percentage ratio of K^+ comparatively to N for C_4 species decreased considerable with less variation than C_3 species along the salinity gradient which says about high sensitivity of C_3 species to salinization of soils. The percentage ratio

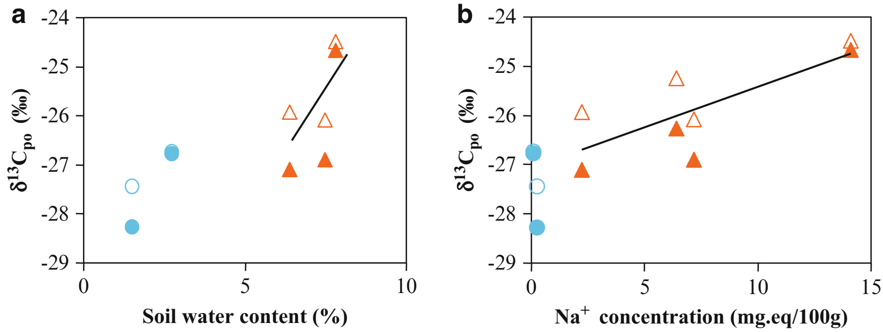

Fig. 38.6 The $\delta^{13}C_{om}$ in *A. diffusa* (*circles*) and *T. hispida* (*triangles*) plotted against mean water content in the soil of 0–120 cm depth. Open and solid symbols refer to the data for 2007 and 2008, respectively. Dashed and solid lines are simple regression lines for *A. diffusa* of 2007 and 2008, respectively. Results were considered statistically significant at $p<0.05$

of K comparatively to N decreased with high variability from 2.33 times in xerophyte plant community to 0.35 times in haloxerophyte plant community. However, the amount of potassium for C_3 species is increased in haloxerophyte plant community.

Despite significant differences in $\delta^{13}C$ seasonal means for the four species, the results demonstrate a significant convergence in the responses of $\delta^{13}C$ values and water-use efficiency (WUE) to seasonal variations in environmental factors among the species investigated, and that the $\delta^{13}C$ signature for each species gives a strong indication of environmental variables including soil and water salinity.

The results showed that the mean Na^+ concentration in the soil of 0–120 cm depth ranged from 0.1 to 9.0 meq/100 g soil. The mean water content in the soil of 0–120 cm depth ranged from 1.5 to 7.8 water/soil %. Comparing between C_3 species, the $\delta^{13}C_{om}$ was significantly higher in *T. hispida* than in A. *diffusa*. The $\delta^{13}C_{om}$ of *T. hispida* was significantly higher in plot 7, in which Na^+ concentration in soil was the highest, than in plots 1, 5, and 6. The $\delta^{13}C_{om}$ of a C_4 species, *H. aphyllum* ranged from −13 to −12‰. *T. hispida* and *H. aphyllum* could depend on water in the deep layer of the soil at least in plots 1 and 5 and probably in the other plots though there was no direct evidence (Fig. 38.6a, b). *T. hispida* may be able to maintain transpiration low and increase intrinsic water-use efficiency even in high-salinity zones because they depend on less-salinity water in the deeper layer of the soil and exclude excessive salts by salt glands if they absorb much salts.

Results suggest that *H. aphyllum* may keep transpiration low at a wide range of soil moisture and salinity. Simple correlations between the distributional/spatial behavior of species and salinity and the concentration of individual ions were generally low, while correlations with combinations of ions in the form of ratios (notably sodium and potassium adsorption ratios) were higher.

Xerophyte plant community is characterized with the lowest value of rangeland productivity consisting of 300 kg of biomass per hectare. More than 90% of biomass proportion of xerophyte plant community is represented by C_3 species. The

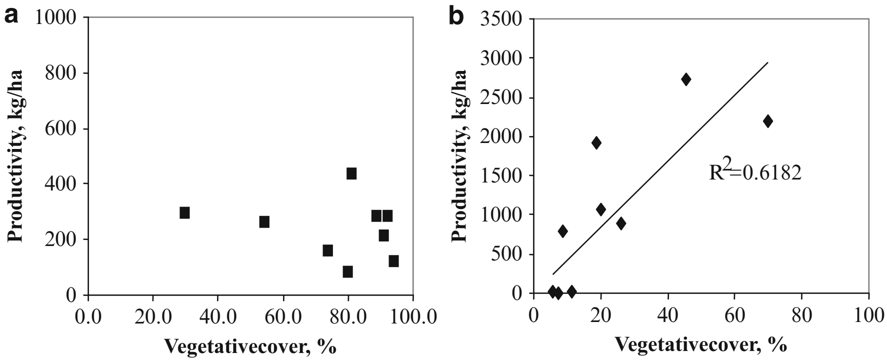

Fig. 38.7 Correlation between biomass and vegetative cover of C_3 (**a**) and C_4 (**b**) species

total productivity of all plants in xerohalophyte plant community is 1,000 kg ha^{-1} of which 15% belongs to C_3 species and 85% to C_4 species. The ratio of C_4 species is considerably increased in productivity of haloxerophyte plant community and covered 87% of total biomass. Only 8.6–18.4% of total biomass belongs to C_3 species. Haloxerophyte plant community is characterized with highest biomass among other plant communities – 2.600 kg ha^{-1} (Fig. 38.7a, b). Seasonal dynamics of total biomass production of vegetation communities is characterized by increased trend during the vegetation period reaching the highest values in autumn seasons for the amount of C_4 species. However, there is opposite dynamics of biomass depending on the photosynthesis type plants: decreased trend for C_3 and increased trend for C_4 species during the seasons. The halophytic pasture yields expressed as t ha^{-1} dry weight for representative biotopes as is shown in Table 38.1 increased with radical changes in soil salinity and water table level. Haloxerophytes and halophytes (salt-loving plants) usually produce huge green biomass due to juicy stems and leaves. The highest yield of dry biomass was observed for halophytic plant communities, which were the first colonizers of salt marshes or wet solonchaks biotopes.

In this study, it was found that among cited plant resources, there are a number of both C_3 and C_4 plants suitable for reclamation of salt-affected and waterlogged drylands that could be proven very useful in demonstration trials. However, these areas have been abandoned by agropastoralists and are not yet widely used as part of the arid fodder production system. The rangelands grazing capacity and yield of green/dry biomass significantly increase, when agro-silvi-pastoral management practices are applied. Based on the map vegetation pattern distribution and on ground data, we found that there were only a few core species, which determine productivity of rangelands of the studied biotopes/niches. Assessing the grazing potential of degraded rangelands by mapping zonal halophytic vegetation allowed us to identify salt pioneer plant species for each studied zone in order to initiate the reclamation process of saline-prone soils. Among frequently found species, there were *C. lanata*, *Kochia scoparia*, *Atriplex nittens*, *Salsola rigida*, *Halothamnus subaphylla* (Chenopodiaceae), and *Glycyrrhiza glabra* (*Fabaceae*) annual and perennial species, growing well both on salty crusts (solonchak-alkaline soils), on clay and gypsum deserts, on takyr, and on high-saline sandy soils. Therefore, we consider these species as a model plant for calculation of rangeland productivity both on virgin area and under cultivation (agro-silvi-pastoral model) by using supplement irrigation with low-quality water and application of fertilizers (Toderich et al. 2008).

38.3.2 Agro-Silvi-Pastoral Experiments to Improve Productivity of Marginal Salt-Affected Lands

Results of present study indicate the coexistence of C3 and C4 species is facilitated because C3 species can colonize nutrient-rich microsites, while C4 species canopy nutrient-poor microsites. Comparing different species within a small-scale habitat along a salinity gradient, we found that short-lived annuals or herbaceous species had significantly lower values than perennial species. Therefore, an agroforestry model by using native tree/shrubs plantation intercropped between rows with annual halophytes and forage crops was established on saline marginal lands. The selection for trees with low $\delta^{13}C$ (carbon isotope discrimination index) and, therefore, high transpiration efficiency, has the potential to increase total tree biomass growth in water-limited arid saline environments. Trees/shrub plantations were deeply seedlings planting (sticks tap into the water table) in early spring or late autumn seasons. These were initially irrigated with low-quality water during the initial stage of growth before sole reliance on available drainage water (higher salinity; EC 4.5–12.3 dS m^{-1}) before the trees/shrubs can rely on the available groundwater resources. Soil salinity at root zone was about 45 dS m^{-1}. The salinity level of the groundwater range between 8.0 and 16.5 dS m^{-1}, though inappropriate for the common local agricultural crops, did not restrict growth of these tree species. Due to soil moisture by the groundwater and irrigation (although applied at deficit rates), the trees tolerated the strong soil salinity without inhibition in survival and growth rate. The assessment of tree performance in the region during the first 3 years on marginal land showed high growth rates, which were comparable to those reported for trees on irrigated agricultural land (Khamzina et al. 2008).

The results (Table 38.2) revealed that the leading tree species with regard to survival rate, growth characteristics, and adaptability to high-saline natural environment proved to be *H. apphyllum*, *Salsola paletzkiana*, *S. richteri* at saline sandy sites, followed by *E. angustifolia*, *Populus euphratica*, *P. nigra* var. *pyramidalis*, *Robinia pseudoacacia*, *Morus alba*, *and M. nigra*, whereas fruit species such as *Cynadon oblonga*, *Armeniaca vulgare*, *Prunus armeniaca*, and species of genera Malus. These plant species, though desirable from the farmer's financial viewpoint, showed low biodrainage potential. Aboveground dry matter (DM) production for 2007–2008 seasons were in the order of *A. ampliceps*>*E. angustifolia*>*M. alba*,

Table 38.2 Performance indicators of native and introduced of C_3/C_4 tree and shrubs species under condition

Parameters species	Growth rate (at first year)	Root establishment	Reproduction	Aboveground DM	Biodrainage; feed and firewood value	Soil salinity level	Winter frost tolerance	Rate survival (%)
Haloxylon aphyllum[a]	+	±	a.b.c	+	±	+	+	±
Tamarix hispida		+	Invasive	±	±	+	+	+
T. androsovii	±	+	Invasive	±		+	+	±
Populus alba	±	±	a.b	±		+	±	+
P.nigra var. pyramidalis	±	±	a.b	±	+	±	+	–
P.euphratica	±	±	a.b	±	+		±	–
Salix babylonica	±	±	a.b.c	±	±	+	±	–
Hyppophae ramnoides	±	±	a.b.c	±	±	+	±	+
Elaeagnus angustifolia	+	+	a.b.c	+	+	+	±	+
Robinia pseudoacacia	–	+	a.b.c	+	+	±	+	±
Morus alba	+	±	a.b	+	–	±	±	+
Morus nigra	+	±	a.b	+	±	±	±	±
Malus domestica	±	±	a.b	±	±	–	–	±
Malus silvestris	±	_	a.b	±	±	±	+	±
Cynadon oblonga	±	±	a.b	±	±	±	–	+
Armeniaca vulgare	±	±	a.b.c	±	±	±	–	+
Thuja occidentalis	–	_	b	–	–	–	±	–
Persimmon diospyros	+	+	a.b.	+	+	+	±	–
Rosa canina L.								
Atriplex undulata[a]	+	+	a.b.c	–	+	+	+	+
Artemisia diffusa	+	+	a.b.c	+	–	–	+	+

+ high potential, ± medium potential, – low potential
[a]C_4 species, while others tested species belong to C_3

M.nigra>*P. euphratica*>*R. pseudoacacia*>*T. occidentalis* among the species tested. These species combined fast growth with a moderate ability to develop leaf biomass rapidly and showed characteristics of feed quality sufficiently to be used during the off-season. Genus *Tamarix*, with high absolute values of aboveground biomass, was very tolerant to saline-alkali soil with pH values of up to 8.5.

The overall ranking of the trees, weighing all parameters, concurrently shows that species of genus *Tamarix* and *Elaeagnus angustifolia* have the highest potential for growing on both loamy and sandy soils, which represent the dominant soil textures in the region. As results, at marginal sites where a shallow, slightly-to-moderately saline groundwater is available throughout the growing season, *Elaeagnus angustifolia*, *Robinia pseudoacacia*, and newly introduced *Acacia ampliceps* showed the fastest growth and highest water use. This indicates the suitability for planting on low-fertility saline lands. Preliminary outcomes of the study on salt-affected soils have also indicated that tree plantations with *E. angustifolia*, *Populus nigra var. pyramidalis*, *and Morus* spp. have potential for increasing the soil organic matter due to the relatively rapid leaf litter decomposition. *Morus nigra* and *Cydonia oblonga* showed reasonable DM production on degraded land, with high biomass allocation toward the root fraction. Among tree species, Poplar (*Populus alba*, *P. nigra var. pyramidalis*, and *P. euphratica*) showed maximum growth for all parameters studied followed by mulberry (*Morus nigra*). The *Populus diversifolia* which displayed high rates of leaf and wood production appeared to be the most sensitive to saline sandy-soil type. Similarly, it had slow longitudinal root growth and low root DM production at sandy site while exhibiting superior belowground development at the sandy loamy soils. Introduced coniferous species *Thuja occidentalis* was the only species that showed poor growth under furrow irrigation at the Dashauz province and at the second year died due to its high sensitivity to frosts.

Evaluation of survival rate, performance, and productivity including biomass and seed production of nonconventional tree/shrubby halophytes firstly introduced in Central Asian flora including *Acacia ampliceps*, *Atriplex nummularia*, *A. undulata*, and *A. amnicola* by Dubai-based International Center for Biosaline Agriculture showed its high potential for the reclamation of salt-affected marginal lands. All species tolerated average root zone salinity of 8–16.8 dS m^{-1}. Seedlings of *Acacia ampliceps* were obtained from by direct seed sowing in the field (February 2006) and through the establishment in plastic bags. The growth rate was very fast at 12–18 cm month at the rooting stage and 25–30 cm month, when the basal stems develop a woody character. Plant growth of *A. ampliceps* raised from direct seeding was much higher than with similar plants grown after transplanting by seedlings (from plastic bags). Among shrubs, *Atriplex* spp. dog rose and redberry showed a high seed germination and survival rate. Among *Atriplex* spp., highest seed germination (approximately 89%) under field condition was observed for *Atriplex undulata*, which showed a rapid growth rate and accumulation of biomass. Being grown at a high plant density of 10–12 plants m^{-2} (normal density of this shrub is 4 plants m^2) in the first year, this species with its large canopy can occupy the interrow spaces forming a dense mono-compo-

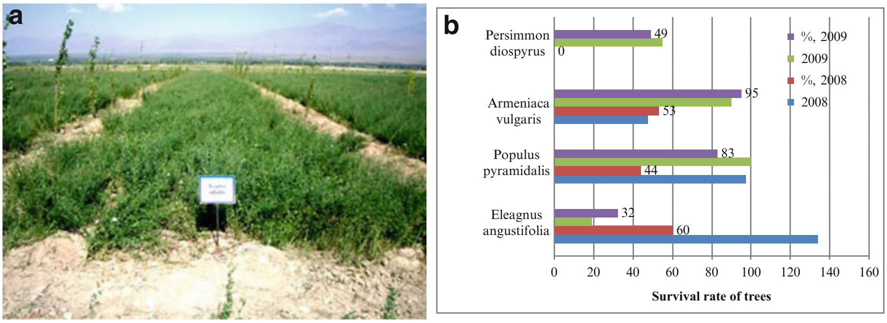

Fig. 38.8 Agroforestry trial at the second year of tree planting. (**a**) Performance of fruit trees planted into an agro-silvi-pastoral system at Yangiobod Farm, northern Tajikistan ((**b**) average for 2008–2009)

nent halophytic pasture. The biomass produced in 1.5 years was 5.6 kg m^{-2} and was readily browsed by cattle and small ruminants. Biomass of *Atriplex undulata* at the Akdepe experimental site increased with high density level of plant per square meter (5.0–5.8 thousand plant ha^{-1}). Replacement of 30% of individuals has been done in August 2006 in order to maintain the stand and decrease plant density.

Low seed germination of about 55% was observed in *Atriplex nummularia* and *A. amnicola* (only four shrubs of the latter plant survived). Comparative studies on seasonal plant performance and accumulation of green biomass in *Acacia ampliceps*, *A. nummularia*, *A. amnicola*, and *A. undulata* were observed after transplantation into the open field.

The findings from the screening of six multipurpose tree species (MTS) at Yangiobod Farm, northern Tajikistan, showed high survival and quick relative growth rates. As shown in Fig. 38.8, the most promising are *Populus euphratica*, *P. pruinosus*, *P. nigra var. pyramidalis*, *Elaeagnus angustifolia*, *Armeniaca vulgaris*, and *Diospyros virginiana L.* cultivated in mixed stands with various traditional salt-tolerant fodder crops.

Trees/shrubs plantation requires limited irrigation during the initial stage of growth before sole reliance on available drainage water (EC ≈ 4.0–6.3 dS m^{-1}) resources becomes possible. Species of *Elaeagnus angustifolia* having an exceptional ion-salt translocation/bioremediation mechanism might be referred to as aggressive colonizers since they tend to invade natural habitats and push out less salt-tolerant species; however, further monitoring is necessary. Trees planted at the Yangiobod trial, especially Elaeagnus, offer possibilities as supplementary feed to the low-quality roughages throughout the off-season. Seasonal differences in soil water uptake for various combinations of tree cover, alfalfa, and annual forage crops communities like barley, sorghum, corn, and pearl millet should be developed and documented. The optimal integrated agroforestry farming system comprising 12% tree cover, 30% alfalfa, and 58% annual forage crops of virgin pastures with traditional agriculture practice provides satisfactory drainage control of saline environments preventing salt accumulation at the root zone area.

38.4 Conclusions and Recommendations

The results of this study showed that spatial and temporal changes of natural rangelands vegetation in the arid area affected by salinity in order to initiate different revegetation strategies. Information about soil ion content, electrical conductivity, performance of indicator species, and biomass clearly indicates which plant species are most likely to contribute to the reclamation process of saline soils. Plant species diversity and distribution is determined by local soil specificity, i.e., its physical and chemical composition, microrelief, and soil moisture. The climate itself as has been noted by Shuyskaya et al. (2008) plays a secondary role. We also found that halophytes as underutilized plant resources grow well in association with a variety of arid/semiarid rangeland species and often provide severe competition to perennial species, both in natural and improved pastures. Incorporation of fodder halophytes into the agro-silvi-pastoral system or domestication of wild halophytes species represents low-cost strategies for rehabilitation of desert degraded rangelands and abandoned farmer lands affected both by soil and water salinity. Late summer and early autumn time should be considered as the optimal period for transplanting of all the above-mentioned nonconventional halophyte species. Introduction of strip-alley livestock-farming system increased the productivity of rangelands by 2.0–2.5 times and decreased further degradation of rangelands. The proposed system of creation of agro-phytocenosis by mixture of natural halophytes (list of plants was developed by the present studies) with salt-tolerant crops, fodder legumes, and grass allows getting forage for animal almost all around the year. Salt-tolerant crops cultivated into an agro-silvi-pastoral model benefit from the improvement of soils and microclimatic conditions provided by the shrubs. A considerable reduction in wind speed and potential evapotranspiration, buffered temperatures, and decrease in the intensity of sand storms were observed. First screening of wild halophytes for their gradual domestication should be done based on the following criteria: ash composition of forages, nutritional values, and needs of farmers.

Integrated Biosaline Agriculture Program for sustainable use of marginal mineralized water and salt-affected soils for food-feed crops and forage legumes developed will assist to improve food security, alleviate poverty, and enhance ecosystem health in smallholder crop-livestock systems. Such diversification of agroecosystems and development of new agricultural capacities could increase income source of rural poor and farmers, which so far are often dependent on two major crops (e.g., cotton and wheat). Furthermore, the activities proposed here will also contribute to large-scale biomass production, which will build up the soil organic matter. It will thus also contribute to make the poor farmers more resilient against climate change. The evaluation, domestication, and large-scale utilization of native and introduced halophytes and salt-tolerant plant resources in sole or mixed farming system would have a significant impact on salinity control and remediation as well as on the economic development of arid/saline lands commonly observed in the whole Aral Sea Basin. Although, the cultivation of trees requires a waiting period, the use of multipurpose species, as investigated in this study, promises the farmers a return from those areas of their land where crops are no longer profitable. The expansion and commercialization of non-timber forest products have the potential to increase the cash income of rural Uzbek households. An aspect that remains unstudied is the degree to which this type of afforestation effort can contribute, on a larger spatial scale, to carbon sequestration; however, methane emissions from unfertilized poplar plantations as well as natural Tugai vegetation are below the detection limit. If carbon trading benefits can be added to the benefits from non-timber forest products, this would create a "win-win" situation from both an ecological and economic point of view (Gintzburger et al. 2005).

Planting herbaceous fodder crops between fruit and fodder trees on intensive agroforestry plantations leads to increase the productivity of degraded lands. Better plant growth, accumulation of green biomass, and consequently yield of both fresh and dry matter were significant for alfalfa both in pure stand and mixed artificial agrophytocoenosis, including trees. The agroforestry concept evaluated in this study provides a means of on-farm drain water management, thus alleviating the need for expensive and potentially hazardous evaporation ponds. Moreover, it could create conditions for maintaining the investigated target remote desert and semidesert areas as viable farming regions. Immediate actions to direct research toward reclamation of saline-prone and desert lands, generation of useful non-timber products, and achieving co-benefits of C sequestration by conserving natural resources and reducing poverty through improving household food and nutrition security should be further investigated.

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References

Akhani H, Trimborn P, Ziegler H (1997) Photosynthetic pathways in Chenopodiaceae from Africa, Asia, and Europe with their ecological, phytogeographical and taxonomical importance. Plant Syst Evol 206:187–221

Akramkhanov AR, Sommer R, Martius C, Hendrickx JM, Vlek PL (2008) Comparison and sensitivity of measurement techniques for spatial distribution of soil salinity. Irrig Drain Syst 22:115–126

Ehleringer JR, Cooper TA (1988) Correlations between carbon isotope ratio and microhabitat in desert plants. Oecologia 76:562–566

Farquhar GD, Ball MC, von Caemmerer S, Roksandic Z (1982) Effect of salinity and humidity on $\delta^{13}C$ value of halophytes – evidence for diffusional isotope fractionation determined by the ratio of intercellular/atmospheric partial pressure of CO_2 under different environmental conditions. Oecologia 52:121–124

Farquhar GD, Hubick KT, Condon AG, Richiards RA (1989) Carbon isotope discrimination and water-use efficiency. In: Rundel PW, Ehleringer JR, Nagy KA (eds) Stable isotopes in ecological research. Springer, New York, pp 21–46

Feldman S, Bisaro V, Biani NB, Prado DE (2008) Soil salinity determines the relative abundance of C_3/C_4 species in Argentinian grasslands. Global Ecol Biogeogr 17:708–714

Flowers TJ, Lauchli A (1983) Sodium versus potassium substitution and compartmentation. In: Lauchli A, Bieleski RL (eds) Inorganic plant nutrition. Springer, Berlin, pp 651–681

Gintzburger G, Le Hourou HN, Toderich K (2005) The steppes of Middle Asia: post 1991 agricultural and rangeland adjustment. J Arid Land Res Manage 19:19–43

Gupta RJ, Kienzler K, Martius C, Qadir M (2009) Research prospectus: a vision for sustainable land management research in Central Asia. Regional Office of ICARDA for Central Asia and the Caucasus (CGIAR-PFU-CAC), Tashkent, Uzbekistan, p 81. ISSN 025-8318 www.icarda.org/cac

Guy RD, Reid DM, Krouse HR (1980) Shifts in carbon isotope ratios of two C3 halophytes under natural and artificial conditions. Oecologia 44:241–247

Hendrikx JMH, Baerends B, Raza ZI, Sadiq M, Chaudhry MA (1992) Soil salinity assessment by electromagnetic induction of irrigated land. Soil Sci Soc Am J 56:1933–1941

Heuperman AF, Kapoor AS, Denecke HW (2002) Biodrainage – principles, experiences and applications. Knowledge synthesis report no. 6, International Programme for Technology and Research in Irrigation and Drainage (IPTRID). FAO, Rome, p 79

Khamzina A, Lamers JPA, Martius C, Worbes M, Vlek PLG (2006) Potential of nine multipurpose tree species to reduce saline groundwater tables in the lower Amu Darya River region of Uzbekistan. Agroforest Syst 68:151–165

Khamzina A, Lamers JPA, Vlek PLG (2008) Tree establishment under deficit irrigation on degraded agricultural land in the lower Amu Darya River region, Aral Sea basin. Forest Ecol Manage 255:168–178

Lamers JPA, Khamzina A, Worbes M (2005) The analyses of physiological and morphological attributes of 10 tree species for early determination of their suitability to afforest degraded landscapes in the Aral Sea Basin of Uzbekistan. Forest Ecol Manage 221:249–259

Marcar NE, Craw-Ford DF (2004) Trees for saline landscapes. Rural Industries Research and Development Corporation (RIRDC), Canberra, p 245

Pyankov VI, Ziegler H, Kuz'min A, Edwards GE (2001) Origin and evolution of C_4 photosynthesis in the tribe Salsoleae (Chenopodiaceae) based on anatomical and biochemical types in leaves and cotyledons. Plant Syst Evol 230:43–74

Pyankov VI, Black CC, Stichler W, Ziegler H (2002) Photosynthesis in *Salsol*a species (Chenopodiaceae) from southern Africa relative to their C_4 syndrome origin and their African-Asian arid zone migration pathways. Plant Biol 4:62–69

Rhoades JD, Chanduvi F, Lesch S (1999) Soil salinity assessment: methods and interpretation of electrical conductivity measurements. FAO irrigation and drainage paper. Food and Agriculture Organization of the United Nations, Rome, p 57

Seemann JR, Critchley C (1985) Effect of salt stress on growth, ion content, stomatal behaviour and photosynthetic capacity of a salt-sensitive species, *Phaseolus vulgaris* L. Planta 164:151–162

Sheets KR, Hendrickx JMH (1995) Noninvasive soil water content measurement using electromagnetic induction. Water Resour Res 31:2401–2409

Shuyskaya EV, Matsuo N, Toderich KN, Sunada K, Gismatullina L, Radjabov T, Ivanova LA, Ronjina DA, Ivanov LA, Voronin PYu, Black CC (2008) Carbon ^{13}C isotope discrimination with C3 and C4 photosynthesis under soil salinity stress. In: Abstracts international conference on physical-chemical basis of structure-functional of plant organization, Yekaterinburg. Russia, 6–10 Oct, pp 28–29

Shuyskaya E, Rajabov T, Matsuo N, Toderich K, Gismatullina L, Voronin P, Yamanaka N (2012) Seasonal dynamics of Asiatic desert C3/C4 species related to landscape planning and rehabilitation of salt-affected lands. J. Arid Land Stud 22–1:77–82

Toderich KN, Clanton C, Black EJ, Osamu K, Tolib M (2007) C3/C4 plants in the vegetation of Central Asia, geographical distribution and environmental adaptation in relation to climate. In: Lal R, Suleimenov M, Stewart B, Hansen D, Doraiswamy P (eds) Climate changes and terrestrial sequestration in Central Asia. Taylor & Francis/Balkema Publishers, Amsterdam, pp 33–65

Toderich KN, Ismail S, Juylova EA, Rabbimov AR, Bekchanov BB, Shyuskaya EV, Gismatullina LG, Kozan O, Radjabov T (2008) New approaches for biosaline agriculture development, management and conservation of sandy desert ecosystems. In: Chedly A, Munir O, Muhamad A, Claude G (eds) Biosaline agriculture and salinity tolerance in plant. Birkhauser Verlag, Basel, pp 247–264

Toderich KN, Shuyskaya EV, Ismail S, Gismatullina L, Radjabov T, Bekhchanov BB, Aralova D (2009) Phytogenic resources of halophytes of Central Asia and their role for rehabilitation of sandy desert degraded rangelands. J Land Deg Dev 20(4):386–396

Toft C, Elliott-Fisk D (2002) Patterns of vegetation along spatiotemporal strands of a desert basin lake. Plant Ecol 158:21–39

Yeo A (1998) Molecular biology of salt tolerance in the context of whole-plant physiology. J Exp Bot 49:915–929

USDA (1954) Diagnosis and improvement of saline and alkali soils. Handbook 60 US Salinity Laboratory Staff. US Government Printing Office, Washington, DC

Chapter 39
Atriplex Production Under Saline Soil and Saline Irrigation Practices

Hesham Attar

Abstract This chapter addresses various aspects of *Atriplex* cultivation (*Atriplex halimus* and *Atriplex nummularia*) from Egypt and Morocco. The species were analyzed for germination and growth under irrigation with different water salinity levels (5, 10, and 20 dS m^{-1}) and freshwater as control. Germination experiments were conducted on filter paper and sterilized soils. Growth and development parameters were measured on plants growing in sandy soil. One set of 64 containers was flushed with saline water to start the experiment. The germination experiment was continued for 2 months. Germination percentage, plant height, number of shoots and lateral shoots, fresh and dry weight, leaf area, xylem water potential, and Na and Cl ion content in plants were recorded in germination tests. Soil salinity (EC) at various depths and Na and Cl ions in soil were determined. It has been found that the germinability of both species (fresh seeds) is correlated linearly to water EC; both species gave different quantitative responses to various treatments, and the best response was with non-freshwater treatment, indicating that plants showed a good potential of taking up salt from saline soil in the soil column. A strict correlation was contributing to the desalinization of the saline soil irrigated with freshwater that promptly leached the salinized soil, while irrigation with diluted seawater caused a progressive enrichment of salts in soil and subsequently in the leaves and xylem water potential. It is concluded that *Atriplex* can be profitably grown in saline environment where conventional plants cannot grow. However, more research is needed to explore many ecophysiological aspects as well as to assess the long-term sustainability of saline water irrigation.

Keywords Atriplex • Fodder production • Halophytes • Saline irrigation • Salt balance

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39.1 Introduction

The main problem of many countries in the world is the scarcity of freshwater resources for agricultural use due to the increasing demand for domestic use and industrial sectors (Choukr-Allah 1996). At least 1,500–1,800 m^3 of water per person per year is required to provide an adequate standard of living, while the resources of freshwater become limited especially in the arid and semiarid regions. The major challenges facing water planner and managers derive from the fact that the demand of water resources increases, while its physical availability is either fixed or not improving. The question is how to balance water supply and demand under such stressed conditions (Hamdy 1996). Soil salinity is affecting over 3×10^9 ha of rangeland, 172×10^6 ha of rain-fed cropland, and 27×10^6 ha of irrigated land in arid areas (Dregne 1983). Ten percent of the world's land surface is affected to various levels of salinity and sodicity (Szabolcs 1991). Half of the world's irrigated lands are affected by secondary salinization, alkalinization, and waterlogging (Choukr-Allah 1996). Salinization affects physical, chemical, and biological properties of soils that eventually influence soil fertility for glycophytes.

It is estimated that 20×10^6 ha of land is degraded each year. In Africa, 47 countries were critically short of land for agricultural production in year 2000 (Dudal and Purnell 1986). Similarly in Southwest Asia, 42 countries face critical land shortages. The situation is being made worse not only by further land deterioration but also by the population increase. According to FAO-UNESCO between 1960 and 1985, the population of arid lands increased by 81% compared to the total world population increase of 56%.

Scientists in one school of thought attempt to reclaim salt-affected soils through integrated soil reclamation approach for crop production. The scientists of second school of thought succeeded in growing plants (halophytes) which can tolerate salinity to seawater level, and hence, an opportunity to use as alternative plants to conventional ones when freshwater is not available (Gorham 1996). It has been shown that halophytes and mangroves can be successfully planted in the deserts of the UAE, Saudi Arabia, Israel, USA, and Australia, with saline irrigation up to seawater salinity (Hamdy 1999). Halophytes can be used for many different economic purposes, such as soil protection, reclamation and rehabilitation, grazing plantations, fuel production, landscaping or roadside covering, and dune stabilization (O'Leary and Glenn 1994; Le Houerou 1993, 1996). Other potential uses include detergent production, color development for dried fruit, ornamentals, and as medicinal plants. Halophytes (*Salicornia*) are cropped as vegetables in Belgium, Netherlands, and France, and trials are undertaken to produce oilseed yields.

Several problems exist prior to the use of halophytes as cash crops, such as germination of many halophytic species is lower than the conventional crops (Miyamoto 1989). A 50% reduction in seed germination of many halophytic species occurs at NaCl concentration of 10 g L^{-1} (e.g., *Atriplex lentiforms, Atriplex linearis, Atriplex canescens*). Presoaking of halophyte seeds in a saline solution could enhance the rate of germination (Miyamoto 1989). The study of physiological aspects of halophyte germination needs to be further investigated. In the present study, germination and fodder production of halophytes (*Atriplex species*) under saline conditions is investigated. Halophytes can take salinity from the soil, accumulate in biomass, and exclude from salt glands. Halophytes can desalinize low level of soil salinity. The reclamation of slightly salinized soil is a great opportunity for farmers in semiarid region countries.

39.2 Objectives

The objectives of the present study are:

- To identify the environmental demand of two *Atriplex* species for germination and juvenile growth.
- To determine salt accumulation when irrigated with different water salinity levels and to measure soil salinity changes during the growth period of the *Atriplex.*
- To analyze the uptake of Na and Cl ions by the plants at different salinity levels.
- To elucidate the changes in the *Atriplex* growing parameter in salinized soils as well as the utility of using *Atriplex* species for reducing the salt load in soils and particularly in the root zone.

39.3 Materials and Methods

The experiment was conducted in the greenhouse in the south coast of Italy (Bari), during the academic year 1999–2000. The experiment was divided into two parts: (1) the germination experiment and (2) the greenhouse experiment. Both experiments were carried out under the same conditions in the greenhouse.

39.3.1 Germination Experiment

39.3.1.1 Experimental Layout

The experiment consists of 108 containers (12 cm wide, 8 cm height). The containers were filled with pure sand. The upper 2–3 cm of the container was kept empty for irrigation purpose. Four varieties of *Atriplex* (two each from Egypt and Morocco) were tested with eight water salinity levels and freshwater used as a control. The water salinities were developed by mixing freshwater (EC 1.14 dS m^{-1}) with seawater (EC 48.9 dS m^{-1}). Each irrigation treatment was triplicated giving a total number of 27 containers. A total of 675 seeds (25 seeds per container) were used in the experiment. Composition of irrigation water used in germination experiment is given in Table 39.1.

Table 39.1 Chemical composition of waters used for germination experiment

Treatment	EC (dS m^{-1})	SAR (mmoles L^{-1})$^{0.5}$	pH	Cations (meq L^{-1})				Anions (meq L^{-1})		
				Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}
Control	1.14	5.2	8.50	7.0	0.2	1.0	2.6	3.8	3.0	0.7
1	3.20	11.6	8.43	22.9	0.4	1.6	6.2	4.7	16.0	1.2
2	6.23	2.1	8.39	43.0	1.3	3.2	14.2	6.4	50.0	1.7
3	8.87	16.9	8.23	57.0	1.6	3.7	19.0	7.1	68.0	1.9
4	12.98	20.4	8.16	90.7	2.9	4.3	35.3	4.2	110.5	3.0
5	15.10	22.2	8.12	105.5	3.4	4.9	40.0	4.7	130.5	3.2
6	20.00	28.4	8.10	137.8	4.6	5.1	42.0	5.0	176.8	3.7
7	26.10	24.7	8.00	160.5	6.3	6.8	78.0	6.9	230.0	3.9
8	30.40	23.3	8.00	171.6	8.7	8.7	100.0	7.8	273.0	4.2

The nine water salinity levels were developed by diluting seawater with freshwater according to Ayers and Wescott (1989) formula [(EC seawater*X1)+(EC freshwater*X2)] = (maximum EC of mixed water). Where X1 and X2 are the fractions of the water used. The electrical conductivity was expressed in terms of dSm^{-1}.

39.3.1.2 Seed Treatment

The germination experiment was divided into two trials. In the first trial, seeds were soaked in freshwater for 24 h to 1 week, heated in water bath up to 53°C for 6 min, and treated by 1% solution of sodium hypochlorite; none of these treatments were successful for long time, nearly 3 months. Probably, this may be due to long storage time that no germination occurred for some varieties, while germination rate was very low for others. In the second trial, different seeds were used, soaked in freshwater for 4 days, and germinated on filter papers.

39.3.1.3 Germination on Filter Papers

Seeds of both species *(Atriplex halimus and Atriplex nummularia)* from Egypt and Morocco were kept at a constant temperature (25°C) and watered as required. After germination, the percentage of successful seeds was determined.

39.3.1.4 Germination on Sterilized Soils

The seeds were soaked in freshwater for 4 days and placed on sterilized soils to germinate at constant temperature (25°C) and watered. After germination, the percentage of successful seeds was determined.

39.3.2 Greenhouse Experiment

Four varieties of *Atriplex* were used with four replicates of each treatment and four water salinity levels (FW-control, 5, 10, 20 dS m^{-1}) used for irrigation. The experiment was divided into two: (1) on non-salinized sandy soil and (2) on artificially salinized sandy soil. In each type, 64 lysimeters (4 varieties * 4 treatments * 4 replicates) were used.

39.3.2.1 Experimental Site

The experiment was carried out in the plastic-covered greenhouse of the Mediterranean Agronomic Institute of Bari in southern Italy at an altitude of 72 m

Table 39.2 Ionic composition of the different soil salinity concentration levels used for the greenhouse experiment

			Cations meq L^{-}				Anions meq L^{-}		
Treatments	EC (dS m^{-1})	pH	Na^{+}	K^{+}	Ca^{2+}	Mg^{2}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
Control	1.17	7.90	7.0	0.2	3.0	2.4	3.8	8.0	0.3
1	5.90	7.75	38	1.9	4.3	6.0	4.7	44.0	0.8
2	9.73	7.84	63	6.5	9.5	14.2	17.0	82.9	1.8
3	20.00	8.01	140	12.1	14.5	19.0	30.7	177	2.45

at 41°03′ 16″ E latitude. The temperature of the greenhouse was maintained at 20 °C through an automated heating and aeration system.

39.3.2.2 Experimental Setup

The basic setup of the experiment included four ecotypes of *Atriplex halimus and Atriplex nummularia* from Egypt and Morocco. Sandy soil was used in this experiment; the soil was pretreated in two different ways (repeated pre-irrigation with saline water until soil solution reached to approximately the EC 2, 5, 10, and 20 dS m^{-1} (Table 39.2) in one group and no pre-irrigation in the other). Four salinity levels of the soil which had received no pre-salinization (1.5, 5, 10, 20 dS m^{-1}) are used, while the pre-salinized soil was irrigated exclusively with freshwater, with four replicates for each treatment giving a total number of 128 units. The germinated seedlings of the four ecotypes were transplanted in the greenhouse, and two plants were planted in the lysimeters (80 cm height, 42 cm diameter). The bottom of the lysimeter was filled with coarse gravels and protected with plastic screen permitting a free drainage of excess water. Three porous cups were placed at 20, 40, and 60 cm depth of each lysimeter.

Four different seawater concentrations from a minimum salinity value of 1.2 dS m^{-1} were prepared according to the Ayers and Wescott equation reported above. However, some adjustments were made by trial and error in order to obtain the desired final EC. Such four treatments were applied to the non-salinized soil, as mentioned above, whereas the containers with the salinized soil were only irrigated with freshwater.

39.3.2.3 Irrigation Scheduling

Irrigation was scheduled according to crop water requirements and water volume determined for all treatments by using irrigation indicators. One container in each treatment was abundantly irrigated above soil field capacity, and drainage water was collected and recorded; the difference between applied and drainage water gave the indication of the volume required to restore moisture to soil capacity in all the other containers. The prefixed irrigation intervals were 1 week in containers irrigated with saline water and 4 weeks in those which had been pre-salinized and were subsequently irrigated with freshwater. This was aimed to compare plant response to conditions of frequent water supply and water stress.

39.3.2.4 Measurements

Plant measurements were started from the seedling stage and successively proceeded to cover the different growing stages. These measurements were carried out periodically with a time interval of 10 days over some selected parameters, height of plants, number of primary shoots, number of lateral shoots, leaf water potential, leaf area, and aerial dry matter. The leaf water potential was measured by a pressure chamber of the Soilmoisture Equipment Corp. Leaf area was measured by the LICOR-300 meter.

39.3.2.5 Dry Matter Analysis

After harvest, the fresh plant materials were dried in oven for 48 h at 70°C. After oven drying, the material was crushed in a mill. The 0.5-g material was digested with sulfuric and perchloric acids (7:3). The Na ions were measured by flame photometer (JENWAY PFP7) and Cl ions by Chloride Analyzer 926.

39.3.3 Soil Analysis

Soil solutions were collected by sucking through the porous cups placed at 20, 40 and 60 cm depths and connected to a vacuum pump to facilitate the suction of the soil solution in circulation. This operation was completed for each irrigation cycle. These soil solutions were analyzed for Na, Cl, and EC by CRISON8 MICRO CM 2201 type. Chlorides were determined using standard titration procedure with silver nitrate (0.01% N) and potassium chromate as an indicator. The sodium was determined by using flame photometer (JENWAY PFP7). The data were statistically analyzed to test their significance and correlations.

39.4 Results and Discussions

39.4.1 Seed Germination Experiments

The experiments described above highlighted the ability of *Atriplex* species to germinate under conditions of relatively high salinity (up to 20 dS m^{-1}) without any significant difference in germination between *A. halimus and A. nummularia*, the

Table 39.3 Comparison of plant parameters in two soils

Parameters	Non-salinized soil	Salinized soil
Leaf area (mm^2 $plant^{-1}$)	2.5	2.4
Fresh weight (g $plant^{-1}$)	176.0	175.0
Dry weight (g $plant^{-1}$)	65.0	60.0
Plant height (mm)	1,010.0	1,218.0
Number of shoots (total)	1,864.0	1,809.0
Mean Cl content (%)	113.2	148.9
Mean Na content (%)	101.5	106.3

first trials of germination failed; this may be due to being stored for a long time. The germination in the second trials succeeded and gave high germination percentage with the two species and a linear decrease closely correlated water EC moistening the seeds. The overall regressions are highly significant (0.001) as given below:

Atrilpex halimus (Morocco) $y = 77.36 - 2.667x$ (correlation = 0.97; $n = 9$)

Atrilpex halimus (Egypt) $y = 66.79 - 2.443x$ (correlation = 0.98; $n = 9$)

Atrilpex nummularia (Morocco) $y = 69.21 - 2.517x$ (correlation = 0.98; $n = 9$)

Atrilpex nummularia (Egypt) $y = 75.77 - 2.77.3x$ (correlation = 0.98; $n = 9$)

where y is germination percentage and x salinity level
The constant term is the highest for *Atriplex halimus* (Morocco) (77.36), suggesting a higher germination percentage with freshwater with this ecotype; however, the lowest slope value (2.443) is suggesting more tolerance to salinity as has been found in *Atriplex halimus* (Egypt). Conversely, this ecotype had the lowest germination percentage with freshwater and consequently from the statistical elaboration of the data results a constant value of 66.79.

39.4.2 Greenhouse Experiments

The symbols V1 to V4 correspond to V1 *Atriplex halimus* (Morocco), V2 *Atriplex halimus* (Egypt), V3 *Atriplex nummularia* (Egypt), and V4 *Atriplex nummularia* (Morocco). The response of four *Atriplex species* to the various treatments gave interesting indications and somewhat unexpected results. Plant response was investigated in terms of fresh weight, dry weight, height, leaf area, xylem water potential and number of shoots, as well as Na and Cl content in leaves, both in the pre-salinized soil and in the soil irrigated with diluted seawater. In no instance plant response was significantly influenced by the difference between salinized and non-salinized soils. A systematic comparison of parameters is given in Table 39.3.

In terms of fresh weight, the plants irrigated with freshwater yielded in all the cases less than the others, with differences often exceeding 100%, while generally only minor statistically significant differences were detected among the other treatments (Fig. 39.1a, b). *Atriplex nummularia* from Morocco and Egypt yielded more than *Atriplex halimus*; these results concur to demonstrate that *Atriplex* is a true halophyte, rather than a salt-tolerant plant. In terms of dry weight, the freshwater-irrigated plants produced less biomass than those irrigated with saline water; however, the difference among the various treatments was not so dramatic as with fresh weight (Fig. 39.1c, d).

Opposite to fresh weight, *Atriplex halimus* dry weight in all cases is higher than that of *Atriplex nummularia*. The dry matter to fresh matter ratio ranges between 0.42 and 0.49 for the former and 0.27 and 0.33 for the latter. Such variation depends on genetic characteristics and variability of the plants; this not only explains the reverse outcome in fresh and dry matter but can be advantageously exploited in the future according to the planned utilization of the plants (e.g., to use them as a fodder or to generate bioenergy).

The response of leaf area paralleled to that obtained in salinized soils showing in all cases the lowest area when compared to the average values of all those irrigated with non-salinized soils (1,304-cm^2 $plant^{-1}$ vs. 2,217-cm^2 $plant^{-1}$) in *Atriplex halimus* and (1,393-cm^2 $plant^{-1}$ vs. 2,807-cm^2 $plant^{-1}$) in *Atriplex nummularia*. In this case, *Atriplex nummularia* from Morocco showed no poorer performance than the other ecotype (Fig. 39.1e, f).

The xylem water potential was clearly affected by different irrigation water salinity levels in spite of the identical water volume applied; in fact, the values ranged from −16.7 bars in salinized soil to −30.6 bars in those irrigated with 20-dS m^{-1} water in case of non-salinized soil. In case of soil salinized prior to planting, the values ranged between −10.3 bars in the freshwater-treated soil and −23.2 bars in that with an initial salinity of 20 dS m^{-1} (Fig. 39.1g, h). Of course, the different xylem potential readings in freshwater-irrigated plants from salinized and non-salinized soils reflect only the variations in soil water status (plants from the two soils were in fact sampled in two different dates, with a time lag of 3 weeks, at various time distances from water application), whereas in the other treatments, the values are strongly influenced by osmotic potential differences.

The experiments with the two different soil treatments gave some preliminary indication on water and salt balance in the soil. Since the main focus of the research was to assess *Atriplex* response to water deficiency (in the pre-salinized soil, with a four-irrigation interval) and saline stress (in saline treatments), no provision was made for applying a leaching fraction.

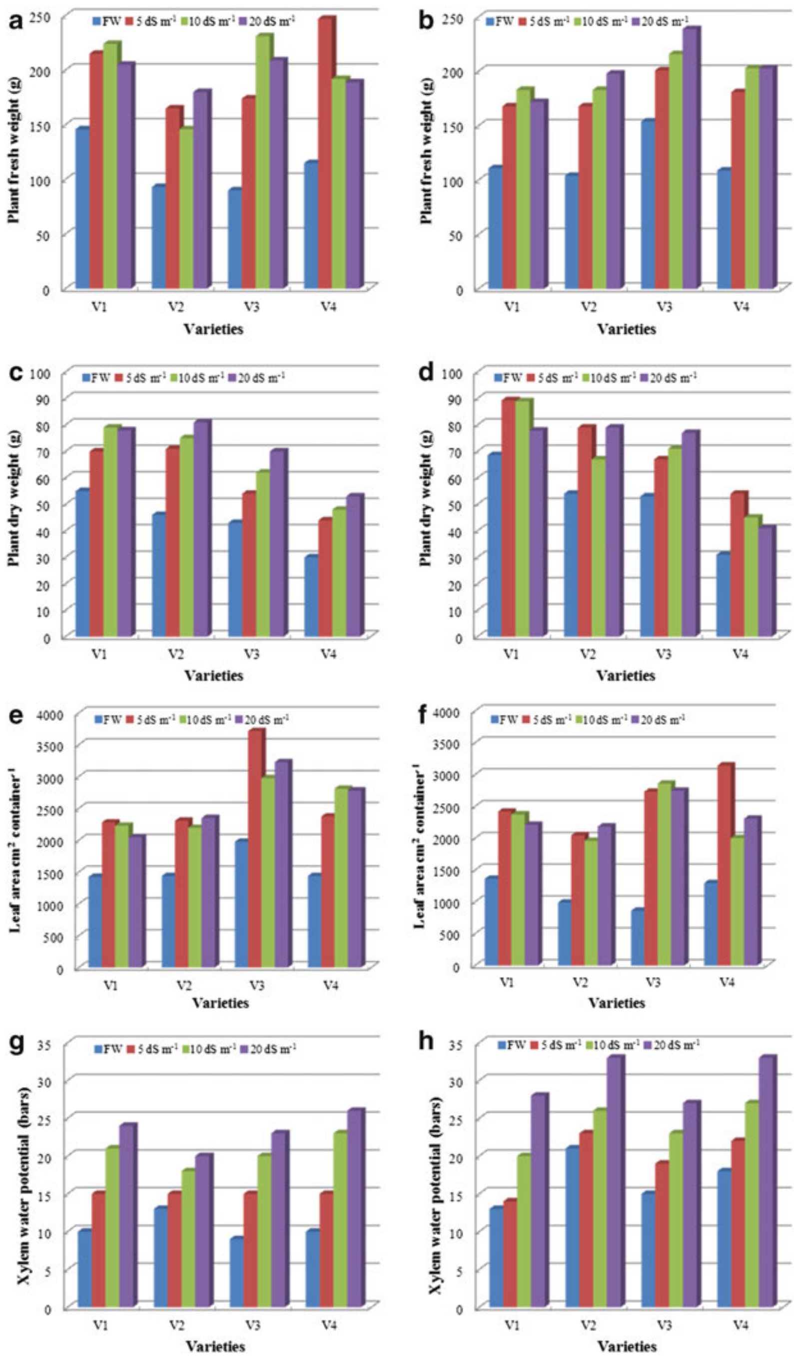

Fig. 39.1 Plant fresh weight: (**a**) salinized soil, (**b**) non-salinized soil. Average plant dry weight: (**c**) salinized soil, (**d**) non-salinized soil. Average leaf area: (**e**) salinized soil, (**f**) non-salinized soil. Average xylum water potential in bars: (**g**) salinized soil, (**h**) non-salinized soil

39.5 Conclusions

The experiments conducted with *Atriplex halimus* and *Atriplex nummularia* implied a variety of parallel investigations in different directions. Seed germination experiments demonstrated the necessity of using fresh seeds for maximum germination; even with some level of water salinity, it is possible to obtain a certain degree of germination, albeit reduced in comparison to freshwater. The study demonstrated the ability of both species to thrive under medium-salinity conditions. The research pointed out the true-halophytic behavior of *Atriplex*, since the best responses were obtained in saline treatments. The ability of the two *Atriplex* species to tolerate combined salt and water deficiency stress was also demonstrated. The research on soil-water-plant-salinity relationships highlighted salt distribution and its quantitative changes along the soil profile as influenced by salt content in soil and water and uptake of salt by plants. The reduction of salinity in the soil water was confirmed although it was not possible to fully quantify it in this phase of the study because the root system of the plants remained in the soil for further continuation of the experiments. *Atriplex* has a considerable potential as a crop to be introduced/extended in many environments where saline and/or water deficiency stress does not permit growing conventional crops. More research by seed producers is required to select those ecotypes best matching the local needs and constraints, since remarkable differences in responses to saline irrigation were found not only among different species but within the same species as well. The salinity expressed as EC obtained by diluting seawater can bring about a better plant response than those obtained with the use of water having the same EC from a different origin. It is well known that nutrient in seawater has a beneficial effect. For this reason, the results reported here may not match other results obtained under different experimental conditions. The research on soil-water-salinity relationships highlights salt distribution and its evolution along the soil profile as influenced by salt content in soil and water. The balancing of NaCl uptake by Atriplex plants makes them potential species for the desalinization of soil where previous irrigation with lower salinity water has increased the soil water salinity beyond the use of the field for glycophytic crops.

References

Ayers RS, Wescott DW (1989) Water quality for agriculture. FAO Irrig Drain Pap 29:737–746

Choukr-Allah R (1996) The potential of halophytes in the development and rehabilitation of arid and semi-arid zones. Halophytes and biosaline agriculture. Marcel Dekker, New York

Dregne HE (1983) Desertification of arid lands: advances in arid land technology and development, vol 3. Harwood Academic Publishers, London, p 242

Dudal R, Purnell MF (1986) Land resources: salt affected soils. Reclam Reveg Res 5:1–10

Gorham J (1996) Mechanisms of salt-tolerance of halophytes. In: Choukr-Allah R, Hamdy A, Malcolm CV (eds) Halophytes and biosaline agriculture. Marcel Dekker, Inc., New York, pp 31–50

Hamdy A (1996) Saline irrigation: assessment and management techniques. In: Choukr-Allah R, Hamdy A, Malcolm CV (eds) Halophytes and biosaline agriculture. Marcel Dekker, Inc., New York, pp 147–174

Hamdy A (1999) Saline irrigation assessment and management for a sustainable use. In: Non conventional water resources management and practices (UWRM) sub-network special session on non-conventional water resources practices and management and annual meeting UWRM, sub-network partners. Iav Hassan II Rabat, Morocco, 28 Oct 1999

Le Houerou HN (1993) Salt-tolerant plants for the arid regions of the Mediterranean isoclimatic zone. In: Lieth H, Masoom A (eds) Towards the rational use of high salinity tolerant plants, vol 1. Kluwer Academic, Dordrecht, pp 403–422

Le Houerou HN (1996) Forage halophytes in the Mediterranean basin. In: Choukr-Allah R, Hamdy A, Malcolm CV (eds) Halophytes and biosaline agriculture. Marcel Dekker, Inc., New York, pp 115–132

Miyamoto S (1989) Pecan salinity management. In: Texas Agricultural Extension Service (ed) Pecan production handbook. Texas Agricultural Extension Service, Danford, pp 22–26

O'Leary JW, Glenn EP (1994) Global distribution and potential for halophytes. In: Squires VR, Ayoub A (eds) Halophytes as a source for livestock and for rehabilitation of degraded land. Kluwer Academics, Dordrecht

Szabolcs I (1991) Desertification and salinization. In: Choukr Allah R (ed) Plant salinity research. Proceedings of the international conference on agriculture management of salt-affected areas, Agadir Inst Agronomique et veterinarie Hassan II CHA Agadir, Morocco, 26 Apr–3 May 1991, pp 3–18

Chapter 40
Exploring Saline Land Improvement Through Testing *Leptochloa fusca* and *Sporobolus virginicus* in Egypt

Medhat M. Tawfik, A.T. Thalooth, and Nabila M. Zaki

Abstract Land degradation is a major global issue because of its adverse impact on agricultural productivity and sustainability. Population pressure along with the demand for more food, fodder, and fuelwood has generated a chain of interrelated economic, social, and environmental issues associated with the land degradation especially in developing countries in arid and semiarid regions. In this concern, two pot experiments were conducted in the greenhouse of the National Research Centre, Dokki, Giza, to study the mutual influence of soil salinity (five initial soil salinity levels, i.e., 2.84, 5.36, 10.22, 17.45, 20.56, and 24.69 dS m^{-1}) referred as S_0, S_1, S_2, S_3, S_4, and S_5, respectively, on the growth, physiological aspects, and some cation content as well as biomass production of *Leptochloa fusca and Sporobolus virginicus* grasses. Moderate levels of initial soil salinity significantly increased most of the growth characters in both seasons. The S_2 and S_3 treatments for *Sporobolus virginicus* and S_3 and S_4 treatments for *Leptochloa fusca* gave the highest values for all growth characters and biomass production in the first and second seasons, respectively. The improvement of growth characters and biomass production of both species in the second season is due to improving the initial soil salinity. Meanwhile, leaf/stem ratio increased with increasing the initial soil salinity in both seasons. Increasing initial soil salinity significantly increased Na^+, soluble carbohydrates, and proline concentration in the plant tissues. On the other hand K^+, K^+/Na^+ ratio, and Ca^{2+} content insignificantly decreased with the same treatment compared to control. No clear effects were recorded for Mg^{2+}. As for the effect of successive growing of *Leptochloa fusca* and *Sporobolus virginicus* on the soil quality is concerned, all cations, anions (except for HCO_3^-), sodium adsorption ratio, and electrical conductivity decreased by the end of the first season and reached its lowest values by the end of the second season; this is due to the leaching and to the accumulation of salts as halophyte plants are capable of accumulating salts into their leaves' vacuoles and

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excrete it through their salt glands. *Leptochloa fusca* had more pronouncing effects on improving soil quality more than *Sporobolus virginicus*.

Keywords Biological restoration • Growth • *Leptochloa fusca* • Soil salinity • *Sporobolus virginicus*

40.1 Introduction

The total area of Egypt amounts to one million square kilometers or the equivalent of 238 million feddans, of which the agricultural land area in Egypt is estimated to be about 8.2 million feddans (3.45% of the state total area), with 5.7 million feddans of old irrigated lands in Delta and the Valley, 2.2 million feddans reclaimed and irrigated lands, and about 0.3 million feddans of rain-fed cultivations in both western and eastern coasts. About 30% of these lands suffer from salinity and sodicity due to climatic conditions (high temperature and low rainfall). Salt-affected soils impact vegetation through adverse physiological effects, and high levels of sodium degrade the physical structure of soil. Soil salinity results in the direct inhibition of plant growth or function due to osmotic stress, ion toxicity, or decreased absorption of essential nutrients (Hameed et al. 2008). High sodium levels often inhibit plant growth by giving rise to poor physical soil characteristics including low aggregate stability, impervious subsoil layers, low infiltration rates, low hydraulic conductivities, and soil surface crusting which may impede or prevent seedling emergence (Qadir et al. 2005).

Restoring the productivity of saline lands, improving the ameliorative conditions, combating desertification, and soil fertility improvement are some of the most important issues. The methods of biological restoration of saline lands with the use of halophytes have been proved to successfully solve these problems. Halophytes are geologically, physiologically, and biochemically specialized plants which are able to function and produce in the conditions of saline soils (Ravindran et al. 2007). Domestication of halophytes will make a promising solution for increasing fodder supply and utilization of the abandoned salt-affected soils and offers a low-cost approach to reclaiming and rehabilitating saline habitats. This approach would lead to the domestication of wild, salt-tolerant plants for use as forage crops (González et al. 2005). Whereas, *Leptochloa fusca* and *Sporobolus virginicus* are highly salt-tolerant C4 perennial halophytic forage plants grown well in coastal salt marshes. These grasses have a special place in newly emerging farming systems, especially in coastal areas and where freshwater resources are unavailable or scarce. They represent a good alternative as a grazing or forage crop and for their ability to reclaim saline soils in arid regions. However, few forage halophytes have been domesticated, and hence, special management practices for their cultivation, adaptation, and new agronomic traits must be developed and tested (Akhter et al. 2004). The key to survival under saline conditions lies in the ability and capacity of a plant to minimize the effect of sodium and other harmful salts present. This can be achieved theoretically by restricting salt buildup in plant tissue (exclusion) or allowing it to a certain limit (inclusion) in plants, depending on their genetic makeup (Masters et al. 2007).

40.2 Materials and Methods

Two pot experiments were conducted in the greenhouse of the National Research Centre, Dokki, Giza, during the two successive summer seasons of 2006 and 2007 to study the mutual influence of (five initial soil salinity levels referred as S_1, S_2, S_3, S_4, and S_5 in addition to the control) the growth, physiological aspects, some cation content, and biomass production of *Leptochloa fusca* and *Sporobolus virginicus* plants. Soils in the pots were previously artificially salinized in a previous experiment, except the control treatment, until they reached 2.84, 5.36, 10.22, 17.45, 20.56, and 24.69 dS m^{-1}. Pots were arranged in complete randomized design (CRD), and treatments were quadruplicated. Rhizomes of *Leptochloa fusca* and *Sporobolus virginicus* were transplanted on 9–10 May in the first and second seasons, respectively, in plastic pots 40 cm in diameter. The soil was sandy loam (Soil Survey Division Staff 1993) composing of 73% sand, 16% silt, and 11% clay. The chemical analysis of the soil was carried out at the beginning of each season and at the end of the second season by using the standard method described by Klute (1986).

After each cutting, each pot was fertilized with 6.2 g calcium superphosphate (15.5% P_2O_5) and 1.5 g potassium sulfate (48.0% K_2O) and 6.75 g of urea (46.5% N) at the rate of 76 kg P_2O_5 ha^{-1}, 57 kg K_2O ha^{-1}, and 250 kg N ha^{-1}, respectively. Three cuttings were taken at 42-day intervals. Four replicates were used for each soil salinity level to determine biomass production as total productivity of the three cuttings(g) and crop growth rate, $CGR = [(W_2 - W_1) / (T_2 - T_1) \text{ g week}^{-1}]$, where W_1 and W_2 are dry weights of the whole plant at time T_1 and T_2 in week, respectively. Plant height, tiller number, and stem/root ratio were determined in the second cutting. The following physiochemical measurements were determined in the fresh harvested shoot of the second cutting: the proline (μg g^{-1}) was measured according to Bates et al. (1979). The harvested shoots were dried to constant weight at 70°C to determine values of succulence (ratio of fresh weight/dry weight) according to the equation describe by Tiku (1979). Salt tolerance index was calculated as total plant dry weight obtained from different soil salinity levels compared to total plant dry weight obtained from plants irrigated with tap water, $STI = [(TDW \text{ at } Sx / TDW \text{ at } S_1) \times 100]$, where STI = salt tolerance index, TDW = total dry weight, S_1 = control treatment, and $Sx = x$ treatments (Seydi et al. 2003). Soluble carbohydrate content was determined by the method described by Dubois et al. (1956). The contents of sodium and potassium were determined in the digested material using JENWAY flame photometer as described by Williams and Twine (1960), while calcium and magnesium were determined by versenate method according to Jackson (1967). The K/Na and Ca/Na ratios were calculated for each treatment. Soil samples were collected from upper 30 cm of each pot. The samples were analyzed for salinity at the beginning and end of each experiment. The results were subjected to statistical analysis of variance in complete randomized design according to the method described by Snedecor and Cochran (1980).

40.3 Results and Discussion

40.3.1 Effect of Soil Salinity on Some Growth Characters and Biomass Production of Leptochloa fusca and Sporobolus virginicus

Table 40.1 illustrates the effect of soil salinities on some growth characters and biomass production of *Leptochloa fusca* and *Sporobolus virginicus*. Increasing the soil salinity level from S_0 to S_3 for *Leptochloa fusca* and from S_0 to S_2 for *Sporobolus virginicus* in the first season significantly increased plant height, tiller number/plant, CGR, and succulence as well as biomass production compared with the control plants. Further increase in the initial soil salinity adversely affected all the previous characters. Table 40.1 also shows that S_4 treatment for *Leptochloa fusca* and treatment S_3 for *Sporobolus virginicus* gave the highest values for all the previous characters in the second season. The results indicate also that there was improvement in the growth characters of plants in the second season due to improvement in the initial soil salinity by reducing pH, EC, SAR, and ESP. In this regard, Khan et al. (2006) stated that salt-tolerant plants may be able to extract salts from the soil, transport to the shoot, move salt ions out of the cytoplasm and add into vacuoles, and excrete excess salt from salt glands. While Zedler et al. (2003) hypothesized that beneficial effects of plants in reclamation are not well understood but appear to be related to the physical action of the plant roots. These results are in agreement with those obtained by Youssef (2009). Masters et al. (2007) stated that the deleterious effects of salinity on yield are thought to result from low water potentials, ion toxicities, nutrient deficiencies, or combination of these factors. Furthermore, raising the initial soil salinity significantly increased leaf/stem ratio in both seasons. The increase may be due to the increased salt accumulation in leaves than the stem, and that consequently increased the succulence of the leaves more than the stem. Debez et al. (2004) stated that succulence is one of the mechanisms that halophytes utilize to deal with the high internal ion concentrations; they added that succulence decreased at higher salinities because tissue water per plant basis decreased with the increase in salinity levels. This indicates that high salinity caused a reduction in the total water content and eventually the growth of plants. Khan et al. (2006) reported that water content of 19 grasses declined with the increase in salinity. This decrease in succulence with salinity could be attributed to low ion accumulation in the shoot tissue, as there was little variation in ash content with the increase in salinity. Plants maintain their osmotic balance by reducing the tissue water. Ravindran et al. (2007) reported that low NaCl concentrations stimulate growth of some

Table 40.1 Effect of soil salinity on some growth characters and biomass production of *Leptochloa fusca* and *Sporobolus virginicus*

		Plant height (cm)		Number of tillers/plant		Leaf/stem ratio		Succulence		Crop growth rate (g week^{-1})		Biomass production (g pot^{-1})	
Plant species	Soil salinity	First season	Second season	First season	Second season	First season	Second season	First season	Second season	First season	Second season	First season	Second season
Leptochloa fusca	S0	81.27	80.27	32.50	31.25	1.12	1.04	1.98	1.88	7.52	7.37	75.15	73.69
	S1	84.65	85.36	36.25	39.50	1.23	1.15	2.02	1.99	8.43	9.43	84.26	94.25
	S2	96.02	98.41	40.50	44.25	1.29	1.22	2.13	2.02	9.44	10.13	94.36	101.26
	S3	99.56	102.04	41.03	45.36	1.36	1.30	2.22	2.19	9.74	10.24	97.36	102.36
	S4	92.36	106.37	35.25	47.36	1.41	1.37	2.14	2.28	8.13	10.74	81.26	107.36
	S5	88.52	88.27	32.25	32.25	1.52	1.48	1.99	2.21	6.64	8.84	66.36	72.21
LSD 5%		4.02	4.25	1.61	1.65	0.056	0.052	0.092	0.094	0.27	0.57	2.69	5.65
Sporobolus virginicus	S0	35.26	36.25	19.00	20.50	1.39	1.31	1.88	1.82	3.22	4.14	32.24	41.36
	S1	36.51	38.14	20.50	22.00	1.41	1.38	1.95	1.95	4.00	5.53	39.99	55.26
	S2	40.26	42.26	22.25	23.50	1.62	1.55	2.09	2.02	5.43	6.13	54.26	61.25
	S3	38.57	44.51	22.00	24.00	1.69	1.59	2.01	2.17	4.43	6.86	44.26	68.59
	S4	37.51	38.47	21.50	22.50	1.75	1.65	1.94	2.09	3.52	4.53	35.18	45.25
	S5	36.26	35.01	18.00	17.00	1.81	1.78	1.88	1.99	2.86	3.81	28.59	38.05
LSD 5%		2.36	2.41	1.26	1.38	0.062	0.056	0.099	0.103	0.20	0.24	2.03	2.36

halophytic species. Such stimulatory effect of moderate salinity on growth of some halophytic plants may be attributed to improved shoot osmotic status as a result of increased ion uptake metabolism. On the other hand, the reduction in growth as a result of high soil salinity levels may be attributed mainly to the osmotic inhibition of water absorption, the excessive accumulation of ions such as Na^+ or Cl^- in plant cells, and inadequate uptake of essential nutrients (Munns and Tormaat 1986). However, our findings may account much more to the findings of Sameni and Bassiri (1982) who reported that highly soluble salts in the root zone cause physiological scarcity in plant to absorb water. Thus, the availability of water may then become so critically low; hence, growth parameters are inhibited. Moreover, Shabala et al. (2005) stated that plants showed stunted growth under high salinity levels perhaps to save energy for normal developmental and other metabolic processes. Furthermore, Al-Garni (2006) added that the reduction in growth and yield under high salinity levels could be due to reduction in photosynthesis, disturbance in mineral uptake, protein synthesis, or carbohydrate metabolism. He added that in most halophytic species, growth decreases gradually with the increase of salt rate in the culture medium above, a critical threshold specific to each species. In addition, Ashour et al. (2004) attributed the reduction in growth at higher salinity level to reduced turgor and high energy cost of massive salt secretion and osmoregulation. Similar results were obtained by Tawfik et al. (2008).

40.3.2 Effect of Soil Salinity on Some Cations of *Leptochloa fusca* and *Sporobolus virginicus*

Data presented in Table 40.2 revealed that increasing initial soil salinity significantly increased Na^+ concentration in the plant tissues of *Leptochloa fusca* and *Sporobolus virginicus* in both seasons; this may be due to the accumulation of Na^+ in the leaves for osmotic adjustment. It is also cleared that Na^+ is the major cation of the cationic content of the leaves; this may be due to the higher influx of Na^+ into leaves which reflects the importance of Na^+ for osmotic adjustment. In general, K^+ content insignificantly decreased with increasing initial soil salinity as compared with control treatment. Moreover, K^+ was the lowest cation of the cationic content; this may be due to the selectivity of Na^+ over K^+ as a major cation for osmotic adjustment. Furthermore, Ca^{2+}, K^+/Na^+ ratio, and Ca^{2+}/Na^+ ratio significantly decreased with increasing soil salinity. This may be due to the high accumulation of Na^+ in the leaves faster than the accumulation of K^+ or Ca^{2+}. In this concern, Khan et al. (2009) stated that salinity tolerance is inversely associated with K^+/Na^+ ratio and Ca^{2+} content where the higher K^+/Na^+ ratio and higher Ca^{2+} content is related to the lower salinity tolerance and vice versa. With this regard, the greatest accumulation of sodium by plants at high salt concentration may be attributed to the damage of the protoplasm of plant cells and, as a result of the selective salt absorption, is replaced by passive absorption which causes abnormal accumulation of salts in plant organs

Table 40.2 Effect of soil salinity on some cation content of *Leptochloa fusca* and *Sporobolus virginicus*

		Potassium mg g^{-1} dry weight		Sodium mg g^{-1} dry weight		Calcium mg g^{-1} dry weight		Magnesium mg g^{-1} dry weight		K/Na ratio		Ca/Na ratio	
Plant species	Soil salinity	First season	Second season	First season	Second season	First season	Second season	First season	Second season	First season	Second season	First season	Second season
Leptochloa fusca	S0	12.63	12.85	7.58	7.55	3.12	3.25	4.69	4.65	1.67	1.70	0.41	0.43
	S1	11.02	12.03	8.69	8.36	3.48	3.55	4.65	4.85	1.27	1.44	0.40	0.42
	S2	10.69	11.54	9.57	9.45	3.69	3.87	4.96	4.74	1.12	1.22	0.39	0.41
	S3	10.36	10.99	11.36	10.54	3.94	3.74	4.58	4.69	0.91	1.04	0.35	0.35
	S4	9.56	10.65	13.59	11.69	4.25	3.89	4.98	4.25	0.70	0.91	0.31	0.33
	S5	9.02	9.86	19.36	14.36	4.69	4.02	4.87	4.56	0.47	0.69	0.24	0.28
LSD 5%		0.41	0.52	0.98	0.87	0.15	0.22	0.23	NS	0.18	0.19	0.11	0.12
Sporobolus virginicus	S0	10.36	10.69	8.36	8.12	3.69	3.55	4.89	5.36	1.24	1.32	0.44	0.44
	S1	9.68	10.02	9.36	9.36	3.88	3.67	5.69	4.69	1.03	1.07	0.41	0.39
	S2	9.36	9.36	11.26	10.36	4.02	3.84	5.36	5.02	0.83	0.90	0.36	0.37
	S3	9.12	9.01	14.36	12.54	4.36	3.99	5.49	5.46	0.64	0.72	0.30	0.32
	S4	8.35	8.99	16.90	14.25	4.89	4.05	4.99	5.36	0.49	0.63	0.29	0.28
	S5	8.02	8.56	18.36	16.45	4.95	4.25	5.02	5.16	0.44	0.52	0.27	0.26
LSD 5%		0.36	0.65	0.68	0.65	0.21	0.29	NS	NS	0.14	0.16	0.10	0.13

(Kader and Lindberg 2005). They added that under saline conditions, sodium influx across the plasmalemma to the vacuole might play a major role in permitting turgor maintenance. He et al. (2005) added that the accumulation of sodium ions inside the vacuoles reduces the toxic levels of sodium in cytosol and increases the vacuolar osmotic potential with the concomitant generation of a more negative water potential that favors water uptake by the cell and better tissue water retention under high salinity levels. Similar results were obtained by Tawfik et al. (2008). On the other hand, the depressing effect of salinity on potassium could be attributed to the difficulty of its uptake due to competition with the high concentration of the sodium in the root medium. Lacerda et al. (2005) reported that the greatest salinity tolerance observed in plants under saline conditions was associated with lower Na/K ratio and greater capacity for osmotic adjustment. Recently, Khan et al. (2009) proved that specific ions such as sodium may have toxic effects on plants: reducing growth or causing damage to cells and membranes. They added that the decrease in K was due to the presence of excessive Na in the growth medium because high external Na content is known to have an antagonistic effect on K uptake in plant. Furthermore, sodium uptake causes plasma membrane depolarization, leading to activation of outward-rectifying K channels and a consequent K loss (Shabala et al. 2005). No specific trend was found in Mg^{2+} content with increasing soil salinity. The results agreed with that obtained by Tawfik et al. (2008).

40.3.3 Effect of Soil Salinity on Proline Content of Leptochloa fusca and Sporobolus virginicus

It can be concluded from Fig. 40.1 that increasing initial soil salinity caused an increase of proline content compared with the control treatment in both seasons. However, S_5 recorded the highest proline content in both *Leptochloa fusca* and *Sporobolus virginicus*. The obtained results are in agreement with the findings of Tawfik et al. (2008). The observed accumulation of proline in the plants growing under saline conditions may be attributed to the enhancement of hydrolytic effect of salinity on protein which led to accumulation of the intermediary substances containing nitrogen such as ammonia, amino acids, amides, and urea (Munns et al. 2002). They added that the accumulation of nontoxic substances under saline conditions such as proline, organic acids, and pigments may have protective properties. In this concern, Hanson et al. (1977) suggested that proline accumulation may result from stress damage, in particular to the mitochondrial membranes. Stewart and Hanson (1980) emphasized that proline accumulation may be due to influence of NaCl stress on the activity of certain enzymes (P-S-C reductase), and they added that proline accumulation could be eliminated by hydration. Thus, proline can be used as organic osmolyte solute protectants, as an amphiphilic molecule, the hydrophobic parts of protein which suffer first when water potential is lowered; proline converts them into hydrophilic parts (Kirst 1990). Reid and Wample (1985) reported that the acceleration of free proline accumulation under saline conditions could be

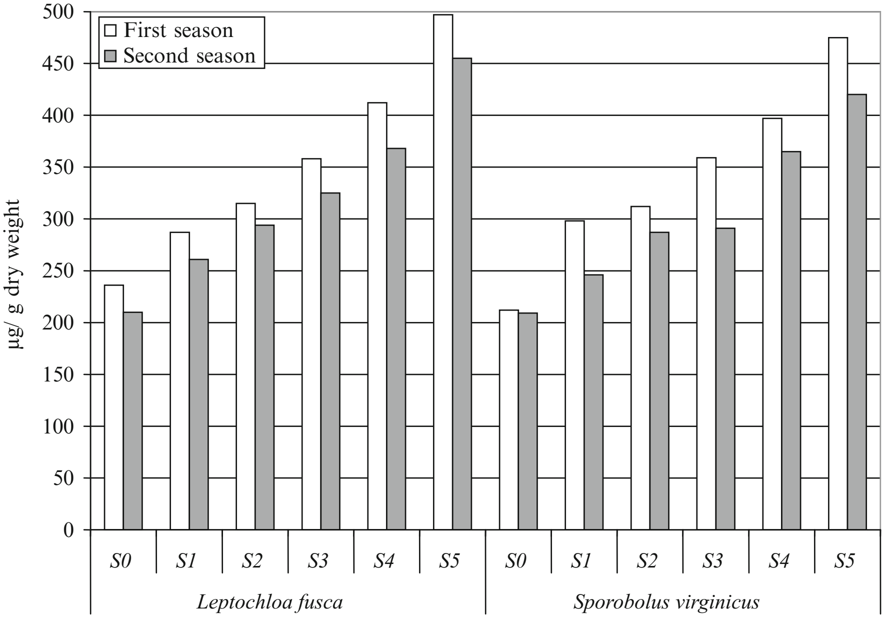

Fig. 40.1 Effect of soil salinity on proline content of *Leptochloa fusca* and *Sporobolus virginicus*

attributed to the inhibition of protein synthesis leading to extensive diversion of nitrogen to proline or to the breakdown of protein and the conversion of some amino acids resulted from the degradation of protein such as glutamic and aspartic acids to proline. Figure 40.1 also shows that *Leptochloa fusca* accumulated more proline content in their tissues. Recently, Youssef (2009) suggested that proline functions as a source of solute for intracellular osmotic adjustments under saline conditions.

40.3.4 Effect of Soil Salinity on Soluble Carbohydrates of Leptochloa fusca and Sporobolus virginicus

Figure 40.2 shows increasing initial soil salinity has a stimulating effect on soluble carbohydrate content in both plant species. Irrespective of plant species, the highest values of soluble carbohydrate contents were attained in plants growing under S_5 treatment for both plant species in two seasons. These results coincide with those obtained by Tawfik et al. (2008). The observed increase in soluble carbohydrates at high levels of soil salinity was considered as a protective mechanism against protein denaturation or dehydration (Turner et al. 1978). Chevan and Karadge (1986) attributed the increase in soluble carbohydrates by increasing salinity to the incomplete utilization of sugars in polysaccharide synthesis. Moreover, Weimberg (1987) stated that the increase of soluble sugars under salinity stress may play a role in osmotic

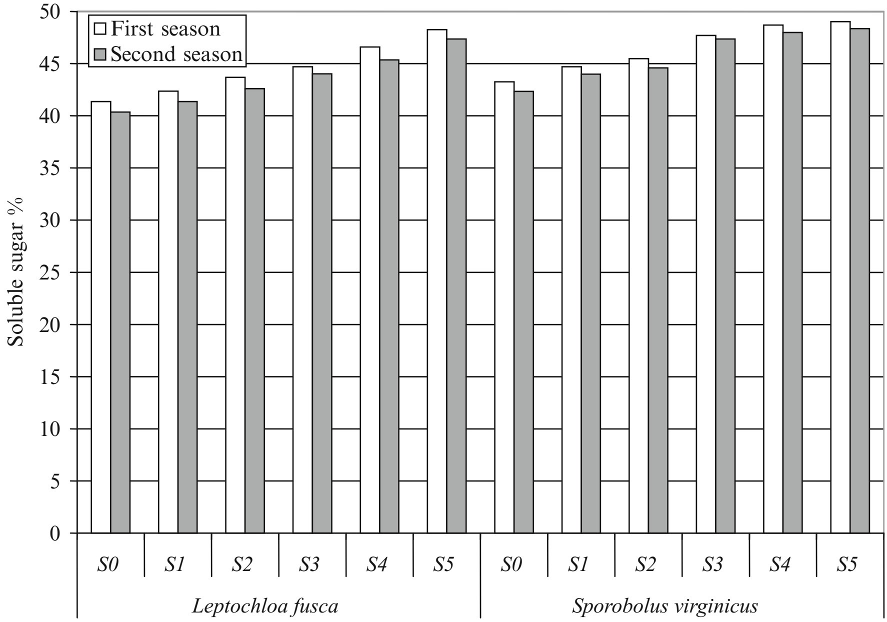

Fig. 40.2 Effect of soil salinity on soluble carbohydrates % of *Leptochloa fusca* and *Sporobolus virginicus*

adjustment. Figure 40.2 shows that *Sporobolus virginicus* accumulated more soluble carbohydrates than *Leptochloa fusca*. Similar results were obtained by Youssef (2009). He added that the response of carbohydrate accumulation varied irregularly in its magnitude in different species as well as various stages of development.

40.3.5 Effect of Soil Salinity on Salt Tolerance Index (STI) of Leptochloa fusca and Sporobolus virginicus

Figure 40.3 shows the effect of initial soil salinity on salt tolerance index (STI) of *Leptochloa fusca* and *Sporobolus virginicus* plants. However, raising the initial soil salinity led to increase in STI value. It is clear from Fig. 40.3 that the highest (STI) value was recorded under S_3 and S_4 for *Leptochloa fusca* and S_2 and S_3 for *Sporobolus virginicus* in the first and second seasons, respectively. On the other hand, the least values of STI were recorded under S_5 for both plant species in both seasons. Figure 40.3 also shows that *Sporobolus virginicus* recorded higher STI value more than *Leptochloa fusca*, especially under S_2 and S_3 treatments. Similar results were obtained by Seydi et al. (2003). Soil analyses from pot experiments where *Leptochloa fusca* and *Sporobolus virginicus* were grown show (Tables 40.3, 40.4, 40.5, 40.6, and 40.7) that all the cations and anions (except for HCO_3^-),

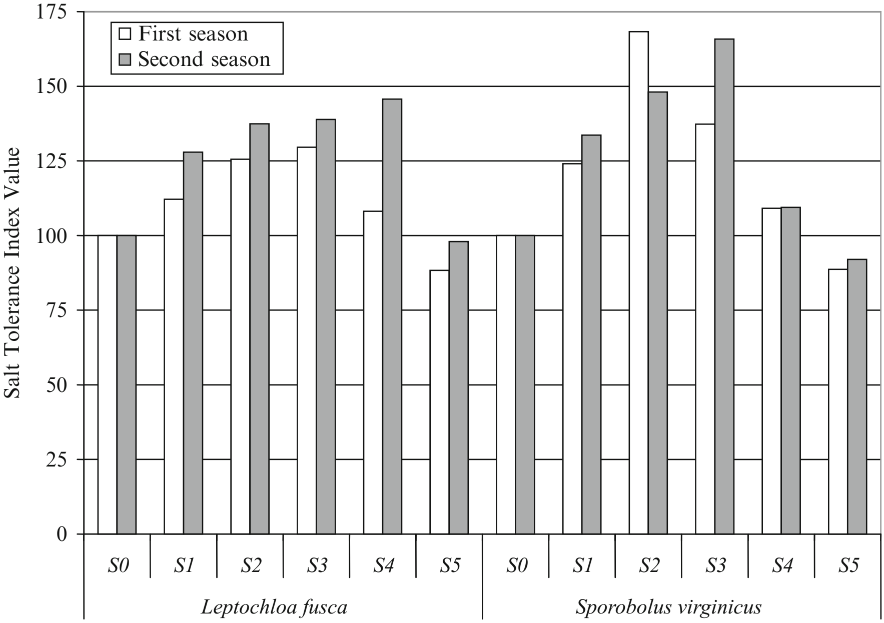

Fig. 40.3 Effect of soil salinity on (STI) of *Leptochloa fusca* and *Sporobolus virginicus*

Table 40.3 Chemical characteristics of the saturated soil paste extract before transplantation

Treatments	pH	EC (dS m^{-1})	Cations (meq L^{-1}) Ca^{2+}	Mg^{2+}	K^+	Na^+	Anions (meq L^{-1}) HCO_3^-	Cl^-	SO_4^{2-}	SAR (mmoles L^{-1})$^{0.5}$
S_0 (control)	8.02	2.84	12.4	5.7	1.8	7.7	3.4	11.3	15.5	2.6
S_1	8.21	5.36	18.4	10.4	1.6	25.4	3.5	35.7	26.6	6.7
S_2	8.15	10.22	22.4	14.3	1.4	47.3	3.6	55.5	34.3	11.0
S_3	8.35	17.45	27.4	19.4	1.2	88.6	3.8	84.4	55.4	18.3
S_4	8.44	20.56	30.2	24.0	0.9	120.6	3.6	120.6	72.1	23.2
S_5	8.48	24.69	33.5	28.7	0.8	145.6	3.8	154.4	84.4	26.1

Table 40.4 Chemical characteristics of saturate soil paste extract at the end of the first season after (*Sporobolus virginicus*)

Treatments	pH	EC (dS m^{-1})	Cations (meq L^{-1}) Ca^{2+}	Mg^{2+}	K^+	Na^+	Anions (meq L^{-1}) HCO_3^-	Cl^-	SO_4^{2-}	SAR (mmoles L^{-1})$^{0.5}$
S_0 (control)	8.10	2.26	11.4	4.2	1.63	6.4	3.60	9.4	13.79	2.3
S_1	8.06	3.85	13.7	7.4	1.47	21.4	3.66	23.2	21.4	6.6
S_2	8.22	6.36	17.4	11.4	1.32	39.4	3.56	45.2	29.4	10.4
S_3	8.18	12.36	21.4	14.4	1.12	75.4	3.86	69.3	43.2	17.8
S_4	8.42	15.36	24.4	19.4	0.87	99.4	3.70	88.4	52.4	21.2
S_5	8.38	18.36	28.4	21.4	0.66	110.3	3.90	102.6	62.2	22.1

Table 40.5 Chemical characteristics of saturate soil paste extract at the end of the second season after (*Sporobolus virginicus*)

Treatments	pH	EC ($dS\ m^{-1}$)	Cations ($meq\ L^{-1}$)				Anions ($meq\ L^{-1}$)			SAR ($(mmoles\ L^{-1})^{0.5}$)
			Ca^{2+}	Mg^{2+}	K^+	Na^+	HCO_3^-	Cl^-	SO_4^{2-}	
S_0 (control)	8.05	2.13	10.4	3.6	1.55	5.4	2.4	8.9	12.0	2.0
S_1	8.09	2.69	11.4	5.6	1.36	14.4	2.6	15.4	14.4	4.9
S_2	8.22	5.69	13.4	7.4	1.25	21.4	2.6	22.4	18.6	6.6
S_3	8.35	9.36	15.1	10.2	1.10	44.2	2.8	45.4	24.4	12.4
S_4	8.43	11.36	17.4	12.4	0.71	75.4	2.9	56.2	29.4	19.5
S_5	8.45	14.36	19.4	14.6	0.56	88.2	3.0	64.4	31.3	21.4

Table 40.6 Chemical characteristics of saturate soil paste extract at the end of the first season after (*Leptochloa fusca*)

Treatments	pH	EC ($dS\ m^{-1}$)	Cations ($meq\ L^{-1}$)				Anions ($meq\ L^{-1}$)			SAR ($(mmoles\ L^{-1})^{0.5}$)
			Ca^{2+}	Mg^{2+}	K^+	Na^+	HCO_3^-	Cl^-	SO_4^{2-}	
S_0 (control)	8.21	2.14	10.4	3.7	1.66	5.7	3.5	8.7	11.36	2.1
S_1	8.32	3.25	11.3	6.6	1.54	15.6	3.4	19.7	16.5	5.2
S_2	8.45	5.69	15.5	9.6	1.45	31.4	3.4	36.2	24.7	8.9
S_3	8.39	11.25	19.2	11.4	1.32	61.3	3.8	51.3	34.3	15.7
S_4	8.69	14.36	21.4	15.4	1.02	77.7	3.7	69.5	43.1	18.1
S_5	8.55	16.35	25.2	17.4	0.78	94.3	3.8	88.2	49.6	20.4

Table 40.7 Chemical characteristics of the saturate soil paste extract at the end of the second season after (*Leptochloa fusca*)

Treatments	pH	EC ($dS\ m^{-1}$)	Cations ($meq\ L^{-1}$)				Anions ($meq\ L^{-1}$)			SAR ($(mmoles\ L^{-1})^{0.5}$)
			Ca^{2+}	Mg^{2+}	K^+	Na^+	HCO_3^-	Cl^-	SO_4^{2-}	
S_0 (control)	8.11	1.95	9.6	3.5	1.54	5.2	3.14	7.7	11.7	2.0
S_1	8.26	2.65	10.6	5.7	1.65	12.7	2.66	13.5	13.5	4.4
S_2	8.24	3.25	12.6	6.8	1.39	18.6	2.87	18.0	17.7	6.0
S_3	8.33	4.88	14.0	9.2	1.22	38.2	2.71	35.6	21.6	11.2
S_4	8.46	7.69	16.2	11.4	0.98	66.2	2.83	45.2	25.7	17.8
S_5	8.51	8.56	17.6	13.5	0.79	74.4	2.94	51.2	27.4	18.9

EC electrical conductivity, *SAR* sodium adsorption ratio

SAR, and electrical conductivity increased with increasing initial soil salinity in each season; however, all the previous characters decreased in the soil analysis by the end of the first season and reached its lowest values by the end of the second season; this may be due to the leaching and to the accumulation of salts by *Leptochloa fusca* and *Sporobolus virginicus* as a halophyte plant is capable of accumulating salts into their leaves' vacuoles to excrete it later through special organs (salt glands). These results are in agreement with those obtained by Zedler et al. (2003). In this concern, Akhter et al. (2004) stated that kallar grass

(*Leptochloa fusca*) accomplished the best removal of salts but had very little beneficial effect on pH and SAR.

Numerous suggestions have been advanced to remediate the effects of salts in the soil by some halophytic plant species by their ability to mitigate salts in soil solution either by plant uptake or by chemical alteration of the soil remediation method as the most environmentally sustainable method in dealing with the saline-sodic condition. In this concern, Ravindran et al. (2007) hypothesized that beneficial effects of plants in reclamation are not well understood but appear to be related to the physical action of the plant roots, the addition of organic matter, the increase in dissolution of $CaCO_3$, and mobilization of calcium that help reclaim soil sodicity and crop uptake of salts. They added that *Suaeda maritima* and *Sesuvium portulacastrum* exhibited greater accumulation of salts in their tissues as well as higher reduction of salts in the soil medium.

40.3.6 Advantages

Low initial capital input, promotion of soil aggregate stability and creation of macrospores, better plant nutrient availability, more uniform and greater zones of reclamation, and finally financial benefits from crops growing through reclamation are the advantages of growing halophytes. Khan et al. (2006) stated that halophytes have other strategies to reduce salt load. Faced with high salt uptake, they are able to excrete excess salts through specialized salt glands, governed by salt concentration of the growth medium, light, temperature, oxygen, pressure, and the presence of metabolic inhibitors. They added that active secreting glands have been listed in many halophytic plant species, which protects young developing shoots and leaves from toxic salt levels, first in the apoplast and then in the symplast.

40.4 Conclusion and Recommendations

The results indicate that establishment of salt-accumulating halophytes can sufficiently remediate the land to the point where native plants can reestablish. As well as the potential benefits for nature conservation and agriculture, an important outcome of remediation and revegetation is a reduction in soil erosion with accordingly reduced salt and silt discharge into water courses. Furthermore, utilization of salt-tolerant plants such as *Leptochloa fusca* and *Sporobolus virginicus* for rehabilitation and reclamation of salt-affected soil could be an appropriate option for alleviating desertification problems and providing alternative good quality and economic unconventional feed materials for animals. However, additional research to identify the agronomic treatment for these plant species is important in developing strategies for their use in agroforestry.

An appropriate selection of plant species capable of producing adequate biomass is vital for cultivating salt-affected soils. Such selection is generally based on the ability of a crop to withstand ambient levels of soil salinity and sodicity to develop varieties of plants for saline wetland restoration that will drive high-productivity ecosystems without continual human input. Disseminate knowledge about using salt-tolerant plant varieties to develop sustainable agriculture in salinized area to solve wetland restoration problems and exchange information on the performance of varieties of salt-tolerant plants under various types of agroecosystems and wetland restoration sites. The experiments are conducted in the greenhouse conditions; it is recommended to test these experiments further under field conditions prior to large-scale application of rehabilitation strategies.

References

Akhter J, Murray R, Mahmood K, Malik KA, Ahmed S (2004) Improvement of degraded physical properties of a saline-sodic soil by reclamation with kallar grass (*Leptochloa fusca*). Plant Soil 258(1/2):207–216

Al-Garni SMS (2006) Increasing NaCl- salt tolerance of a halophytic plant *Phragmites australis* by mycorrhizal symbiosis. Am-Euras J Agric Environ 1(2):119–126

Ashour NI, Batanouny KH, Thalooth AT, Zaid KM, Tawfik MM (2004) Response of *Medicago sativa* and some halophytic forage plants to irrigation with diluted seawater. 1: effect on some physiological aspects. Bull NRC 29(4):361–377

Bates LS, Waldrem RP, Tear LD (1979) Rapid determination of free proline for water stress studies. Plant Soil 39:205–207

Chevan PD, Karadge BA (1986) Growth mineral nutrition, organic constituents and rate of photosynthesis in *Sesbania grandiflora L.* grown under saline conditions. Plant Soil 93(3):395–404

Debez A, Ben HK, Grignon C, Abdelly C (2004) Salinity effects on germination, growth, and seed production of the halophyte *Cakile maritima*. Plant Soil 262:179–189

Dubois M, Gilles KA, Hamilton J, Rebes R, Smith F (1956) Colorimetric method for the determination of sugar and related substances. Anal Chem 28:350

González MB, Fournier JM, Ramos J, Benlloch M (2005) Strategies underlying salt tolerance in halophytes are present in *Cynara cardunculus*. Plant Sci 168(3):653–659

Hameed M, Naz N, Sajid M, Ahmad A, Din I, Riaz A (2008) Morphological adaptation of some grasses from the salt range of Pakistan. Pak J Bot 40(4):1571–1578

Hanson AD, Nelsen CE, Everson EA (1977) Evaluation of free proline accumulation as an index of drought resistance using two contrasting barley cultivars. Crop Sci 17:720–726

He CX, Yan JQ, Shen GX, Fu LH, Holaday AS, Auld D, Blumwald E, Zhang H (2005) Expression of an Arabidopsis vacuolar sodium/proton antiporter gene in cotton improves photosynthetic performance under salt conditions and increases fiber yield in the field. Plant Cell Physiol 46(11):1848–1854

Jackson ML (1967) Soil chemical analysis. Constable and Co. Ltd., London

Kader MA, Lindberg S (2005) Uptake of sodium in protoplasts of salt-sensitive and salt-tolerant cultivars of rice, *Oryza sativa* L. determined by the fluorescent dye SBFI. J Exp Bot 56(422):3149–3158

Khan MA, Ansari R, Gul B, Qadir M (2006) Crop diversification through halophyte production on salt-prone land resources. Perspect Agric Vet Sci Nutr Nat Res 1:48

Khan MA, Shirazi MU, Alikhan MA, Mujtaba SM, Islam E, Mumatz S, Shereen A, Ansarir U, Ashraf SY (2009) Role of proline, K/NA ratio and chlorophyll content in salt tolerance of wheat. Pak J Bot 41(2):633–638

Kirst GO (1990) Salinity tolerance of Eukaryotic marine algae. Rev Plant Physiol 41:21–35
Klute A (1986) Methods of soil analysis. In: Klute A (ed) Part 1: Physical and mineralogical methods. Part 2: Chemical and Microbiological properties, 2nd edn. Soil Science Society of America, Madison
Lacerda CF, Cambraia J, Oliva MA, Ruiz HA (2005) Changes in growth and in solute concentrations in sorghum leaves and roots during salt stress recovery. Environ Exp Bot 54(1):69–76
Masters DG, Benes SE, Norman HC (2007) Biosaline agriculture for forage and livestock production. Agric Ecosys Environ 119(3–4):234–248
Munns R, Tormaat A (1986) Whole plant response to salinity. Aust J Plant Physiol 13:143–160
Munns R, Husain S, Rivelli A, Richard A, James AG, Lindsay M, Lagudah E, Schachtman D, Ray A, Hare R (2002) Avenues for increasing salt tolerance of crops, and the role of physiologically based selection traits. Plant Soil 247:93–105
Qadir M, Noble AD, Oster JD, Schubert S, Ghafoor A (2005) Driving forces for sodium removal during phytoremediation of calcareous sodic and saline–sodic soils: a review. Soil Use Manage 21:173–180
Ravindran KC, Venkatesan K, Balakrishnan V, Chellappan KP, Balasubramanian T (2007) Restoration of saline land by halophytes for Indian soils. Soil Biol Biochem 39(10):2661–2664
Reid DM, Wample RL (1985) Water relation and plant hormones. In: Pison A, Zimmermann MH (eds) Encyclopedia of plant physiology. New series, vol II. Springer, Belrin/Heidelberg/New York/Tokyo
Sameni AN, Bassiri A (1982) Interactive effects of N, salinity duration on the growth and chemical composition of broad beans. Iran Agric Res 1(1):49–60, (cf Faba bean Abst 3(4):36, 1983)
Seydi AB, Hassan EK, Yilmaz ZA (2003) Determination of the salt tolerance of some barley genotypes and the characteristics affecting tolerance. Turk J Agric 27:253–260
Shabala L, Cuin TA, Newman IA, Shabala S (2005) Salinity-induced ion flux patterns from the excised roots of Arabidopsis sos mutants. Planta 222:1041–1050
Snedecor GW, Cochran WG (1982) Statistical methods. 7th edn. Iowa State University, Iowa, p 507.
Soil Survey Division Staff (1993) Soil survey manual, USDA handbook no 18. US Government Printing Office, Washington, DC
Stewart CR, Hanson AD (1980) Proline accumulation as a metabolic response to water stress. In: Tumer NC, Kramer PJ (eds) Adaptation of plants to water and high temperature stress. Wiley, New York, pp 173–189
Tawfik MM, Magda HM, El-Habbasha SF (2008) Optimizing management practices for increasing the efficiency of using seawater as alternating methods of irrigation. Egypt J Appl Agric Res 1(2):253–267
Tiku GL (1979) Ecophysiological aspects of halophyte zonation. Plant Soil 43:355
Turner NC, Begg JE, Tonnett ML (1978) Osmotic adjustment of sorghum and sunflower crops in response to water deficits and its influence on the water potential of which stomata close. Aust J Plant Physiol 5:597–608
Weimberg R (1987) Solute adjustments in leaves of two species of wheat and two different stage of growth in response to salinity. Physiol Plant 70:381–388
Williams CH, Twine JR (1960) Flamephotometric method for sodium, potassium, and calcium. Modern methods of Plant Analysis 5:3–5. Springer-Verlag-Gottingen-Heidelberg
Youssef AM (2009) Salt tolerance mechanisms in some halophytes from Saudi Arabia and Egypt. Res J Agric Biol Sci 5(3):191–206
Zedler JB, Morzaria-Luna H, Ward K (2003) The challenge of restoring vegetation on tidal, hypersaline substrates. Plant Soil 253:259–273

Chapter 41
Improvement of Soil Quality Through Agroforestry System for Central Plain Zone of Uttar Pradesh India

Shamim Ahmad Khan and Rizwan Khan

Abstract A large area of Indian soils is of marginal quality with high pH and alkalinity especially in semiarid conditions. Such soils contain excessive sodium salts and possess impermeable hard pan of calcium carbonate below the soil which affects the survival of crops. Currently, these soils are reclaimed by using chemical amendments and mechanical means which exert higher costs, and this practice is repeated every year prior to sowing of crop. In India, per capita land is decreasing every year due to steep rise in population which requires more food to fulfil their requirements. The land is limiting factor. The only way to increase land is through reclamation of abandoned saline and sodic lands and their use for crop production. Permanent reclamation of alkaline soils (high pH) is possible by the adoption of agroforestry system in which trees and crops are grown together which sustain agricultural production and productivity. Keeping in view the seriousness of the problem, an experiment was conducted to improve soil characteristics through agroforestry system for Central Plain Zone of Uttar Pradesh, India. The project was undertaken during the year 1989–2002, at Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India. The key objective of the experiment was the selection of suitable multipurpose trees which can improve soil quality of high pH (alkaline soils) for crop. The experiment consists of ten multipurpose tree species, namely, *Azadirachta indica, Dalbergia sissoo, Albizia procera, Terminalia arjuna, Eucalyptus hybrid, Leucaena leucocephala, Acacia nilotica, Acacia catechu, Morus alba and Cassia siamea,* and in between two rows

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of trees, agricultural crops were planted. The initial average soil pH, organic carbon and electric conductivity were 10.5, 0.41% and 0.73 dS m^{-1}, respectively. After 12 years experimentation, it was concluded that the planting of multipurpose trees improved the soil organic carbon up to 0.59% and reduced the soil pH up to 8.10 and EC 0.31 dS m^{-1}. The agricultural crops, namely, rice in Kharif (rainy season) and wheat in Rabi (winter season), were found suitable with trees. Among the trees, Eucalyptus hybrid reduces the soil pH and EC drastically as compared to other trees, whereas higher carbon was estimated with *Leucaena leucocephala* followed by *Dalbergia sissoo, Acacia nilotica and Morus alba*.

Keywords Agroforestry • India • Saline soils • Semiarid • Uttar Pradesh

41.1 Introduction

In India, about 175-million-hectare land is subjected to various types of degradation, of which 6.75-million-hectare land is suffering from salinity and alkalinity. In sodic soils, the survival of crops is very difficult due to the accumulation of high exchangeable sodium and pH in the root zone. In such soils, the drainage is restricted due to impermeable hard pan of calcium carbonate at 60–120 cm depth which impeded the leaching of hazardous salts in the soil and creates waterlogged condition during rainy season. It also inhibits infiltration and percolation of harmful salts in the lower horizon of the soil profile. These soils possess high pH, low organic carbon and nutrient availability. Such conditions restrict plant growth subsequently resulting in poor yield. By and large, these soils are to be reclaimed temporarily by chemical and mechanical means which involve heavy machinery, chemical amendments and extra water which is beyond the reach of common farmers. These soils can be reclaimed permanently by plantation of trees along with crops (Khan et al. 1995) such as agroforestry. These trees improve the permeability of soil through root penetration which enhances the leaching of salts to subsurface and also improve the organic matter content of soil through organic litter fall (biomass) on the soil surface. The cost involve in plantation is significantly less as compared to reclamation of salt-affected soils by chemical and mechanical means. The system also provides fuel wood, fodder, timber and food grains and sustains crop production and productivity and maintain friendly ecosystem. It also reclaims degraded land permanently. Keeping in view the manifold advantages of tree crop association, the present study was undertaken.

41.2 Materials and Methods

The field experiment was conducted during the year 1989–2002 at Regional Research Station on high-pH soils at Dilip Nagar, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India. This station is situated in the Central Plain Zone of Uttar Pradesh, India, and lies under subtropical, semiarid

Table 41.1 Plants used and geometry

S. No.	Particulars	Plant geometry (M)[a]
1.	*Azadirachta indica*	4×4
2.	*Dalbergia sissoo*	4×4
3.	*Albizia procera*	4×4
4.	*Terminalia arjuna*	4×4
5.	*Eucalyptus hybrid*	4×2
6.	*Leucaena leucocephala*	4×1
7.	*Acacia nilotica*	4×2
8.	*Acacia catechu*	4×2
9.	*Morus alba*	4×2
10.	*Cassia siamea*	4×2

[a]Row to row and plant to plant distance

climatic zone with an average rainfall of 800 mm, of which about 90% rain is received from July to October and rest 10% as winter showers.

The soil of the experimental field is alluvial in nature and has high pH (10.5), where the irrigation facilities were available. The initial soil pH, electric conductivity (EC) and organic carbon were 10.5 (very strongly alkaline), 0.73 dS m^{-1} and 0.41%, respectively. The soil possesses poor drainage and a hard pan of calcium carbonate at a depth of 60–120 cm. which impeded infiltration and percolation of harmful salts. The soil was low in available phosphorus (6.0 kg ha^{-1}) and medium in potash (85.0 kg ha^{-1}).

41.2.1 Agroforestry Experiment

The experiment is comprised of ten multipurpose tree species, namely, *Azadirachta indica, Dalbergia sissoo, Albizia procera, Terminalia arjuna, Eucalyptus hybrid, Leucaena leucocephala*, *Acacia nilotica, Acacia catechu, Morus alba* and *Cassia siamea* and planted in pits of 60 cm×60 cm×90 cm (0.324 m^3) filled with 3 kg of pyrite-FeS_2 (soil amendment)+5 kg compost (manure)+10 kg sand and the soil of the same field. The pits for planting were prepared prior to onset of rain by tractor-driven soil auger to break the hard pan of calcium carbonate during the month of May, and 1-year-old plant seedlings were used for plantation. These plant species were planted in plot of 12 m×12 m in Randomized Block Design (RBD) and quadruplicated in following plant geometry during the month of July and August 1989 (Table 41.1).

Drainage cum irrigation channels was prepared in between two plots. The agricultural crops like rice in rainy season and wheat in winter season were sown in between two rows of tree species. The plants were irrigated as and when required, and excess water was drained during rainy season. The crops and plants were sown after the establishment of tree seedlings during the year 1990. The soil samples of experimental field were collected once in a year for chemical analysis for which one representative replication was selected. The soil (pH) was analysed by Beckman pH metre, electrical conductivity of soil saturation extract measured by standard electrical conductivity metre (Richards 1954), organic carbon was measured by standard Walkley and Black methods, N by Kjeldahl apparatus, available phosphorus by spectrophotometer and available potash by flame photometer method.

41.3 Results and Discussion

41.3.1 Changes in Soil pH and EC

The soil pH and EC was remarkably influenced by the adoption of agroforestry system on alkaline soils (Table 41.2). It is indicated from the table that prior to tree crop plantation, the soil pH and EC were 10.5 and 0.73 dS m^{-1}, respectively, during the year 1989. After regular experimentation, pH and EC decrease up to 8.15 and 0.305 dS m^{-1}, respectively, in the year 1998 and further decreased to 8.10 (pH) and 0.21 dS m^{-1} (EC) during the year 2002 (Table 41.2). The soil becomes comparable to normal in which agricultural crops have been grown successfully. It may be attributed due to leaching of harmful salt through roots of plants or utilized by tree crop association. These results corroborate with that of Singh et al. (1997).

41.3.2 Soil Amelioration and Nutrient Status of Soil

The tree species play an important role in soil amelioration and improvement of soil nutrients capacity (Table 41.3). By the adoption of agroforestry system, the pH and EC of soil reduced, whereas organic carbon, available phosphorus and potash were improved appreciably. Among the tree species, lowest status of pH and EC was

Table 41.2 Change in soil pH and EC by adoption of agroforestry system

No.	Year	pH	EC_e (dS m^{-1})
1.	1989	10.50	0.730
2.	1990	10.25	0.702
3.	1991	9.95	0.658
4.	1992	9.30	0.592
5.	1993	9.00	0.505
6.	1994	8.50	0.469
7.	1995	8.25	0.320
8.	1996	8.20	0.310
9.	1997	8.15	0.308
10.	1998	8.10	0.305
11.	1999	8.10	0.300
12.	2000	8.10	0.280
13.	2001	8.10	0.210
14.	2002	8.10	0.210

Table 41.3 Nutrient status of soil in relation to plant species during the year 2002

S. No.	Name of plant species	pH	ECe (dS m^{-1})	Organic carbon (%)	Available phosphorus (kg ha^{-1})	Available potash (kg ha^{-1})
1.	*Azadirachta indica*	8.4	0.31	0.75	13.5	240
2.	*Dalbergia sissoo*	8.4	0.31	0.85	15.0	220
3.	*Albizia procera*	8.2	0.32	0.65	12.5	180
4.	*Terminalia arjuna*	8.6	0.40	0.58	11.5	178
5.	*Eucalyptus hybrid*	7.3	0.24	0.55	10.5	150
6.	*Leucaena leucocephala*	7.6	0.28	0.88	19.5	245
7.	*Acacia catechu*	8.3	0.31	0.68	20.5	230
8.	*Acacia nilotica*	8.4	0.30	0.82	14.0	235
9.	*Morus alba*	8.3	0.32	0.78	14.5	212
10.	*Cassia siamea*	8.3	0.32	0.84	24.5	200
	Average	8.2	0.31	0.738	15.6	209

exhibited by the *Eucalyptus hybrid* closely followed by *Leucaena leucocephala*. It is further revealed that the highest soil organic carbon was recorded by the tree species *Leucaena leucocephala* closely followed by *Dalbergia sissoo, Cassia siamea* and *Acacia nilotica.* The increase in nutrient status by these trees is due to higher leaf fall and their belonging to Leguminosae family that has the ability to fix nitrogen and improve nutrient status of soils. The tree species *Cassia siamea* showed the highest value of available phosphorus followed by *Acacia catechu*, *Leucaena leucocephala* and *Dalbergia sissoo* and was the lowest with *Terminalia arjuna*. The highest available potash was estimated in soils where *Leucaena leucocephala* was growing, closely followed by *Azadirachta indica, Acacia nilotica* and *Acacia catechu,* and was the lowest with *Eucalyptus hybrid*.

41.3.3 Plant Growth and Biomass Production

A remarkable difference in plant growth and biomass production was observed due to different plant species. The plant growth is indicated by girth. It is indicated from Table 41.4 that plant girth varied due to different plant type. The *Acacia nilotica* exhibited highest plant girth closely followed by *Dalbergia sissoo* and *Azadirachta indica* and being the lowest with *Morus alba*. The highest girth of these plants may be due to hardy nature of plant which grows well under adverse soil conditions like salinity and alkalinity. In India, a large number of farmers require fuel wood to cook their foods for which dry twigs of plants are required. The study indicated that highest dry twig yield was estimated with tree species *Leucaena Leucocephala* followed by *Albizia Procera*, *Morus alba* and *Acacia nilotica* and poorest was recorded with *Azadirachta indica*. The *Leucaena* is a fast-growing tree which produces high branching in a short time so that it has produced higher twigs. It is also indicated (Table 41.4) that litter fall was also raised due to different plant type. The highest litter fall was observed with *Cassia siamea* closely

Table 41.4 Plant girth (cm) at breast height, litter fall and twig yield of tree species, during the year 2002

S. No.	Name of plant species	Litter falls (tonnes ha^{-1})	Dry twig (kg ha^{-1})	Plant girth (cm)
1.	*Azadirachta indica*	5.2	2,005	63.00
2.	*Dalbergia sissoo*	6.5	3,000	68.50
3.	*Albizia procera*	10.5	6,000	63.50
4.	*Terminalia arjuna*	5.0	2,500	49.00
5.	*Eucalyptus hybrid*	5.2	2,500	51.50
6.	*Leucaena leucocephala*	11.5	7,500	52.00
7.	*Acacia catechu*	10.5	4,000	45.00
8.	*Acacia nilotica*	10.0	4,500	69.90
9.	*Morus alba*	8.3	5,000	25.50
10.	*Cassia siamea*	12.5	4,000	44.50

followed by *Leucaena leucocephala*, *Albizia procera*, *Acacia catechu* and *Acacia nilotica,* whereas the lowest litter fall was noticed with *Terminalia arjuna* and *Eucalyptus hybrid*. The tree species *Cassia siamea*, *Leucaena leucocephala* and *Albizia procera* produced higher branching which possesses more leaves and resulted in higher litter fall per year as compared to other species tested. These results corroborate with those of Khan et al. (1995), Lal and Khan (1998), and Anonymous (1998).

41.4 Conclusions and Recommendations

It is concluded that the planting of multipurpose trees improved the soil organic carbon up to 0.59% and reduced the soil pH and EC up to 8.10 and 0.31 dS m^{-1}, respectively. The agricultural crops, namely, rice in Kharif (rainy season) and wheat in Rabi (winter season) were found suitable with trees to improve soil quality significantly. Among trees, Eucalyptus hybrid reduces the soil pH and EC drastically as compared to other trees, whereas higher carbon was estimated with *Leucaena leucocephala* followed by *Dalbergia sissoo, Acacia nilotica* and *Morus alba.*

References

Anonymous (1998) Annual report. IGFRI, Jhansi

Khan SA, Yadav VK, Shukla IN (1995) Screening of tree species in relation to crop and higher biomass production under Central UP. In: Seminar on agro-forestry for higher crop and biomass production, organized by NRCAF, Jhansi, UP, India 24–25 Mar 1995

Lal B, Khan SA (1998) Technology for salt-affected soil of central UP. In: National symposium on research management and crop productivity. Haryana Agriculture University, Hisar, 16–18 Feb 1994

Richards L (ed) (1954) Diagnosis and improvement of saline and alkali soils. USDA handbook no. 60. US Government Printing Office, Washington, DC
Singh KG, Singh NT, Abrol IP (1997) Agroforestry technique for the rehabilitation of salt effected soil of India. Land Degrad Rehabil 5:223–242

Part VI
Microbiological Interventions for Marginal Soils and Water Resources

Chapter 42
Bacterial Exo-Polysaccharides: A Biological Tool for the Reclamation of Salt-Affected Soils

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Abstract Accumulation of salts on soil surface and in the root zone damages physico-chemical and biological properties of salt-affected soils. Exo-polysaccharides (EPS), the polymers of monosaccharides, are synthesised and released in soil by microorganisms inhabiting rhizosphere, roots of the plants and the decomposing organic residues. The bacterial EPS are involved in formation and stability of soil micro-aggregates, a factor that ensures fertility of the cultivated soils. The rhizosheaths formed around roots by bacterial EPS contribute to build up soil physical structures, regulate nutrients and water flow from rhizosphere soil to the plants, promote growth and protect the roots against pathogens. Thus, the bacterial EPS are directly and indirectly involved in and impacted both physico-chemical soil characteristics and growth of the plants. However, the role of the bacterial EPS in improving soil fertility and interaction with constituents of the salt-affected soils has rarely been explored. Research studies, therefore, were conducted to observe the effect of the bacterial EPS extracted from *Microbacterium* sp. MAS133 isolated from a salt-affected soil on soil moisture release and aggregate stability at three (native, acidic and alkaline) pH values of clay fraction of a saline-sodic soil compared to a normal soil. Results showed that the processes and phenomenon of soil aggregate formation and stability in the colloidal form with interactive effect of

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biopolymers and SMA (suspended micro-aggregates) as well as water retention and release of a saline-sodic soil were all influenced by the bacterial EPS. Although extent and nature of the bacterial EPS-micro-aggregates interactions varied with pH, soil type and EPS concentration, the effect was consistent and persistent for extended time periods. Moreover, 16S rRNA gene sequence analysis showed that MAS133 belonged to *Microbacterium hominis* of the lineage of the Firmicutes and the EPS produced on sucrose medium were fructose biopolymers. Interaction of the bacterial biopolymer with soil constituents and a positive impact of the bacterial inoculation on soil aggregation around roots and mitigation of negative effects of salinity on plant growth observed in earlier studies suggest the EPS-producing bacteria a useful biological tool for reclamation of the salt-affected soils. Additionally, a strategy of provision of carbohydrate substrates to foster growth and production of the EPS by the bacterial populations living in the salt-affected soils through field water distributaries and the 'bioretention' or 'biomonitoring' cells could help overcome the economy and the environmental concerns associated with application and use of the bacterial inoculum in the field.

Keywords Biofilm bacteria • Exo-polysaccharides • Soil aggregates • Soil moisture loss • Soil reclamation

42.1 Introduction

Exo-polysaccharides (EPS) are the microbial biopolymers with homo- and hetero-monosaccharides backbone. These EPS are synthesised and released in the environment by a myriad of microorganisms either for protection from biotic and abiotic stresses like osmotic, ionic, heat, desiccation, drought, water, water turbulence and invasion by other organisms or nutrient acquisition from their surroundings as well as their own pathogenesis and virulence against other organisms (Cowan et al. 2000; Chavant et al. 2002; de Martins et al. 2008; Ullrich 2009). Besides providing physical and functional protection to the dwelling microbes, the EPS help bacteria to adhere with the environmental surfaces, an association termed as the microbial biofilm (Kreft and Wimpenny 2001; Danhorn and Fuqua 2007). The attachment of the EPS-producing bacteria with roots of the plants through these EPS could help monitor and regulate the uptake of water and influx of soil nutrients into the plants (Amellal et al. 1999; Alami et al. 2000; Czarnes et al. 2000). Because of unique electrokinetic and colligative properties, a vast majority of the microbial EPS have been used in food, dairy, paint, oil, pharmaceutical, cosmetic industries and environmental applications, e.g. sewerage and waste water treatment (Hebber et al. 1992; Sutherland 2001; Bueno and Garcia-Curz 2006; Gerbersdorf et al. 2008; Kremer and Stal 2008). Although micro-aggregates formed by the bacterial EPS could remain stable under intensive agriculture practices for 20 years (Aspiras et al. 1971), use and application of the microbial EPS and the EPS-producing microbes for agriculture productivity and reclamation of the degraded and the salt-stressed lands has rarely been explored and understood. The research studies at Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Pakistan, therefore, were undertaken to isolate and identify the EPS-producing bacteria from salt-stressed soils and to explore their role in improving fertility and productivity of those soils (Ashraf et al. 1999, 2004, 2006). Using RCV-sugar media, BIOLOG and API methods, a number of EPS-producing bacteria were isolated and identified from cultivated and uncultivated salt-affected soils and from roots of wheat and barley plants grown on those soils (Ashraf et al. 1999). The objectives of this investigation were to select an efficient EPS-producing bacterium among the collection and study (1) its growth on solid and liquid media with a high salt content, (2) interaction of the bacterial EPS with constituents of clay fraction of a saline-sodic soil at different pH levels compared to a nonsaline (normal) soil and (3) effect of the bacterial EPS compared to the commercial polysaccharides on moisture loss and retained by the saline-sodic and nonsaline soils.

42.2 Materials and Methods

42.2.1 Description of the Site

The soil was sampled from Biosaline Research Station (BSRS) of Nuclear Institute for Agriculture and Biology (NIAB), Faislabad, Pakistan. The country of Pakistan with geographic location of 61°.76° E and 24°.37° N in subtropical zone is situated in one of the largest alluvial plains of the world, the Indus basin. The dominate climate of the country is arid to semiarid. The winter with an average temperature of 20 to −2°C is fairly cool. However, the high summer temperatures ranged from 39 to 53°C, prevailed in most parts of the country, lead to an excessive rate of evapotranspiration than the precipitation (an average rainfall 200–350 mm). The imbalance meteorological conditions thus resulted in accumulation of salts in the root zone and surface of the soil rendering it unsuitable for crop cultivation. More than 6.2 million ha (MINFAL 2000) of arable land of the country have suffered with the problem of soil salinity at various degrees. Although patches of the salt-affected areas are distributed throughout irrigated plains of four provinces of the country, a major 43.2% part is located in Punjab followed by Sindh 34.2%, Baluchistan 21.8% and the Khyber Pakhtonkhwa 0.8%. The plain of Indus basin also possesses an extensive groundwater aquifer under 16.2 Mha; however, it fluctuates and severely influence by monsoon rains. Moreover, most part of the aquifer is moderately (total soluble salts, TSS; 1,000–3,000 mg L^{-1}) to highly (TSS >3,000 mg L^{-1}) saline, while only a small part 22.1% is of good quality (TSS <1,000 mg L^{-1}) water.

The site BSRS is located at geographic coordinates longitude 72°.49.188 E and latitude 31°.14.685 N, at Pacca Anna 50 km in south-west of Faisalabad at an elevation of 190 m from sea. The research station was established by NIAB in 1992 on 400 ha of salt-affected land for bio-saline agriculture and agroforestry research experiments. Initially, the whole area was a barren land with sparse natural vegetation of *Prosopis juliflora*, *Suaeda fruticosa*, *Aeluropus lagopoides* and *Eleusine flagelliflora*, but 20 years of extensive research activities have succeeded to bring half of the area under forest plantation and crop cultivation. In addition to the soil salinity, the good quality irrigation water is not available while the ground water is brackish ((EC 4.8 dS m^{-1}, SAR 40 (mmoles $L^{-1})^{0.5}$, RSC 21 meq L^{-1})) and unfit for irrigation.

The climate of the area with an average annual rainfall of 325 mm is semiarid, while the mean summer temperature ranged from 32 to 37°C. A typical soil profile (0–250 cm depth) of the site with 0.5 cm surface salt crust, hard pan and water table absent from the upper 250 cm showed the *coarse loamy, mixed, hyperthermic Sodic Haplocalcids* soil type with a well-defined *calcic* diagnostic horizon (Shahid and Aslam 2007). The processes of salinisation, sodication, decalcification and calcification (Shahid et al. 2009) have been contributed to formation of the soil from the mixed calcareous alluvium parent material derived from rocks of Himalayas. Presence of young and the old flood plains linked the soil of *Pleistocene* age. The bulk density of the soil varied from 1.15 to 1.32 g cm^{-3}, 50–57% porosity and loamy sand to sandy loam soil texture. The ECe, pHs and the exchangeable sodium percentage (ESP) values (4–11 dS m^{-1} and 9.1–10.0, 44–59%, respectively) presented nature of the soil from slightly to moderately saline, strongly alkaline and saline-sodic soil. The ionic composition of the saturation extract indicates the dominance of Na^+, Cl^- and SO_4^{2-} with variable concentrations of Ca^{2+}, Mg^{2+} and K^+ cations. Anions HCO_3^{2-} and CO_3^{2-} were absent from all horizons, but the calcium carbonate equivalents range between 9.78 and 16.51% and were higher at 80–120 cm; the diagnostic calcic horizon (Shahid and Aslam 2007) was also recognised that determine the soil taxa.

42.2.2 Soil Characteristics

The soil samples were collected from 0 to 25 cm depth of a field under experimental wheat crop cultivation for the last 5–7 years. The soil was analysed by using standard USDA procedures (Burt 2004). The soil was characterised as saline-sodic with pH of saturated soil paste (pHs 8.3), electrical conductivity of soil saturation extract (ECe 8.7 dS m^{-1}), sodium adsorption ratio (SAR 38.28 (mmoles $L^{-1})^{0.5}$), exchangeable sodium percentage (ESP 44.9), osmotic pressure 3.24 bars and salt concentration 5,312 mg L^{-1}. Other physico-chemical characteristics of an air-dried and sieved through <2 mm screen soil sample were sand 60.2%; clay 12.1% and silt 27.7%; water holding capacity 12%; organic C 0.072%; nitrogen 34 mg kg^{-1} soil, expressed on oven-dried weight basis; and Na^+ 45.7, K^+ 3.4, Ca^{2+} 2.0, Mg^{2+} 0.85, Cl^- 11.3 and SO_4^{2-} 22.7 in meq L^{-1}.

42.2.3 Bacterial Strain Selection and Identification

The strain MAS133 (MAS133 is identified by 16SrRNA gene sequencing as *Microbacterium hominis*), previously isolated from the rhizosphere of wheat (*Triticum aestivum* L.) grown in a salt-affected soil, was used in this study. The EPS production on N-deficient solid RCV-sucrose medium of this bacterium was consistent and higher than the other EPS-producing bacterial isolates (Ashraf et al. 1999). The MAS133 was sub-cultivated and maintained on TSA/10 (ten times diluted Tryptic Soy Agar) medium. The MAS133 was previously identified to *Microbacterium* sp. by BIOLOG@ system. The nearly complete 16S rRNA gene sequence was obtained by sequencing the PCR product obtained using primers Fd1 and S17, according to Berge et al. (2002), and was used for a BLAST search at NCBI database.

42.2.4 Growth of EPS-Producing Bacterial Strain on Salt Media

Various EPS-producing bacterial strains isolated and identified (Ashraf et al. 1999) from rhizoplane and rhizosphere soil fractions of wheat (*Triticum aestivum* L.) grown in a salt-affected soil were spotted on N-deficient RCV-sucrose medium (Heulin et al. 1987) supplemented with 0.26 M NaCl. The bacterial strain for EPS production was selected by observing growth and EPS production at 25°C and 30°C incubation temperature after 5 days. Growth of the selected EPS-producing strain was also studied in liquid broth (LB) containing 0 to 1.3 M NaCl and Na_2SO_4 salts and Na_2SO_4 without and with addition of 40% sucrose as carbohydrate source. The liquid media taken into 250-mL capacity flasks were inoculated with 1 mL of overnight TSB/10 grown culture (10^6 CFU) of the bacterial isolate. The inoculated flasks were then incubated at 30°C on a shaking incubator (Precision, UK) for 2 days. Effect of the salts on growth of the bacterium in the liquid medium was followed by optical density (OD) of the culture at 540 nm on spectrophotometer (Shimadzu, Japan).

42.2.5 Extraction and Purification of the EPS from the Bacterial Strain

For extraction of the EPS, overnight TSB-grown culture of the bacterial isolate was centrifuged at 12,000 rpm for 10 min. The pellets were suspended in sterile biological saline to get McFarland optical density equal to 0.5 (a bacterial population of (10^6 CFU mL^{-1})). One millilitre of the bacterial suspension was then spread on RCV-sucrose medium in multiple replicates of standard culture petri plates and incubated at 30°C. EPS from surface of medium were scratched and dissolved in biological saline. The bacterial pellets were separated by centrifugation and the EPS were recovered by cold ethanol precipitation (Heulin et al. 1987; Hebber et al. 1992). Further purification of the EPS was carried out by passing it through aqueous solution of different grades of cold ethanol. The bacterial EPS recovered from the supernatant were lyophilised at –43°C under vacuum (1×10^{-3} mbar pressure) for 24 h and ground by a ball mill. Carbohydrate composition of the EPS was determined by HPLC (Hebber et al. 1992).

42.2.6 Effect of the Bacterial EPS on Soil Aggregate Stability

Method of He and Horikawa (1997) was followed to study the effect of the bacterial EPS on aggregate stability of clay fractions of saline-sodic and the nonsaline soils. Soil texture was determined using standard Bouyoucos method after giving standard pretreatments to soil (Bouyoucos 1962). Clay suspensions of the soils were obtained by separating upper 500 mL of clay fraction of the soil suspensions after specific time calculated by using the Stoke's law. Organic and inorganic chemical constituents of dried clay suspensions of the soils were determined by X-ray diffraction method (Cheshire et al. 2000).

Clay content of the suspension was determined by drying a known volume of the suspension in triplicate and dried at 105°C for 24 h. Further dilution of the suspension to adjust clay content to 1 mg mL^{-1} was made by distilled deionised water. Similarly, a known quantity of purified bacterial EPS was dissolved in water to get a concentration of 1 mg EPS mL^{-1} of the solution. Six concentrations (ranging from 0.0000001 to 1.0 mg mL^{-1}), 2 nos. each of lower (10^{-1} and 10^{-2}), medium (10^{-3} and 10^{-4}) and higher (10^{-5} and 10^{-6}) of the bacterial EPS, were prepared by serial dilution of the stock solution. The purified bacterial EPS were added to the clay suspension, and the aggregate stability of the suspended micro-aggregates (SMA) was determined. Treatments prepared to study aggregate stability and interaction of the bacterial EPS with clay particles in the colloidal form were as follows:

2 ml clay suspension (1 mg clay ml^{-1}) + 1 ml 10^{-6} EPS solution + 1 ml Distilled H_20
2 ml clay suspension (1 mg clay ml^{-1}) + 1 ml 10^{-5} EPS solution + 1 ml Distilled H_20
2 ml clay suspension (1 mg clay ml^{-1}) + 1 ml 10^{-4} EPS solution + 1 ml Distilled H_20
2 ml clay suspension (1 mg clay ml^{-1}) + 1 ml 10^{-3} EPS solution + 1 ml Distilled H_20
2 ml clay suspension (1 mg clay ml^{-1}) + 1 ml 10^{-2} EPS solution + 1 ml Distilled H_20
2 ml clay suspension (1 mg clay ml^{-1}) + 1 ml 10^{-1} EPS solution + 1 ml Distilled H_20

Aggregate stability of the clay particles in the colloidal form was determined at three pH levels, viz. native, acidic (pH 4.5) and alkaline (pH 7.5) of the clay suspensions. Absorption of the clay suspension added with and without the bacterial EPS was measured by a spectrophotometer at 546 nm after 2, 4, 16 and 24 h of the stability or equilibration period at room temperature. A unit absorption ratio (A_R), the ratio of absorbance of the clay suspensions with (A_X) and without (A_O) bacterial EPS ($A_R = A_X/A_O$), was a measure of a complete dispersion of the clay particles in the suspension; a zero value indicated a complete polymeric flocculation (PFL) of the suspended micro-aggregates (SMA) of the clay fractions. A polymeric weak stability (PWST) and polymeric stability (PST) of the SMA of clay fractions of the soils were indicated by a temporary rise and a stable uniform A_R values, respectively. The absorption spectra drawn as a function of log concentration (LC) of the bacterial EPS were taken as measure of soil aggregate stability in the colloidal form.

42.2.7 *Effect of the Bacterial EPS on Soil Moisture Loss*

Two types of experimental studies were conducted for this purpose. In one of the studies, four different rates 0, 1, 3, 5% of the bacterial EPS obtained from *Microbacterium* sp. strain MAS133 were mixed with 50 g of saline-sodic and a normal soil taken in to 100 mL capacity screw cap plastic containers. The contents were moistened at 60% WHC (water holding capacity) and mixed overnight on swirling mixer. In the second experiment, 50 g of the soils taken in to screw cap plastic containers were mixed with 1% each of the bacterial EPS and the commercially available xanthan gum and levan (a fructose polymer). The moisture loss and retained by treated and untreated soil samples was determined at 105°C by an infrared-closed chamber thermobalance moisture analyzer (THERMORED, ORMA, Italy) at different time intervals until a complete release of the water applied to the soils was achieved.

42.3 Results and Discussion

The nearly complete 16S rRNA gene sequence of strain MAS133 was deposited in GenBank under the no. AJ251194. MAS133 was found to be clearly affiliated to the *Microbacterium* genera using the BLASTN programme (Altschul et al. 1997) that confirms BIOLOG previous identification. Partial 16S rRNA gene sequence of MAS133 had 99.9% identity with that of *Microbacterium hominis* type strain DSM12509^T (GenBank accession no. AM181504) and is then clearly identify to this species. The *M. hominis* type strain was isolated from a clinical sample; however, this species contains bacteria from environment as BLAST result showed that MAS133 is also closely related with strain RM10 found in dried mud (GenBank accession no. EF675621) and strain rj6 isolated from activated sludge (GenBank

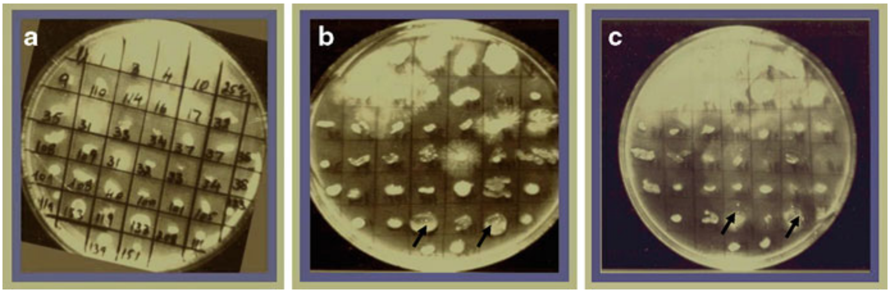

Fig. 42.1 Growth and EPS production by *Microbacterium* sp. MAS133 at 30°C on RCV-sucrose medium (**a**) without (**b**) and with (**c**) 0.25 M NaCl. Arrows and numbers on left show position of the bacterial strain

accession no. AB021324). Preliminary HPLC analysis of purified EPS revealed that MAS133 produced a fructose biopolymer levan that was composed of fructose subunits and some unidentified sugars in the ratio of 3:1. Although exo-polysaccharides production by most of the family members of the genus *Microbacterium* has not been fully understood, both homo and hetero types of biopolymers with glucose, mannose and fructose backbone have been reported (Bae et al. 2008; Asker et al. 2009; Godinho and Bhosle 2009). The structural variability in exo-polysaccharides indicates presence of an array of enzymes and capability of members of the *Microbacterium* genus to grow and assimilate a variety of carbohydrate substrates (Takeuchi and Hatano 1998).

Compared to higher temperature of incubation 30°C, synthesis of the EPS by the bacterial strains on RCV-sucrose medium was lower at 25°C. The extent of low EPS production at 25°C could be attributed to a slow metabolism of the bacterial strains at this temperature. A substantial EPS production at 30°C and intact colony morphology (Fig. 42.1b) indicated 30°C as optimum suitable incubation temperature for growth and EPS synthesis. Addition of NaCl in the medium stimulated the profuse and mucoid spread of the EPS on surface of the solid RCV-sucrose medium (Fig. 42.1c). Whether or not added with the NaCl salt, EPS production on solid RCV-sucrose medium by *Microbacterium* sp. was consistent and higher among the EPS-producing bacterial strains (Fig. 42.1b, c). The researchers (Lloret et al. 1998; Sutherland 2001) have observed variability in EPS production among bacterial genera and even among different strains of a bacterial species. Although addition of salts in the medium has been observed to cause loss in mucoidy of the halotolerant bacteria (Lloret et al. 1998), the response of *Microbacterium* sp., however, could be ascribed to inherent capability of the bacterium to grow and keep potential of the EPS synthesis under diverse culturing conditions especially the salt stress. Moreover, since both composition and culturing conditions of the growth medium are known to affect production and rheological properties of the bacterial EPS (Sutherland 2001), the profuse growth and spreading of the EPS on surface of the NaCl-amended RCV-sucrose medium could be due to decrease in or weakening of tensile and elastic strength of the EPS due to salts (Nadler et al. 1994; Lloret et al. 1998). HPLC

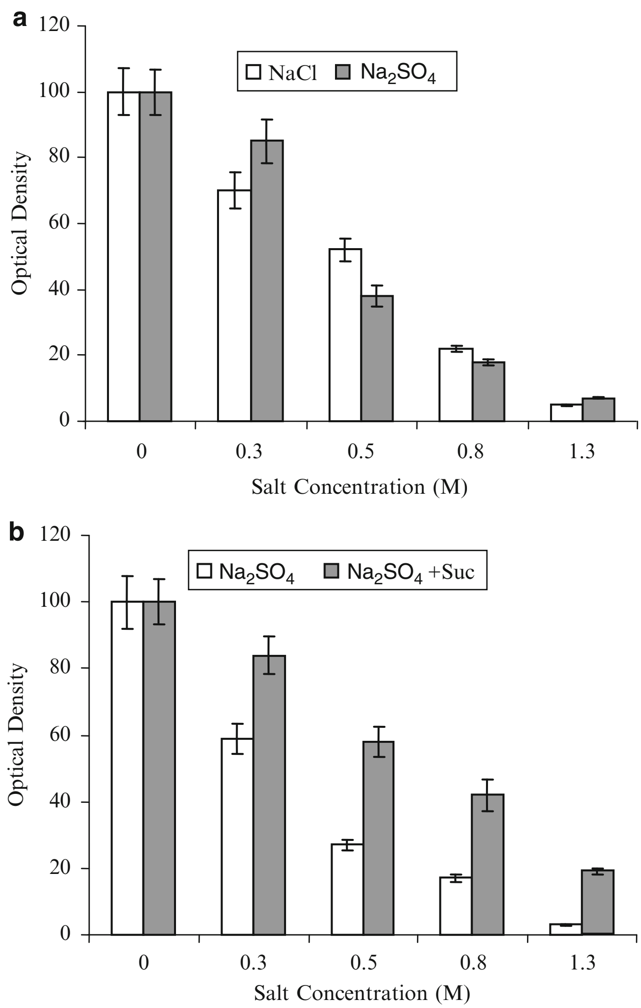

Fig. 42.2 Growth of *Microbacterium* sp. in liquid broth, LB (**a**) with different concentration of NaCl and Na_2SO_4 and in diluted LB/10 (**b**) Na_2SO_4 medium without (a) and with (b) 40% sucrose (error bars ± C.I., confidence interval at $p<0.05$)

analysis revealed that the EPS produced by *Microbacterium* sp. were fructose biopolymer levan that was composed of fructose subunits and some unidentified sugars in the ratio of 3:1.

Growth of MAS133 in the liquid media was affected by addition of salts. Although increasing concentrations of both NaCl and Na_2SO_4 were inhibitory to growth of the bacterium in the liquid broth, the effect did not appreciably differ between the two salts (Fig. 42.2a). Addition of sucrose helped resist the effect of Na_2SO_4 and recover growth of the bacterium in LB/10 medium (Fig. 42.2b). Cationic bridging with the EPS synthesised from carbohydrate substrate would have enabled the bacterium to withstand and resist toxic effects of the ionic stress on growth (Fleming et al. 1999; Gerbersdorf et al. 2009; de Martins et al. 2008). A comparison of growth of the bacterial strain at higher concentrations of salt with and without sucrose confirmed capability of the *Microbacterium* sp. MAS133 to survive and carry on its metabolic activities especially the EPS synthesis under sever salt stress conditions although at a highly decreased rate.

Figure 42.3 shows the interaction of the bacterial EPS with suspended soil micro-aggregates (SMA) of clay fractions of saline-sodic and nonsaline soils at three pH levels. After 2 h of sedimentation period at room temperature, flocculation (PFL) and a weak aggregate stability (PWST) of SMA of clay fraction of the nonsaline soil were observed at acidic pH (Fig. 42.3a(i)). At native pH, the clay particles remained dispersed and suspended in the soil colloid. No response in terms of soil aggregate formation and stability phenomenon by the bacterial EPS was observed (Fig. 42.3a(ii)). A prominent effect of the bacterial EPS on process of soil aggregate formation and stability, however, was observed at alkaline pH (Fig. 42.3a(iii)). At lower rate of EPS addition, the SMA showed PFL, while at highest concentration, a polymeric stability (PST) was exhibited. The pattern of soil aggregate formation and stability remained the same at native and acidic pH levels; however, at alkaline pH, a weak PFL and PWST phenomenon were predicted by SMA at lower and higher concentrations of the EPS after 4 h sedimentation period. Extended equilibration period to 16 and 24 h resulted in PFL of the clay particles at medium concentrations of the EPS addition, and the effect was consistent and similar at all pH levels. Compared to the native, acidic and alkaline pHs enhanced the extent of sedimentation of SMA of clay fraction of the nonsaline soil (Fig. 42.3a).

Micro-aggregates of the clay fraction of saline-sodic soil showed PFL at acidic pH after 2 h of sedimentation period (Fig. 42.3b(i)). The phenomenon of PFL was weak and exhibited at lower and medium EPS concentrations only. A weak PFL was also observed at medium concentration of the bacterial EPS at native pH (Fig. 42.3b(ii)). At higher EPS concentration, the SMA were stabilised. A shift in pH from native to alkaline did not alter the process and pattern of soil aggregate stability (Fig. 42.3b(ii)). The change in pH from native to acidic and alkaline, however, accelerated and fostered the rate of sedimentation of the flocculated and suspended soil particles which resulted in substantial decrease in AR values after 4, 16 and 24 h of stability period. The extent of sedimentation of the soil particles was higher in alkaline than acidic pH. Extended periods of soil aggregate stability did not bring a change in pattern of soil aggregate formation and stability at native and acidic pHs; however, at alkaline pH instead of PST, there was a PWST of the clay SMA at medium concentration of the EPS after 4 h. After 16 and 24 h, no change in pattern of soil aggregate formation and stability was observed at native and alkaline pH, while at acidic pH level, a PWST at lowest, PFL at medium and PST at highest concentrations, respectively, of the SMA were observed. The results presented that the trend and pattern of soil aggregate formation, their stability and sedimentation of the clay constituents of the soil suspensions were all affected by soil type and the pH levels of the soil suspensions. Analysis of dried clay samples by XRD indicated the clay fraction of the suspensions was a complex mixture of organic content and

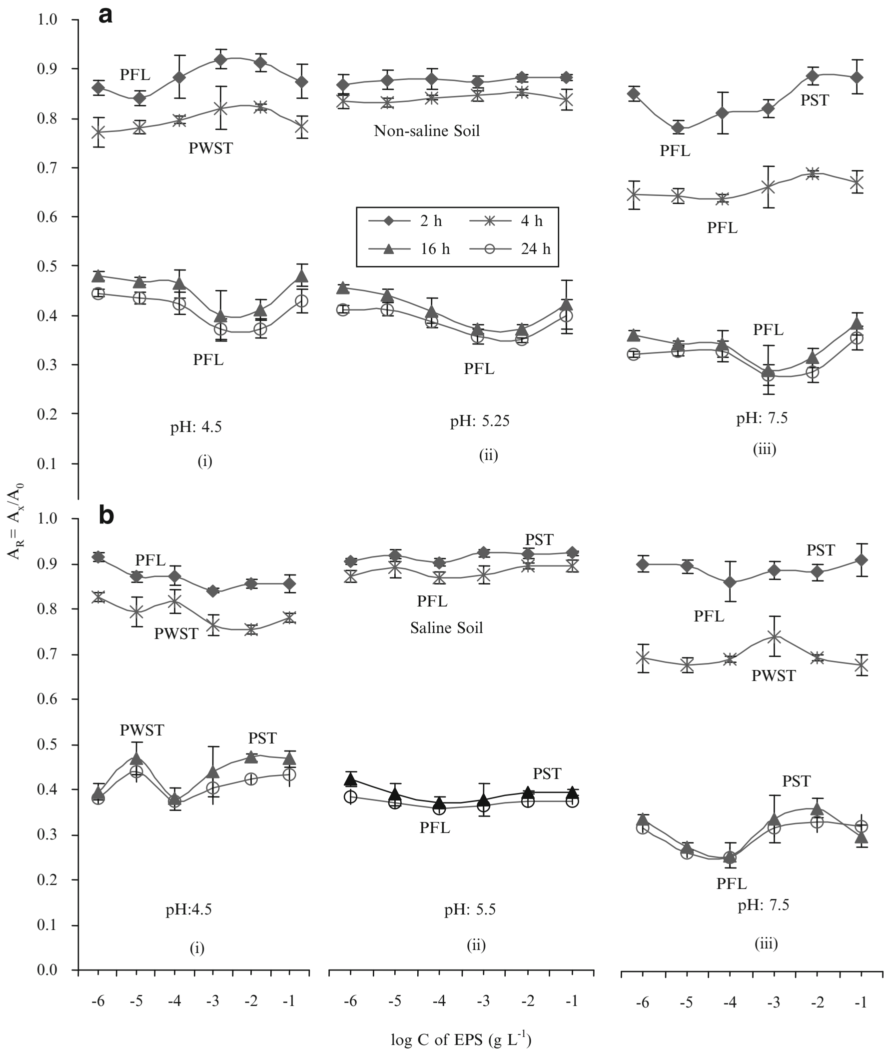

Fig. 42.3 Effect of the EPS obtained from *Microbacterium* sp. MAS133 on soil aggregation behaviour of a nonsaline (**a**) and a saline-sodic (**b**) soils at three pH levels for 2, 4, 16 and 24 h sedimentation periods. PFL, polymeric flocculation; PWST, polymeric weak stability; PST, polymeric stability. The values are means of three replicates (error bars ± C.I., confidence interval at $p<0.05$)

inorganic clay constituents (Table 42.1). Moreover, the two soils varied in extent and composition of the clay constituents. A higher content of organic contents in clay fraction of nonsaline soil indicated that the soil was cultivated more frequently than saline-sodic soil.

Suspended micro-aggregate (SMA)-EPS interactions, adsorption of EPS chains on surfaces of more than one micro-aggregates causing bridging flocculation PFL

Table 42.1 Major organic and inorganic clay constituents of saline-sodic (SS) and nonsaline (NS) soils as analysed by XRD

	SS	NS
Peak frequency (%)		
Organic		
Glucose hydrate	1.3(±0.12)[a]	0.03(±0.001)
Glucose sodium iodide hydrate	8.2(±0.21)	14.3(±0.73)
Glucose sodium bromide hydrate	12.8(±0.93)	15.1(±0.71)
Glucose hydrate sodium chloride	11.1(±0.31)	0.56(±0.03)
Arabinose thiobenzohydrazide	0.05(±0.01)	18.5(±1.12)
Arabinose benzoyl hydrazone	0.01(±0.003)	10(±0.83)
Galactose-phenyl methyl hydrazone	4.5(±0.17)	0.13(±0.007)
Mannose-p-bromo phenyl hydrazone	7.1(±0.53)	7.1(±0.61)
Mannose phenyl hydrazone	–	23.1(±1.23)
Inorganic		
Montmorillonite	27.3(±1.31)	21.3(±2.1)
Illite	9.4(±0.32)	18.8(±1.02)
Muscovite	–	9.8(±0.22)
Pyrrhotite	–	11.5(±0.93)
Wollastonite	8.2(±0.2)	25.7(±1.0)
Biotite	13.2(±0.81)	15.1(±1.04)
Aluminium oxide	23.1(±1.41)	36.4(±1.71)

[a]S.E of means for $n=3$

(polymeric flocculation), PWST (polymeric weak stability) interaction with a small number and PST (polymeric stability) with a higher number of EPS chains varied due to change in pH of the clay suspension, type of the soil and the concentration of the bacterial EPS though the response was not very sharp due to complex composition of the clay minerals. The variability in the trend and pattern of soil aggregate formation and stability observed in the study thus could be attributed to variable behaviour of the bacterial EPS, organic and inorganic clay constituents in the colloidal form at three pH levels (Bhosle et al. 1998; Suci et al. 1998; Nakata and Kurane 1999; Karthikeyan and Beveridge 2002). Change in pH of the clay suspension could affect electrostatic behaviour and result in negatively (−ve) and positively (+ve) charged micro-aggregates and the bacteria EPS. Since the clay fraction was a complex mixture of organic and inorganic soil constituents, a part of the clay fraction negatively charged under alkaline pH could behave as positively particles under acidic pH and vice versa. The process of formation and stability of the suspended micro-aggregates in the soil colloid were thus a net result of interactive effect of positively and negatively charged micro-aggregates and the EPS molecules (Letey 1994; He and Horikawa 1997, 2000). A higher flocculation at alkaline than acidic pH could be ascribed to charge carrying and ion exchange potentials of the clay particles. However, at native pH, the processes and phenomenon of soil aggregate formation and stability in the soil colloid were results of sole effect of the bacterial EPS on micro-aggregates in the colloidal form.

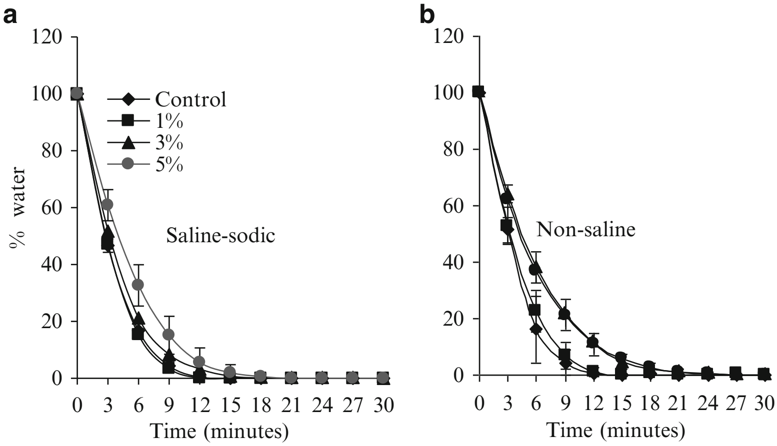

Fig. 42.4 Moisture release (means of three replicates) from saline-sodic (**a**) and nonsaline (**b**) soils amended with and without different rates of EPS extracted from *Microbacterium* sp. MAS133 (error bars ± C.I., confidence interval at $p<0.05$)

The microbial processes are linked to physical and chemical characteristics of the soils, in particular pH and clay content of the soils, the shift in pH level can influence microbial community composition and functioning which could ultimately lead to and affect the soil microbial processes essential for fertility and productivity of the soils (Roper and Smith 1991; Maccio et al. 2002; Delavechia et al. 2003; Harris 2003; Bashan et al. 2004). Moreover, the colloidal stability of soil clays in the presence of polymers and electrolytes is of practical applications for analysing related phenomena in the soil environment, e.g. aggregation, erosion, transport of solutes and colloids involving pollutants as well as the biotic and abiotic environmental soil stresses like salinity (He and Horikawa 1996). The aggregate stability studies conducted with clay fraction of a saline-sodic soil indicated that colloidal behaviours, viz. PFL, PWST and PST, were influenced by pH, the concentration of the bacterial EPS and the organic and inorganic constituents of the clay suspension. A greater flocculation at alkaline than acidic pH could be due to charge carrying and ion exchange potentials of the clay particles. Under alkaline conditions, a net negative charge developed on surfaces of the clay due to protonation could attract a number of cations from the soil solutions, and in consequence, absorption of greater OH^- could result in a decrease in pH of the surrounding solutions.

A complete loss of the water added to control treatment of the two soils occurred in the first 12 min. A longer period, however, was required for a complete release and loss of water from saline-sodic and nonsaline soils added with 3 and 5% than the soils treated with 1% of the bacterial EPS and the control (Fig. 42.4a, b). The time required to release water from the salt-affected soil treated with higher quantities of the bacterial EPS was less than the nonsaline soil treated with similar quantities of the bacterial EPS. The rate of water release was also higher in saline than nonsaline soil.

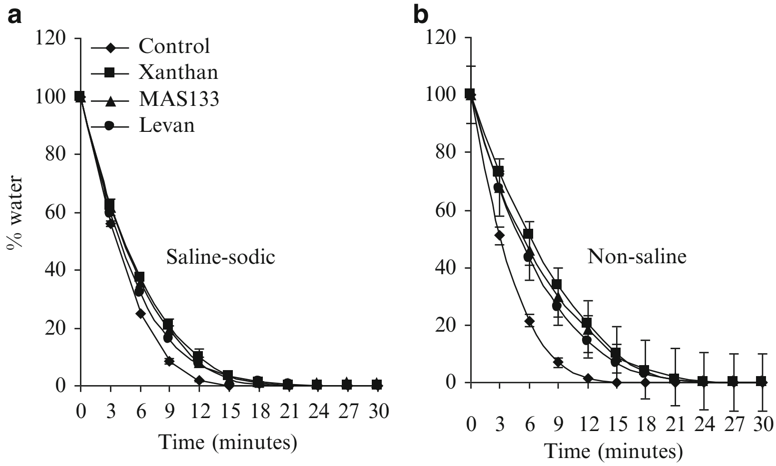

Fig. 42.5 Moisture release (means of three replicates) from saline-sodic (**a**) and nonsaline (**b**) soils amended with and without 1% each of xanthan gum, levan and the EPS extracted from *Microbacterium* sp. MAS133 (error bars ± C.I., confidence interval at $p<0.05$)

Compared to control, the rate of water release from the soil was lower in xanthan gum, levan and the bacterial EPS-treated soils (Fig. 42.5). However, a longer time was required for a complete release of water from the treated nonsaline than the saline-sodic soil (Fig. 42.5a, b). The rate of water release did not vary between saline-sodic and nonsaline soils treated with the bacterial EPS and levan. A slight variation for rate of water loss was observed between xanthan and the bacterial EPS-treated soils. A short period was taken for complete release and loss of water from the bacterial EPS treated than the xanthan gum-treated soils.

A long period and years of observations are required to get appreciable amount of data and information about the effect and role of the bacterial EPS and the bacteria on soil physical properties under field conditions. The soil moisture release curves are thus good methods of studying and predicting effects of organic amendments on soil structural characteristics (Chen and Wagenet 1992; Crawford et al. 1995). Two methods of polysaccharides and soil mixing were used to study effect of the bacterial EPS on soil water release from the saline-sodic and the nonsaline soil. Mixing of different rates of the bacterial EPS with soil by stirring showed the effect of the bacterial EPS on soil water loss at higher quantities (3 and 5%), while patting of the soils before subjecting it to thermobalance analysis has given response at lower (1%) quantities of the EPS. Since soil aggregate formation and its stability is also influenced by physical soil forces, e.g. drying and wetting of the soil clods and mechanical impedance, patting was thus representative of wet field conditions (Cheshire et al. 2000). A prolong period required to release water from the treated than untreated control soils indicated the effect of the bacterial EPS and commercial gums on water retention capacity and permeability of the soils (Crawford 1994; Alami et al. 2000). Both the bacterial EPS and the commercial gums have contributed and improved water retention capacity and permeability of the soils. Although extent and nature of the effect of the EPS varied for saline-sodic and nonsaline soils, the studies demonstrated a prominent influence of the bacterial EPS on physical and chemical soil interactions involved in build-up and maintenance of soil structure characteristics.

42.4 Conclusions

Because of inherent charge capacities and the nature of the charge present at surfaces and edges, polymeric flocculation (PF) of the clay fraction of the soil at certain specific pH of the solution or its interaction with organic colloids results in a polymeric stability (PST) of the soil aggregates. A polymeric weak stability (PWST) phenomenon occurs when the addition of EPS in a soil colloid system causes the partial deflocculation of the clay floccules (dispersion). Hence, a soil colloid system is a rapid and easy method for studying interaction of polysaccharides of microbial origin with soil particles and the mechanisms of soil aggregate formation and their stability. Although nature and extent of bacterial EPS-micro-aggregates interactions varied with concentration of the EPS, soil types, organic and inorganic composition of the clay complex and change in pH of the clay suspension, the results of both soil aggregate stability and soil moisture loss studies exhibited a consistent and sustained contribution of the bacterial EPS in improving physico-chemical characteristics of a salt-affected soil. Findings of the studies and the work conducted earlier on effect of the EPS-producing bacterial inoculation on soil aggregation around roots, root growth, water and cation uptake by the plants grown on the salt-affected soils provide good support to conclude that the EPS-producing bacteria and the bacterial EPS could be a useful biological tool for reclamation and amelioration of the salt-affected soils. However, considerations about economic feasibility, huge task of bacterial inoculum preparation and its field application, the uncertainty about success of the inoculum and its environmental implications as well as the biosafety concerns are the factors which render use of the biological tool in the field. The provision of nutrients and the carbon substrates for growth and activities of the soil microbial populations can enhance extent of the process and production of the biopolymer and its release in the soil. Promoting and fostering growth of the EPS-producing bacterial populations inhabiting the salt-affected soils and their extent of the EPS production through application of saccharide-enriched substrates such as decomposed or undecomposed organic plant residues, leaf litter and the industrial organic wastes like sugarcane bagasse, rice husk and organic composts mixed with soil of the field water distributaries and the especially constructed 'biomonitors' or 'bioretention' cells, therefore, could also help achieve the task of beneficial use and application of the biological tool in the field.

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References

Alami Y, Achouak W, Marol C, Heulin T (2000) Rhizosphere soil aggregation and plant growth promotion of sunflowers by an exopolysaccharide-producing *Rhizobium* sp. strain isolated from sunflower roots. Appl Environ Microbiol 66:3393–3398

Altschul SF, Madden TL, Schaffer AA, Zhang J, Zhang Z, Miller W, Lipman DJ (1997) Gapped BLAST and PSI-BLAST: a new generation of protein database search programs. Nucleic Acids Res 25(17):3389–3402

Amellal N, Bartoli F, Villemin G, Talouizte A, Heulin T (1999) Effect of inoculation of EPS-producing *Pantoea agglomerans* on wheat rhizosphere soil aggregation. Plant Soil 211:93–101

Ashraf M, Berge O, Azam F, Heulin T (1999) Bacterial exo-polysaccharides and productivity of the salt affected soils: I. Diversity of exo-polysaccharide producing bacteria from the rhizosphere of wheat (*Triticum aestivum* L.) grown in normal and saline Pakistani soils. Pak J Bio Sci 2:201–206

Ashraf M, Hasnain S, Berge O, Mahmood T (2004) Inoculating wheat seedlings with exo-polysaccharides producing bacteria restricts sodium uptake and stimulates plant growth under salt-stress. Biol Fertil Soils 40:157–162

Ashraf M, Hasnain S, Berge O (2006) Effect of exo-polysaccharides producing bacterial inoculation on growth of roots of wheat (*Triticum aestivum* L.) plants grown in a salt-affected soil. Int J Environ Sci Technol 3(1):43–51

Asker MMS, Ahmed YM, Ramdan MF (2009) Chemical characteristics and antioxidant activity of exo-polysaccharide fractions from *Microbacterium terregens*. Carbohydr Polym 77:563–567

Aspiras RB, Allen ON, Harris RF, Chesters G (1971) The role of microorganisms in the stabilization of soil aggregates. Soil Biol Biochem 3:347–353

Bae IY, Oh I-K, Lee S, Yoo S-H, Lee HG (2008) Rheological characterization of levan polysaccharides from *Microbacterium laevaniformans*. Int J Biol Macromol 42:10–13

Bashan Y, Holguin G, de-Bashan LE (2004) *Azospirillum*-plant relationships: physiological, molecular, agricultural, and environmental advances (1997–2003). Can J Microbiol 50:521–577

Berge O, Guinebretiere MH, Achouak W, Normand P, Heulin T (2002) *Paenibacillus graminis* sp. nov. and *Paenibacillus odorifer* sp. Nov., isolated from plant roots, soil and food. Int J Syst Evol Microbiol 52:607–616

Bhosle N, Suci PA, Baty AM, Weiner RM, Geesey GG (1998) Influence of divalent cations and pH on adsorption of a bacterial polysaccharides adhesion. Colloid Interface Sci 205:89–96

Bouyoucos CJ (1962) Hydrometer method for making particle size analysis of soil. Agron J 54:464–465

Bueno SM, Garcia-Curz CH (2006) Optimization of polysaccharides production by bacteria. Braz J Microbiol 37:296–301

Burt R (ed) (2004) Soil survey laboratory methods manual. SSIR No 42, Ver 4.0. US Governement Printing Office, Washington, DC

Chavant P, Martinie B, Meylheuc T, Bellon-Fontaine M-N, Hebraud M (2002) *Listeria monocytogenes* LO28: surface physicochemical properties and ability to form biofilms at different temperatures and growth phases. Appl Environ Microbiol 68:4760–4764

Chen C, Wagenet RJ (1992) Simulation of water and chemicals in macropore soils: Part I. Representation of equivalent macropore influence and its effect on soil water flow. J Hydrol 130:105–126

Cheshire MV, Dumat C, Fraser AR, Hillter S, Staunton S (2000) The interaction between soil organic matter and clay minerals by selective removal and controlled addition of organic matter. Eur J Soil Sci 51:497–509

Cowan SE, Gilbert E, Liepmann D, Keasling JD (2000) Commensal interactions in dual-species biofilm exposed to mixed organic compounds. Appl Environ Microbiol 66:4481–4485

Crawford JW (1994) The relation between the structure and the hydraulic properties of soil. Eur J Soil Sci 45:493–502
Crawford JW, Matsui N, Young IM (1995) The relation between the moisture release curve and the structure of soil. Eur J Soil Sci 46:369–375
Czarnes S, Hallett PD, Bengough AG, Young IM (2000) Root- and microbial-derived mucilages affect soil structure and water transport. Eur J Soil Sci 51:435–443
Danhorn T, Fuqua C (2007) Biofilm formation by plant associated bacteria. Annu Rev Microbiol 61:401–422
de Martins PSO, de Almeida NF, Leite SGF (2008) Application of a bacterial extracellular polymeric substance in heavy metal adsorption in a co-contaminated aqueous system. Braz J Microbiol 39:780–786
Delavechia C, Hampp E, Fabra A, Castro S (2003) Influence of pH and calcium on growth, polysaccharide production and symbiotic association of *Sinorhizobium meliloti* SEMIA 116 with alfalfa roots. Biol Fertil Soils 38:110–114
Fleming HC, Wingender J, Moritz R, Mayer C (1999) The forces that keep biofilms together. In: Keevit W, Godfree AF, Holt DM, Dow CS (eds) Biofilms in aquatic systems. Royal Society of Chemistry, Cambridge, pp 1–12
Gerbersdorf SU, Janke T, Westrich B, Paterson DM (2008) Microbial stabilization of riverine sediments by extracellular polymeric substances. Geobiology 6:57–69
Gerbersdorf SU, Westrich B, Paterson DM (2009) Microbial extracellular polymeric substances (EPS) in fresh water sediments. Microb Ecol 58:334–349
Godinho AL, Bhosle S (2009) Sand aggregation by exo-polysaccharide-producing *Microbacterium arborescencs*-AGSB. Curr Microbiol 58:616–621
Harris JA (2003) Measurement of the soil microbial community for estimating the success of restoration. Eur J Soil Sci 54:801–808
He M, Horikawa Y (1996) Stability of allophane, allophanic clay and allophone-halloysite floc in aqueous solutions of an anionic exocellular heteropolysaccharide (gum Xanthan) from *Xanthomonas compestris*. Soil Sci Plant Nutr 42:603–612
He M, Horikawa Y (1997) Effect of inorganic electrolytes on the stability of allophane in aqueous solutions of anionic xanthan polysaccharide. Soil Sci Plant Nutr 43:219–225
He M, Horikawa Y (2000) Partial deflocculation of mutual flocs of allophane and halloysite by xanthan and chistosan and relevance to particle arrangement in the flocs. Soil Sci Plant Nutr 46:81–87
Hebber P, Gueniot B, Heyraud A, Colin-Morel P, Heulin T, Balandreau J, Rinaudo M (1992) Characterization of exopolysaccharides produced by bacteria isolated from plants roots. Appl Microbiol Biotechnol 38:248–253
Heulin T, Guckert A, Balandreau J (1987) Stimulation of root exudation of rice seedlings by *Azospirillum* strains: carbon budget under gnotobiotic conditions. Biol Fertil Soils 4:9–14
Karthikeyan S, Beveridge TJ (2002) *Pseudomonas aeruginosa* biofilms react with and precipitate toxic soluble gold. Environ Microbiol 4:667–675
Kreft JU, Wimpenny JWT (2001) Effect of EPS on biofilm structure and functions as revealed by an individual-based model of biofilm growth. Water Sci Technol 43:135–141
Kremer B, Stal LJ (2008) Calcium carbonate precipitation in cyanobacterial mats from sandy tidal flats of North Sea. Geobiology 6:46–56
Letey J (1994) Adsorption and desorption of polymers on soil. Soil Sci 158:244–248
Lloret J, Wulff BBH, Rubio JM, Downie JA, Bonilla I, Rivilla R (1998) Exopolysaccharide II production is regulated by salt in the halotolerant strain *Rhizobium meliloti* EFB. Appl Environ Microbiol 64:1024–1028
Maccio D, Fabra A, Castro S (2002) Acidity and calcium interaction affect the growth of *Bradyrhizobium* sp. and the attachment to peanut roots. Soil Biol Biochem 34:201–208
MINFAL (2000) Agricultural statistics of Pakistan, 1999–2000. Ministry of Food, Agriculture and Livestock, Government of Pakistan, Islamabad, p 302
Nadler A, Margritz M, Leib L (1994) PMA application techniques and mobility in soil. Soil Sci 158:249–254

Nakata K, Kurane R (1999) Production of an extracellular polysaccharide biflocculant by *Klebsiella pneumoniae*. Biosci Biotechnol Biochem 63:2064–2068

Roper MM, Smith NA (1991) Straw decomposition and nitrogenase activity (C_2H_2 reduction) by free-living micro-organisms from soil: effects of pH and clay content. Soil Biol Biochem 23:275–283

Shahid SA, Aslam Z (2007) Salt tolerant forage project funded by IFAD. Progress report-soil assessment model ICBA-NIAB forage project experimental sites, Pakistan. ICBA, Dubai, p 31

Shahid SA, Aslam Z, Hashmi ZA, Mufti KA (2009) Baseline soil information and management of a salt-tolerant forage project site in Pakistan. Eur J Sci Res 27:16–28

Suci PA, Vrany JD, Mittelman MW (1998) Investigation of interactions between antimicrobial agents and bacterial biofilms using attenuated total reflection Fourier transform infrared spectroscopy. Biomaterials 19:327–339

Sutherland IW (2001) Biofilm exopolysaccharides: a strong and sticky framework. Microbiology 147:3–9

Takeuchi M, Hatano K (1998) Proposal of six new species in the genus Microbacterium and transfer of Flavobacterium marinotypicum ZoBell and Upham to the genus Microbacterium as Microbacterium maritypicum comb. nov. Int J Sys Bacteriol 48:973–982

Ullrich M (2009) Bacterial polysaccharides: current innovations and future. Caister Academic Press, Portland

Part VII
Opportunities and Challenges in Using Marginal Waters

Chapter 43
Agriculture Use of Marginal Water in Egypt: Opportunities and Challenges

Mohamed S. Zidan and Mohamed A. Dawoud

Abstract Egypt is facing several fundamental problems: an ever-increasing population, a limited supply of cultivable land, and a limited supply of water resources. These problems intensify the importance of developing efficient natural resource use strategies. The future of Egypt depends on the water stored in the Nasser Lake reservoir for all purposes. There is strong evidence that governmental policies in the agricultural sector have led to an inefficient allocation of resources in general and water resources in particular, the latter being the focus of this study. These policies should be examined within sound economic frameworks, and policy alternatives should be tested to insure the efficient use of water resources. The last drought in Africa brought attention to the need for optimal intertemporal allocation of this vital resource. There are three major marginal-quality water sources that can be used in Egypt: wastewater, saline, and sodic agricultural drainage water and brackish groundwater. At present, wastewater is reused in many areas sometimes after dilution but mostly without enough treatment. Also, farmers use saline-sodic drainage waters in areas which suffer from irrigation water shortage especially at the end of irrigation canals. Still others irrigate with saline or brackish groundwater, either exclusively or in conjunction with good quality surface water. Many of those farmers cannot control the volume or quality of water they receive. Wastewater often contains a variety of pollutants: salts, metals, metalloids, pathogens, residual drugs, organic compounds, endocrine disruptor compounds, and active residues of personal care products. Any of these components can harm human health and the environment. Farmers can suffer from harmful health effects after contacting with wastewater, while consumers are at risk from eating vegetables and cereals irrigated

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with wastewater. Application of wastewater has to be carefully managed for effective use. In this chapter, the challenges and opportunities of marginal water use in Egypt are discussed. This chapter focuses on the marginal water use considerations technically (including space, time, quantity, and quality), economically, environmentally (including northern lake ecology, Delta salt balance and pollution concentration, and health risks), socially (including acceptance and practice), legally, and institutionally.

Keywords Efficient water management • Irrigation water • Marginal water • Saline water • Treated wastewater

43.1 Introduction

Agriculture is the backbone and major economic activity of Egypt. The agricultural sector currently employs approximately 41% of the work force, provides about 20% of gross domestic product (GDP), and accounts for about 30% of total foreign exchange earnings as expressed by the United States Department of Agriculture (USDA 1990).

Due to the scarcity of freshwater resources in Egypt and increasing demand, at present, two marginal water sources are in use, namely, agriculture drainage water and treated wastewater.

There are three levels of reusing agriculture drainage water in irrigation at Delta area represented by official use, unofficial use, and intermediate use. The official use is meant by main water sources mixed with waterways water (1:1) by the ministry of water resources and irrigation to develop water salinity of 1,085 parts per million (ppm). Unofficial use by farmers without authorized permit, particularly, by farmers living at the waterways ends and suffers from lack of irrigation water; the water salinity exceeds 3,000 ppm. The intermediate use of agricultural drainage water depends on mixing sub-waterways with nearby water courses before reaching the polluted main waterways.

Wastewater use in Egypt is an old practice. It has been used since 1915 in sandy areas like Al Gabal Al Asfar and Abu Rawash near Cairo. Interest in the use of treated wastewater, as substitute for freshwater in irrigation, has accelerated since 1980 (Abdel Wahaab and Omar 2011). At present, Egypt produces 3.51 billion cubic meters (BCM) of secondary treated wastewater (TWW) annually, of which 0.70 BCM is directly used for irrigation or indirectly by blending with agricultural drainage water (ADW). Reuse of treated wastewater could be increased from 0.7 to 2.97 BCM by 2017. The present annual reuse of ADW is approximately 4.9 BCM. The safe and efficient use of marginal waters (ADW and TWW) is a core objective of this study which has been operating from 1997 to date. In general, treated wastewater use is of tremendous potential importance for Egypt as shown in Fig. 43.1.

TWW can be used for high production of oil crops (canola, soybean sunflower, or maize) compared to freshwater, while ADW can be used for high production of

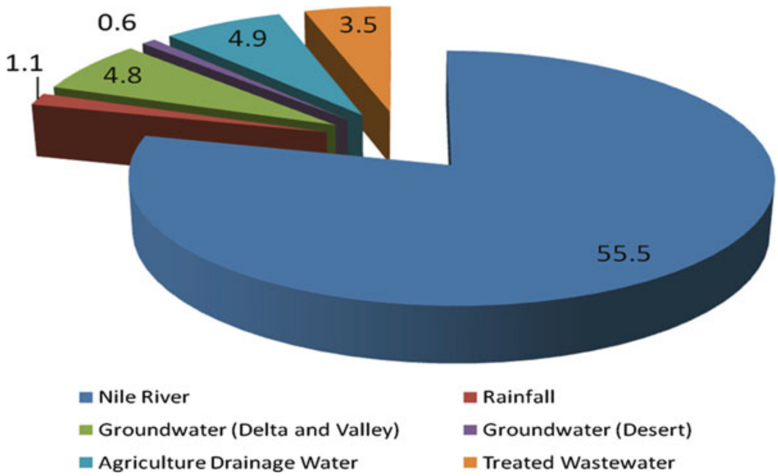

Fig. 43.1 Water resources in Egypt in billion cubic meters

tolerant crops (cotton and sugar beet). Crop quality—using marginal water—increases the concentration of elements (Pb, B, Ni, Co) in all crops; however, these elements were under critical levels (no toxicity hazards). It is better to use alternative irrigation with freshwater under a drip irrigation system to maximize crop production and minimize the adverse effects of such water in field crops quality. Soil pollution and salinity buildup—a drip irrigation system under alternative irrigation by freshwater with TWW or ADW—reduces salinity buildup risks and the levels of elements (Pb, B, Ni, Co) in soil compared to reuse of marginal water. Soil pathogens, using marginal water, slightly contaminated the soil with total fecal coliform (TFC), mites, shigella, and salmonella. Plant anatomy—no great changes in anatomical disturbance—was induced in different structures of plants which were reduced at maturity stage. Based on the primary guidelines for reusing marginal water and from the obtained results, it can be recommended to use marginal water with salinity content between 1.1–3.64 dS m^{-1}, and elemental contents (Pb 3.0–3.51 ppm), (B 0.05–1.67 ppm), (Co 0.04–0.07 ppm), and (Ni 0.08–0.15 ppm) for safe (field, vegetable, and medicinal) crop production. Reuse of biosolids for crop production—sewage sludge produced from treated wastewater—can be safely used by mixing with rice straw (1:1 w/w) for economic crop production and saving mineral fertilizers.

43.2 Available Marginal Water Resources in Egypt

In Egypt, there are three major types of marginal-quality water: (1) wastewater from urban and peri-urban areas, (2) saline and sodic agricultural drainage water, and (3) brackish groundwater. Around cities, farmers use wastewater from residential, commercial, and industrial sources, sometimes diluted but often without treatment. Sometimes farmers in deltaic areas and tail end sections of large-scale irrigation schemes irrigate with a blend of canal water, saline drainage water, and wastewater. Others irrigate with saline or sodic groundwater, either exclusively or in conjunction with higher quality surface water. Many of those farmers cannot control the volume or quality of water they receive:

- Urban wastewater usually refers to domestic effluent, wastewater from commercial establishments and institutions, industrial effluent, and storm water. Many farmers use treated or untreated wastewater for irrigation. In some areas, wastewater is discharged into agricultural drains, and farmers use the mixed water for irrigation.
- Agricultural drainage water includes surface runoff and deep percolation that move through surface ditches or are collected in artificial drainage systems. Drainage water often contains salts, agricultural chemicals and nutrients, and dissolved contents of soil amendments such as gypsum used for the reclamation of sodic soils or to amend water sodicity.
- Saline or sodic surface water and groundwater contain salts that originate when water moves through the soil profile and dissolves within soil layers where groundwater is located. Saline and sodic water may contain metals, metalloids, and pathogens that enter groundwater from land-based activities.

43.2.1 Wastewater

Water reclamation, recycling, and reuse represent significant components of the hydraulic cycle in urban, industrial, and agricultural areas. A conceptual overview of the cycling of water from surface and groundwater resources to water treatment facilities, irrigation, municipal, and industrial applications and to water reclamation and reuse facilities is shown in Fig. 43.2 (Rassoul 2006; Asano and Levine 1996).

Wastewater often contains a variety of pollutants, such as salts, metals, metalloids, pathogens, residual drugs, organic compounds, endocrine disruptor compounds, and active residues of personal care products. Any of these components can harm human health and the environment. Farmers can suffer harmful health effects from contact with wastewater, while consumers are at risk from eating vegetables and cereals irrigated with wastewater. Application of wastewater has to be carefully managed for effective use. In contrast to wastewater, saline and sodic water contains salts that can impair plant growth but rarely contains metals or pathogens. However, it can lead to soil salinization and water logging, which impair productivity of vast agricultural land. Successfully irrigation with saline or sodic water requires careful management to prevent near-term reductions in crop yield and long-term reductions in productivity and soil health.

In general, the demand and supply of wastewater for irrigation are increasing in many areas. Demand is driven by the attractive returns farmers can earn from

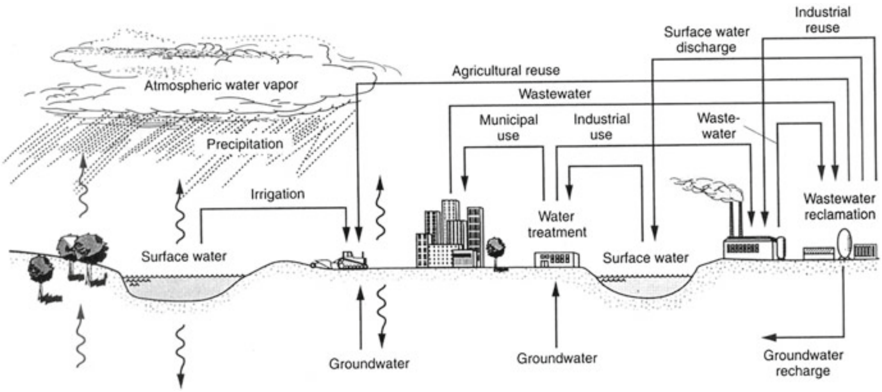

Fig. 43.2 The role of treated wastewater reuse in the water management cycle

producing fruits and vegetables in urban and peri-urban settings. Demand also rises with increasing competition for limited water resources in deltaic areas and large-scale irrigation schemes. The supply of wastewater expands with population growth in large cities, towns, and villages throughout the developing world. In many communities, the volume of wastewater has increased faster than the ability to build and operate treatment facilities, and as a result, more wastewater is released into open ditches or discharged into agricultural drains.

In Egypt, most of rural domestic wastewater is discharged directly into agricultural drains without treatment causing deterioration of drainage water quality. On the other hand, reuse of agricultural drainage water for irrigation has been adopted as a national policy since the present and future demands exceed the available fixed freshwater resources. Being low-quality water, it was important to control the urban wastewater in order to implement such policy on an environmentally sound basis and to ensure the sustainability of drainage water management as a part of the available annual water budget for meeting the water demands. The reuse of polluted drainage water for irrigation may have adverse impacts on the environment. Thus, treatment of wastewater and mitigation measures should be considered before implementing any reuse scheme.

The first use of treated wastewater in Egypt was in 1915 in the eastern desert north east of Cairo. An area of 2,500 acres (1,018 ha) is still under irrigation with wastewater, which receives only primary treatment. With the scarce water resources, it was planned to irrigate 150,000 acres (61,057 ha) with treated wastewater by the year 2000. All urban wastewater is treated at tertiary level and is allowed to reuse for irrigation. Many of the rural areas are still lacking such facilities. The total production of the wastewater in urban and major cities in Egypt was about 3.43 BCM in 1992, 4.93 BCM in 2002, and 6.70 BCM in 2008 (Table 43.1).

Currently, in Egypt, detailed criteria for wastewater reuse in agriculture are under review and preparation. Several pilot programs have been started and under continuous monitoring for some refinements. In an arid country such as Egypt, where water

Table 43.1 Wastewater from urban and major cities of Egypt

Area	Year 1992	Year 2000	Year 2010
	(BCM year^{-1})	(BCM year^{-1})	(BCM year^{-1})
Cairo	1.36	1.70	2.70
Alexandria	0.53	0.65	0.90
Other urban areas	1.54	2.58	3.10
Total	3.43	4.93	6.70

Moustafa et al. (2004)

is scarce in general, wastewater reuse should only be encouraged and promoted whenever, especially in terms of public health, it is safe and economically feasible. Every effort should be made for safe use of reclaimed water, and government should develop more treatment facilities. Treated wastewater could be a valuable resource and may have certain economic advantages, when it meets standard criteria for its safe use. It is usually available close to urban areas where the demand for food and fuel wood crops is high. With proper management and type of crop selection (excluding crops having food part in soil, or those eaten raw), crop yield may be increased by irrigating with raw wastewater. The nutrients inputs from wastewater can reduce the need for commercial fertilizers. However, the uses of raw wastewater and/or treated wastewater are still in its infancy, and have questions on social acceptance in many countries.

Reuse of sewage, after primary treatment in agriculture, has been in practice since 1925 in the eastern desert area of Gabal Al Asfar outside (25 km. NE) Cairo. An area of 20,000 feddans (8,400 ha) of desert land is fully cultivated. Reuse of primary treated sewage water was possible only during the first 20 years of operation at Gabal Al Asfar's treatment plant, and therefore, only raw sewage has been used. The flow reaching the plant had then reached double the capacity of the primary treatment works. The productivity of the reclaimed land had originally increased, but with continued use of untreated sewage in irrigation, the soils start suffering from accumulation and retention of fat end grease at surface. Groundwater in the vicinity of Gabal Al Asfar sewage farm has been found to be extensively and extremely polluted with a broad variety of pathogens. Presently, most of the sewage water is drained to the agricultural drains and actually reused in one way or the other (Eid 2000).

43.2.2 Potential of Treated Sewage Reuse

The experience of large-scale and organized reuse of treated wastewater effluent is still limited in Egypt. However, there are a number of large-scale pilot projects where mostly trees are irrigated beside some field crops, for example, in Abu Rawash, Sadat City, Luxor, and Ismailia. This situation is changing rapidly in the major cities of Egypt due to the installation of modern wastewater treatment plants (WWTPs) that provide secondary treatment, offering an opportunity for water resources planners to fill the gap between supply and demand. In Greater Cairo, there are six wastewater treatment plants, with a total capacity of approximately 27 MCM day^{-1}. All of which will eventually be treated to a secondary standard. With a current combined treatment capacity of this quantity of effluent is potentially sufficient to irrigate about 100,000 feddans (42,000 ha). The sewage system in this area also receives water from industries and commercial activities, and hence, high levels of toxic substance in sewage have been reported. All treatment plants discharge water into agricultural drains, where they act as point sources of pollution. In the desert areas, treated domestic water is used for irrigation.

43.2.3 Concerns Related to Treated Wastewater Reuse

While need for reusing wastewater for irrigation is evident in many developing countries including Egypt, the efforts made so far for its reuse have generally been ad hoc. Countries under water stress release constraints in their wastewater development and reuse projects, as they believe that any additional water available for augmentation is a positive measure. Proper planning of wastewater reuse must support any measure that is being taken because the negative impacts of wastewater have to be considered carefully. This will ensure that cost-effective process can be designed and maintained in agreement with health, environmental, and institutional constraints.

Wastewater is the general term applied to the liquid waste collected in sanitary sewers and sometimes to be treated in a wastewater treatment plant. Municipal wastewater is generally composed of domestic wastewater, industrial wastewater, and infiltration inflow. The volume of wastewater generated in a community on a per capita basis excluding industrial wastewater varies from 50 to 500 L day^{-1}. The wide range of per capita flows reflects differences in water consumption among communities and is largely a function of the price of water, the ability of the community to pay for it, and reliability of the water supply. Normal domestic and municipal wastewater is composed of 99.9% water and 0.1% suspended, colloidal and dissolved solids including organic and inorganic compounds. Untreated industrial effluents may add toxic compounds but often not in detrimental quantities (Pettygrove and Asano 1990).

The physical properties and the chemical and biological constituents of wastewater are important parameters in the design and operation of collection, treatment and disposal facilities, and in the engineering management of environmental quality. The constituents of concern in wastewater treatment and wastewater irrigation are listed in Table 43.2.

The other major concern on the wastewater use is the question of social acceptance in many Islamic countries for agriculture use for food crops.

Table 43.2 Technical and environmental risks of reusing treated wastewater

Constituent	Measures parameters	Reason for concern
Suspended solids and biodegradable organics	Suspended solids including volatile and fixed solids Biochemical oxygen demand (BOD), chemical oxygen demand (COD)	Suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged in the aquatic environment. Excessive amounts of suspended solids cause plugging in irrigation system. It composed principally of proteins, carbohydrates, and fats. If discharged to the environment, their biological decomposition can lead to the depletion of dissolved oxygen in receiving waters and to the development of anaerobic conditions
Pathogens	Indicator organisms, total and fecal coliform bacteria	Communicable diseases can be transmitted by the pathogens in wastewater: bacteria, virus, and parasites
Nutrients stable organics Hydrogen ion activity	Nitrogen, phosphorus, potassium specific compounds (e.g., phenol, pesticides, chlorinated hydrocarbons), pH	Nitrogen, phosphorus, and potassium are essential nutrients for plant growth, and their presence normally enhances the value of the water for irrigation. When discharged to the aquatic environment, they can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land, nitrogen can also lead to the pollution of groundwater. These organics tend to resist conventional methods of wastewater treatment. Some organic compounds are toxic in the environment, and their presence may limit the suitability of the wastewater for irrigation. The pH of wastewater affects metal solubility as well as alkalinity of soils
Heavy metals	Specific elements (Cd, Zn, Ni)	Some heavy metals accumulate in the environment and are toxic to plants and animals. Their presence may limit the suitability of wastewater for irrigation
Dissolved inorganic and residual sodium	Total dissolved solids, electrical conductivity major ions (cations and anions)	Excessive salinity may damage some crops. Specific ions such as chloride, sodium, and boron are toxic to some crops. Residual sodium may pose soil permeability problems
Chlorine	Chlorine	Most chlorine in reclaimed wastewater is in a combined form which does not cause crop damage. Some concerns are expressed as to the toxic effects of chlorinated organic with regard to groundwater

43.2.3.1 Crop Pattern Management

The drainage quality after the operation of the WWTPs should be suitable for categories A and B regarding the degree to which health protection measures are required.

(a) Category A (protection needed only for field workers):

- Crops not for human consumption (cotton).
- Crops normally processed by heating or drying before human consumption.
- Vegetables and fruits grown exclusively for canning or other processing that effectively destroys pathogens.
- Fodder crops sun dried and harvested before consumption by animals.
- Landscape irrigation in fenced areas without public access.

(b) Category B (further measures may be needed):

- Pasture and green fodder crops.
- Crops for human consumption that do not come into direct contact with wastewater.
- Crops for human consumption normally eaten only after cooking.
- Crops for human consumption peeled before eating.
- Crops irrigated using sprinklers.

43.2.3.2 Wastewater Application Methods

Irrigation water (including treated wastewater) can be applied to land using flood, furrows, sprinklers, and localized (trickle, drip, bubbler) irrigation methods. In situations where there is a need to control disease transmission, some of these methods may not be applicable. In view of its low cost, flood irrigation is practiced on leveled land. Protection for field workers, and possibly for crop handlers and consumers, is a further measure that should be considered. The water use efficiency in the sprinkler method is medium, and it does not require land leveling. Some category B crops, especially tree fruits, should not be grown. Minimum distance from houses and roads should be 50–100 m.

43.2.3.3 Human Exposure Control

Four groups of people can be identified at potential risk from the reuse of wastewater in agricultural irrigation. These groups are field workers and their families, crop handlers, consumers, and those living near the affected fields. Agricultural field workers are at high potential risk especially to parasitic infection. Exposure to hookworm infection can be eliminated by the continuous infield use of appropriate footwear. A rigorous health education program and availability of adequate medical facilities are needed. A similar approach may be taken with crop handlers, the risk to them is somewhat less than that to field workers, but it can be reduced by wearing gloves. However, of highly exposed groups, immunization against typhoid and administration of immunoglobulin to protect them against hepatitis may be worth consideration (Shuval et al. 1986).

43.2.4 Drainage Water

The agricultural drainage water in Egypt is considered one of the most important traditional water resources. The idea of reusing agricultural drainage water in irrigation started to take considerable place in the water policies since the 1970s, and then stations for mixing drainage water at the main water ways were established to meet the needed expansions in cultivated areas to overcome the food balance deficit which resulted from the steady increase in population counts. The used agricultural drainage water was estimated to be 4.5 MCM annually in Delta area. Accordingly, the water policy is aiming now to increase the quantities of reused agricultural drainage water in order to reach 8.4 MCM annually in the year 2017.

Reuse of drainage water was practiced since 1970 in the Lower Egypt. With the expansion of drainage reuse activities, in 1975, the government developed a national policy for drainage water reuse in an attempt to raise the Nile water use efficiency and hence to expand the cultivated area. At present, drainage water reuse is widely practiced in Delta region through 23 locations defined as central drainage reuse system. This system provides about 4.0 BCM year^{-1} of drainage water to be mixed with the freshwater of main canals. The government has an ambitious plan to expand drainage water reuse to reach 8.0 BCM year^{-1} leaving a quantity not less than 8.0 BCM year^{-1} to be discharged to the sea, which is thought to be the minimum amount to keep the salt balance for Delta region. As water resources became scarcer in recent years due to the expansion of the cultivated area and then spreading water out of Delta and the expansion of rice cultivation, water deficit at canal tails was recorded. Therefore, farmers opined that the only way to compensate their irrigation is the nearby drains. They started to lift drainage water to their fields violating the irrigation and the drainage laws and regulations, and neglecting the side effects of the polluted drainage water. In this chapter, the highlights on drainage availability, potential of expanding drainage water reuse, and strategic issues in drainage reuse policies and practices are presented.

Three levels of drainage reuse are practiced in Egypt. The first is called “main drainage reuse level” which is implemented through the government programs. The second is called “unofficial drainage reuse level” which is practiced by the individual water users according to the water deficit. The third type of reuse can be defined as “intermediate drainage reuse level,” and it is implemented by the local irrigation directorates in their respective province jurisdiction. These levels of reuse differ from one region to another in terms of reuse pattern, quantity, and quality.

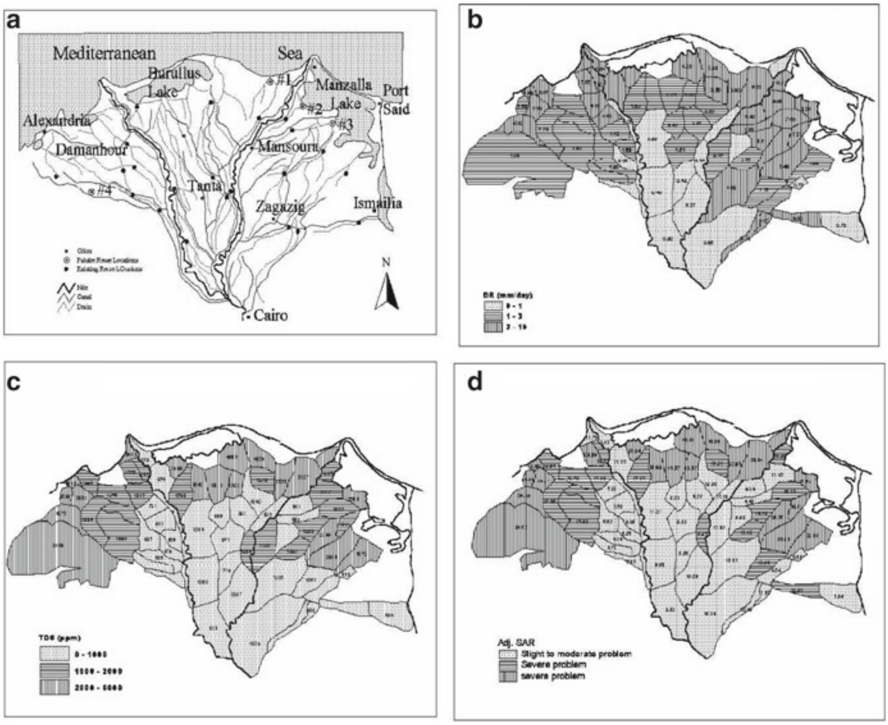

Fig. 43.3 (**a**) Existing and future drainage reuse locations in Delta; (**b**) drainage rate (DR) over Delta region; (**c**) total dissolved solids (TDS) in drainage water over Delta region; (**d**) adjusted SAR in drainage water over Delta region

43.2.4.1 Main Drainage Reuse

Main drainage reuse means mixing drainage water of main drain with main canal. This type of reuse started in early 1970s to raise water use efficiency and then saving water to reclaimed areas. There are 23 main reuse locations in Delta region and nine locations along Bahr Yousef canal in Middle Egypt. Reuse locations in Delta include 21 pump stations and two drains flow by gravity to Rosetta branch. Three other drainage reuse pump stations discharge their drainage water to Damietta branch. Figure 43.3a shows the existing and planned drainage reuse locations in Delta region. Table 43.3 summarizes annual drainage reuse quantity and quality since 1984, while Table 43.4 shows the drainage outflow during the period 1984/1985–1995/1996. Years after 1996 were not considered in the analysis since Aswan releases were higher than normal due to high floods during these years. The drainage reuse increased from 2.8 BCM year^{-1} in the 1980s to about 4.0 BCM year^{-1} in the 1990s, while drainage outflow to the sea looks to be constant and in the order of 12.5 BCM year^{-1}. Increase in drainage water reuse was a result of constructing four new drainage reuse pump stations (Abdel Azim and Allam 2004).

Table 43.3 Drainage water reuse in East, West, Middle, and Nile Deltas

Year	East Delta		West Delta		Middle Delta		Nile Delta	
	Quantity (MCM $year^{-1}$)	Salinity (ppm)	Quantity (MCM $year^{-1}$)	Salinity (ppm)	Quantity (MCM $year^{-1}$)	Salinity (ppm)	Quantity (MCM $year^{-1}$)	Salinity (ppm)
1984/1985	1,301	819	763	826	814	915	2,878	864
1985/1986	1,263	832	748	774	788	966	2,799	858
1986/1987	1,420	858	766	794	807	979	2,993	877
1987/1988	1,381	922	693	902	629	1,216	2,703	986
1988/1989	1,400	979	704	934	555	1,037	2,659	979
1989/1990	1,504	1,005	1,506	1,434	626	954	3,636	1,171
1990/1991	1,585	1,018	1,999	1,088	639	1,005	4,223	1,050
1991/1992	1,445	934	2,058	1,152	617	934	4,120	1,043
1992/1993	1,460	902	1,841	1,082	561	819	3,862	973
1993/1994	1,120	1,011	1,691	1,126	619	717	3,430	1,018
1995/1996	1,390	1,050	1,843	1,190	685	794	3,918	1,069
1996/1997	1,746	1,210	1,815	1,146	706	768	4,267	1,107
1997/1998	1,400	979	704	934	555	1,037	2,659	979
1998/1999	1,504	1,005	1,506	1,434	626	954	3,636	1,171
1999/2000	1,585	1,018	1,999	1,088	639	1,005	4,223	1,050
2000/2001	1,445	934	2,058	1,152	617	934	4,120	1,043

Table 43.4 Annual drainage outflow to sea and lakes

	East Delta		West Delta		Middle Delta		Whole Nile Delta	
Year	Quantity (MCM $year^{-1}$)	Salinity (ppm)	Quantity (MCM $year^{-1}$)	Salinity (ppm)	Quantity (MCM $year^{-1}$)	Salinity (ppm)	Quantity (MCM $year^{-1}$)	Salinity (ppm)
1984/1985	4,391	1,357	4,321	3,686	5,013	2,144	13,725	2,381
1985/1986	4,219	1,498	4,339	3,212	4,883	2,374	13,441	2,375
1986/1987	3,815	1,555	3,955	3,021	4,900	2,381	12,670	2,330
1987/1988	3,514	1,690	4,030	3,616	4,291	2,534	11,835	2,650
1988/1989	3,181	1,766	4,168	3,841	4,142	2,483	11,491	2,778
1989/1990	3,651	1,824	4,573	3,680	4,159	2,554	12,383	2,751
1990/1991	3,726	1,741	5,116	3,994	3,674	2,598	12,516	2,912
1991/1992	3,729	1,536	5,118	3,495	4,092	2,701	12,939	2,675
1992/1993	4,094	1,568	4,312	3,821	3,740	2,618	12,146	2,688
1993/1994	4,219	1,734	4,613	3,520	3,569	2,765	12,401	2,698
1994/1995	4,256	1,907	4,252	3,635	3,966	2,675	12,474	2,739
1995/1996	3,790	2,048	4,469	3,629	4,127	2,662	12,386	2,822
1996/1997	3,181	1,766	4,562	3,542	3,675	2,701	11,418	2,651
1997/1998	3,651	1,824	4,985	3,652	4,102	2,589	12,738	2,624
1998/1999	3,726	1,741	5,120	3,452	3,875	2,651	12,721	2,713
1999/2000	3,729	1,536	5,145	3,658	4,045	2,711	12,919	2,814

43.2.4.2 Unofficial Drainage Reuse

The unofficial drainage reuse is farmer's direct reuse of drainage water without pre-permission from the Ministry of Water Resources and Irrigation (Amer 1992). It exists wherever canal water shortage is recorded, mainly at canal tail. This drainage reuse practice was recorded in the latest decade as the water demand increased versus the constant supply. Two types of unofficial reuse were observed in Egyptian irrigation system: first one is direct pumpage from drain to the field; second is infield reuse through blocking the tile drainage system to hold the water in the field so as not to escape out. This happens in rice fields when water demand could not be met through canal water. Both types of reuse have negative impacts on irrigation system although they solve the problem of deficit irrigation. Issues associated with unofficial reuse are:

- Irrigation with low water quality causes deterioration of soil and decreases crop yield.
- Irrigators are subjected to health hazards as the drainage water sometimes collects the sewage and industrial effluent.
- Installing unofficial reuse pump stations on drain banks causes collapsing these banks.
- Local reuse of tile drainage, through blocking the pipes and collectors in rice fields, causes rise of water table in the neighboring fields cultivating non-rice crops such as maize. This affects the maize crop and damages the tile drainage network.
- Nonregulation of unofficial drainage reuse causes reduction of available drainage water at main reuse pump stations.
- Irrigation with direct drainage water leads to increase the number of irrigation application in order to leach the accumulated salts, and hence increases the cost of agricultural production and pressure on drainage water.

There is no accurate survey available on the unofficial drainage reuses in Egypt. The reason is that it changes from one location to another and from time to time depending on water shortage in the canal and the need for water to meet the crop demand. A figure of about 2.8 BCM year^{-1} was accepted (Abdel Azim 2000).

43.2.4.3 Classification of the Drainage Water in Nile Delta

Drainage water in the Delta region represents a major source of water, particularly for agricultural purposes. If drainage water in Delta is not reused, it will flow out to the sea. Therefore, drainage reuse schemes are vital to save water and maximize the use of limited Nile share for Egypt. However, the drainage reuse is constrained by drainage water quantity and quality. The following parameters were used to classify the drainage water availability and suitability in the Delta region:

- Drainage rate (DR) to measure drainage availability and drainage generation.
- Total dissolved solids (TDS) to measure water salinity and hence its suitability for irrigation directly and after mixing with freshwater.

- Adjusted sodium adsorption ratio (SAR_{adj}) to measure the effect of drainage water on crops and soil properties, particularly infiltration.

Based on these parameters, Delta region is classified into different zones, where each zone is characterized by certain estimates of these selected parameters. Three zones would be considered in Delta. The first zone (south of Delta) has a drainage rate of less than 1.0 mm day^{-1} and a TDS usually less than 1,000 ppm. The second zone has a drainage rate ranging from 1.0 to 3.0 mm day^{-1} and a higher TDS (greater than 1,000 ppm but less than 2,000 ppm). The third zone (north Delta bounded by sea) has the highest drainage rate (greater than 3.0 mm day^{-1}) and TDS (usually greater than 2,000 ppm and reaches sometimes 4,000 ppm). The high rate of drainage in the north of Delta is attributed to the high rate of upward seepage (El-Quosy and El-Guindy 1989). Figures 43.3b–d present the classification of drainage water according to the above-mentioned parameters showing TDS and SAR increase as moving northward. The high values of TDS and SAR in these areas would limit the drainage reuse or increase the need of freshwater for mixing to reduce the salinity of mixed water. Therefore, although the drainage rates are high in northern areas, drainage reuse may not be recommended compared to the southern areas. However, crop diversification plays an important role on the management of drainage water in these areas. This means cultivation of less sensitive crops in the northern area would be preferable in order to increase the potential of drainage reuse.

43.2.4.4 Drainage Reuse Potential

There is obviously a limit on the amount of drain water available for reuse. A central issue in Egypt's water resources management is how much more of the drain water currently being discharged to the Mediterranean Sea can be conserved by increasing reuse. This section addresses this issue by establishing a better understanding of the maximum reuse potential based on drain water salinity and the minimum drainage outflow requirements for the maintenance of freshwater fish production in the northern lakes (APRP 1998).

43.2.4.5 Maximum Drainage Water Reuse Potential

According to the recent drainage monitoring data (DRI 2000), the average salinity of the reused drainage water in the Delta region was 1,076 ppm. For more drainage water reuse, pumping will need to be extended to drains containing higher salinity concentrations. The reuse potential was estimated by 75% of the available drainage water in the Nile Delta that can be reused. Table 43.5 is based on the average of 5 years (1997–2002) drainage water reuse data.

It is not possible to reuse all 75% of the available drainage water where there are three factors limiting the implementation of drainage reuse expansion. Pollution of drains with untreated sewage and industrial effluent limits the reuse potential. Some

Table 43.5 Maximum possible drainage water reuse in Nile Delta (MCM)

Region	Available drainage water	Currently reused	Possible to be reused
Eastern Delta	4,083.65	2,049.89	1,519.02
Middle Delta	5,849.14	2,007.73	2,881.06
Western Delta	3,819.15	1,123.56	2,384.33
Total	13,751.94	5,181.18	6,784.41

of the already existing mixing stations are shut because their delivery outlets are on canals that serve drinking water treatment plants. Another limitation is minimum outflow of the system that has to go to the sea to maintain the salt balance and fragile ecosystem of the Nile Delta.

43.3 Future Perspective

There are many factors that may adversely affect the drainage reuse in the Delta region, including pollution, irrigation improvement program (IIP) implementation, rice area reduction, and the Toshka project (DRI 1998).

By the year 2025, the population of Egypt is expected to be about 90 million; thus, the available freshwater per capita will be about 600 m^3 $year^{-1}$. Under such circumstances, every drop of water must count, and sustainable management of water resources can only be achieved if the water resources and wastewater management policies come together in addressing the water cycle in a holistic manner. In order to do so, certain measures ought to be taken in consideration. The most important of them are stated below:

- Higher quality water should not be used for a purpose that can tolerate lower grade water. In such case, freshwater should be minimally used as a transportation medium for excreta.
- The criteria for wastewater treatment intended for reuse in irrigation differ considerably from treatment systems developed in response of the adverse conditions caused by the discharge of raw effluents to water bodies, while it is intended that pathogens are removed to the maximum extent possible and some of the biodegradable organic matter and most of the nutrients available in the raw wastewater need to be maintained. In this respect, it is advisable to follow the guidelines published in the FAO irrigation and drainage paper No. 47, 1985.
- Water reuse standards must protect both public health and the environment and must be suitable for end reuse objectives and the method of application.
- Wastewater reuse projects should be designed as integral part of the overall wastewater network and water resources plan.
- Innovative low-cost domestic wastewater treatment units should be encouraged.
- Removal of the government subsidies on fertilizers and pesticides and ban on the use of some specific agricultural chemicals (herbicides and pesticides) should be considered.

- Efficient wastewater treatment processes should be used to maximize wastewater reuse opportunities.
- Development of industries not requiring much water is a must.
- The reuse of treated wastewater in industrial applications, such as boiler water and cooling towers, should be encouraged.
- Centralized wastewater management is costly, water intensive, and reduces wastewater reuse opportunities, while decentralized wastewater management reduces water inputs, reduces environmental hazards in case of accidents, and increases reuse opportunities and cost-effectiveness and efficiency. However, it requires institutional reforms for effective operation.
- The EPA suggested guidelines for water reuse should be considered as a minimum required for reclaimed water for different urban reuses.

43.4 Conclusions and Recommendations

Potential of drainage water reuse was found not to exceed 8.6 BCM year^{-1} under a targeted salinity level of 2,000 ppm at which 2.0 BCM year^{-1} of freshwater should be used for mixing to meet leaching requirements. Drainage water outflow at this targeted reuse will be 7.8 BCM year^{-1}, which is thought to be the minimum requirements for maintaining salt intrusion and lake fisheries. It was also found that expansion of drainage water reuse beyond salinity greater than 3,000 ppm is not recommended where effective drainage water reuse will decline as the leaching water requirements increase. This draws the attention about adopting the new policy for drainage water reuse. This policy will mainly focus on intensifying reuse in the southern parts of Delta to capture the good water before getting saltier when it reaches the northern parts. However, pollution in drainage water should be considered. Polluted drainage water, particularly water with high levels of heavy metals, should be avoided so as not to pollute the groundwater aquifer in these areas (where soil permeability is relatively higher). On the other hand, fewer constraints could be applied to drainage reuse in north Delta because groundwater aquifer is not used in this area. Although drainage salinity and SAR are high in northern Delta, salt-tolerant crops could be encouraged to be grown on such type of drainage water and hence saving freshwater for other areas and other users.

The full operation of Toshka project will have its impact on drainage reuse as well as the water allocation to crops. Drainage water salinity will increase by about 13.6%, hence reducing the chance for capturing more drainage water for reuse. In fact, the per feddan consumptive use will be, consequently, reduced by about 16 and 12% in case of non-reduced rice option and reduced rice (at a level of 0.7 million feddans that is 294,000 ha) option, respectively.

Two major factors that would alter the drainage reuse policy and practices in future are the horizontal expansion program (mainly Toshka project) and implementation of Irrigation Improvement Program (IIP). The full operation of Toshka project will have its negative impact on drainage reuse as well as on water allocation to crops. Drainage water salinity will increase by about 13.6%. This salinity increase will reduce the potential expansion of drainage water reuse practice. Implementation of IIP may also affect the drainage reuse practices. As the main objective of IIP is to achieve the equity of freshwater allocation among the water users along the canal, then the unofficial drainage water reuse may disappear. Consequently, drainage water reuse on the intermediate level will also be affected. However, IIP may take a quite long time to be implemented. Then, drainage water reuse programs should consider this in the operation plans. Drainage reuse could be viewed as the solution of next few decades to meet the increasing water demand. Intermediate drainage reuse system should be encouraged and considered a part of water budget for local entities. This means that operation of intermediate reuse should be over the year and not for some seasons or periods to achieve the economic viability. A comprehensive water monitoring program should be implemented over Delta region to include canal/drain system and groundwater aquifer as well. This will measure possible changes in water quality, and hence, modification of reuse policy could be made according to monitoring results.

References

Abdel Azim RA (2000) Agricultural drainage water in Egypt: evaluation of current practices and a vision for future development. PhD thesis, Cairo University

Abdel Azim RA, Allam MN (2004) Agriculture drainage water reuse in Egypt: strategic issues and mitigation measures. Non-conventional water use workshop, Cairo, Egypt, 7–10 Dec 2004, pp 105–117

Abdel Wahaab RA, Omar ME (2011) Wastewater reuse in Egypt: opportunities and challenges, water reuse in the Arab World. Expert Consultation: Wastewater Management in the Arab Region, ICBA, Dubai, 22–24 May 2011

Agricultural Policy Reform Program (APRP) (1998) Water policy reform activity. Report no. 5, Ministry of Public Works and Water Resources and US Agency for International Development, Cairo, Egypt, p 215

Amer H (1992) Reuse of drainage water project: the current situation and its strategic use in future. Paper presented in a workshop under the theme "Water Management in Irrigated Agriculture in Egypt", Cairo, Egypt, pp 102–113

Asano T, Levine AD (1996) Wastewater reclamation, recycling and reuse. Water Sci Technol 33(10–11):1–14

Drainage Research Institute (DRI) (1998) Impact of effluent quality from different wastewater treatment plants on the irrigation and drainage system. National Organization for Potable Water and Sanitary Drainage (NOPWASD), DRI Technical Report (in Arabic), National Water Research Center (NWRC), Egypt, p 85

Drainage Research Institute (DRI) (2000) Reuse monitoring program – Year book 1997/1998: Drainage Water in the Nile Delta. National Water Research Center (NWRC), Egypt, p 114

Eid U (2000) Closing the loop in wastewater management and sanitation. In: Werner C, Schlick J, Witte G, Hildebrandt A (eds) Proceedings of the international symposium on wastewater management, Bonn, GTZ, Boun, Germany, 30–31 Oct 2000, pp 9–12

El-Quosy D, El-Guindy S (1989) Water and salt balance of Nile Delta: a new approach, Cairo, Egypt Report, Land Drainage in Egypt. Drainage Research Institute (DRI), Egypt and the International Institute for Land Reclamation, The Netherlands, National Water Research Center (NWRC), Egypt, p 75

Moustafa H, El Gamal F, Shalby A (2004) Reuse of low quality water in Egypt. In: Proceedings of the non-conventional water use workshop, Cairo, Egypt, 7–10 Dec 2004, pp 93–103

Pettygrove GS, Asano T (1990) Irrigation with reclaimed municipal wastewater: a guidance manual. Lewis Publishers, Chelsea

Rassoul EMA (2006) Prospects of water reuse in Egypt. In: Proceedings of tenth international water technology conference, IWTC10, Alexandria, Egypt, pp 562–567

Shuval HI, Wax Y, Yekutiel P, Fattal B (1986) Transmission of enteric disease associated with wastewater irrigation: a prospective epidemiological study. Am J Public Health 79(7):850–852

United State Department of Agriculture (USDA) (1990) World agricultural trends and indicators, North Africa and Middle East. Economic Research Services. United State Department of Agriculture, Washington, DC, p 180

Chapter 44
Marginal Water in Agriculture and Food Crisis in Sub-Saharan Africa

Olubunmi Lawrence Balogun and Samuel Charles Etop

Abstract Sub-Saharan Africa accounts for 25% of the global figure of chronically undernourished. The region simply does not produce enough food to adequately feed its population, and food production per capita is declining. If nothing changes in sub-Saharan Africa (SSA), the absolute numbers of poor in the region will continue to increase. Unless African governments, supported by the international community, take the lead in confronting the factors that cause nutrient depletion and land degradation, deteriorating agricultural productivity will seriously undermine efforts to bring about food security and to strengthen the foundations of sustainable economic growth in SSA.

This chapter reviews the current state of knowledge related to the condition of SSA land and water resources and highlights the importance of linking degraded land and water management at local and landscape scales in order to address pressing issues of food crisis in the region. There has been less agricultural water development to date in SSA than in any other region. Water management is usually the key to increasing the productivity of arid and semiarid lands. The dominant water resource management challenge over the coming generations is how to secure water to cover food demands of a rapidly expanding population. Promising technologies available to farmers in SSA include conservation tillage, rainwater harvesting, and integrated soil and water conservation. Intensifying agricultural production has in the past often been carried out with negative side effects in terms of land and water degradation. Therefore, legislation that will safeguard a water reserve and efficient water productivity improvements that will make it the region to achieve the

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Millennium Development Goals (MDGs) and thus long-term sustainability in agricultural productivity is recommended.

Keywords Agriculture • Food crisis • Land degradation • Sub-Saharan Africa • Water management

44.1 Introduction

Sub-Saharan Africa (SSA) accounts for 25% of the global figure of chronically undernourished. In 2001, the total population of sub-Saharan Africa (SSA) was estimated at 667 million with 436 million rural, of which 92% (400 million) are engaged in agricultural activities (FAO 2003). The number of undernourished has risen from 170 million in 1990–1992 to 204 million in 2000–2002. According to the Hunger Task Force of the UN Millennium Project (2005) analysis, 80% of the chronically undernourished are rural households. The agricultural sector supports the employment of more than 70% of the economically active population in the region (FAO 2003). In developing countries as a whole, per capita agricultural production increased by about 40% in the last two decades, but in SSA it actually fell by 5%. The DFID's research funding framework in 2004 identified sustainable agriculture, especially in Africa, as one of the crucial research areas for achievement of the Millennium Development Goals (MDGs). The first of the Millennium Development Goals is to eradicate extreme poverty and hunger, with targets of halving, by the year 2015, the proportion of people (whose income is less than US$1 per day).

In sub-Saharan Africa (SSA) as a whole, most people's livelihoods are tied to agriculture. Although two-thirds of SSA's people live on small-scale farms and produce their own food, nearly a third of them are undernourished (FAO 2001). The region simply does not produce enough food to adequately feed its population, and food production per capita is declining over time. Although land is relatively plentiful in comparison to other parts of the world, soil fertility is a key factor in productivity, which is declining, leading to devastating infestations of the parasitic weed. Drought and its partner, crop failure, are regular visitors in SSA. In the past, with all these constraints facing farmers, the one thing they could rely on was family labor. Most economies in SSA are agriculturally based, and about two-thirds of Africans depend on agriculture for their livelihoods.

Agriculture plays a key role in economic development and poverty reduction (Irz and Roe 2000), with every 1% increase in agricultural yields translating into a 0.6–1.2 percentage point decrease in the absolute poor by some estimates (Thirtle et al. 2002). In SSA, agriculture accounts for 35% of gross domestic product (GDP) and employs 70% of the population, and more than 95% of the agricultural area is rainfed (FAOSTAT 2005). There is a correlation between poverty, hunger, and water stress (Falkenmark 1986). The Millennium Project (2005) of UN has identified "hot-spot" countries suffering from the highest prevalence of malnutrition. Total irrigated land in Africa is estimated to be about 12.2 million ha (FAO 1996). This figure includes all land where water is supplied for the purpose of crop production, excluding only areas where water harvesting and spate irrigation are practiced. Irrigated land represents, on average, less than 8% of the arable land, with large differences between countries. Irrigated land percentages are highest in the northern region (99% in Egypt) and lowest in the central region (0.2% in the Democratic Republic of the Congo). The average for SSA is less than 4%. These figures cover a wide range of water management situations, including the productive wetlands of the Gulf of Guinea and the highlands of Central Africa and modern full-control irrigation systems in Zimbabwe. Informal irrigation is estimated to cover between 35 and 50% of the total irrigated land in Africa. Yields of irrigated land are about 2.2 times higher than from rainfed land (FAO 1996).

Unless African governments, supported by the international community, take the lead in confronting the factors that cause nutrient depletion and land degradation, deteriorating agricultural productivity will seriously undermine efforts to bring about food security and to strengthen the foundations of sustainable economic growth in SSA. If nothing changes in SSA, the absolute numbers of poor in the region will continue to increase.

44.2 Problem Statements

Agricultural water management embraces a whole range of wider practices including in situ moisture conservation, water harvesting, rainwater harvesting, supplementary irrigation, irrigation, and various techniques of wetland development such as treadle pumps, drip irrigation systems, and sprinklers systems (IWMI 2006). Improving soil and water conservation is the first action to improve the water supply for agriculture, that is, making a higher percentage of rainwater that falls onto a field available for plants (Rockström 2000). Two hot-spot regions of the world emerge in terms of water needs for food and livelihoods, namely, sub-Saharan Africa (SSA) and Asia. For sub-Saharan Africa, indications suggest a tripling of agricultural water demand by 2025 and an almost fivefold increase by 2050 (Falkenmark and Rockström 2004). Growth of food production in sub-Saharan Africa has during the last decades primarily been achieved through expansion of agricultural land and increase in water use. According to the comprehensive assessment of the freshwater resources of the world (E/CN.17/1997/9), submitted to the Commission on Sustainable Development at its fifth session in 1997, about one-third of the world's population live in countries that are experiencing moderate to high water stress partly resulting from increasing demands from a growing population and human activities. By 2025, it is estimated that as much as two-thirds of the world's population (over five billion people) could be living in countries under water stress conditions. Irrigated agriculture accounts for the largest part of the water withdrawal, globally about 70%. Only a part of this water is consumed, when it returns to the atmosphere as evaporation from reservoirs and evapotranspiration from the "open landscape" or is incorporated in the crop.

Table 44.1 shows projected crop-harvested area and production by region and for sub-Saharan Africa. In SSA, crop area is still expected to increase at 0.6% annually, while in other, for instance, China, it is expected to increase by 0.18%. The projected declining in crop area expansion places the burden to meet future food demand on crop yield growth on the region. However, crop yield growth will vary considerably by commodity and country; in the aggregate and in most countries, it also will continue to slow down. The global yield growth rate for all cereals is expected to decline from 1.96% year^{-1} in 1980–2000 to 1.01% year^{-1} in 2000–2050. By 2050, approximately one-third of crop-harvested area is projected to be under irrigation. In SSA, irrigated harvested area is projected to grow more than twice as fast as rainfed area (79% compared to 34%). However, the proportion of irrigated area to total area in 2050 will be only 1% higher compared to 2000 (4.5 and 3.4%, respectively).

Agricultural productivity depends in turn on the quantity and quality of resources used in agricultural production. Data on resource quality have historically been scarce, but recent improvements have allowed a more complete understanding of how land quality in particular affects productivity and food security. However, growing awareness of the "world water crisis" is leading to increased recognition that water scarcity and food security are interrelated problems. Management of water resources is closely related to the development goals of poverty eradication, socioeconomic progress, and environmental protection. Forecasts by World Water Council in 2000 indicate that three or four billion people will face water scarcity by 2025. Considerable regional variations are evident, and SSA will not be affected as badly as some other regions, but avoidance of water scarcity cannot be at the cost of food security (or vice versa). Lack of access to water is now seen as a key constraint to development. International development initiative has been focused on prospects for future food security with a view to achieving the target to halve the number of undernourished people by 2015.

These are formidable challenges, and if they are to be tackled successfully, then it is important to identify any conflict between them at the outset. On one hand, it is desired to increase water allocations to domestic users and industries, but also it is necessary to make more water available for crop production, and at the same time, we must secure ecosystem health on which human life ultimately depends. It is therefore necessary to ask the following:

1. To what extent does future food security depend on expansion of irrigated agriculture?
2. Is it feasible to ease the water crisis by increasing water productivity in agriculture?
3. Can increased water productivity in agriculture (rainfed and irrigated) enable food security to be assured without increasing water diverted to irrigation?

Table 44.1 Crop-harvested area and production by region and for sub-Saharan Africa

Description	Rainfed agriculture		Irrigated agriculture		Total agriculture		Share of irrigated agriculture in total	
	Area (thousand ha)	Production (thousand Mt)	Area (thousand ha)	Production (thousand Mt)	Area (thousand ha)	Production (thousand Mt)	Area (%)	Production (%)
Regions								
United States	38,471	211,724	69,470	442,531	107,942	654,255	64.4	67.6
Canada	27,267	65,253	717	6,065	27,984	71,318	2.6	8.5
Western Europe	59,557	462,403	10,164	146,814	69,721	609,217	14.6	24.1
Japan and South Korea	1,553	23,080	4,909	71,056	6,462	94,136	76.0	75.5
Australia and New Zealand	21,500	67,641	2,387	27,656	23,886	95,297	10.0	29.0
Eastern Europe	38,269	187,731	6,091	40,638	44,360	228,369	13.7	17.8
Former Soviet Union	86,697	235,550	18,443	75,798	105,139	311,347	17.5	24.3
Middle East	30,553	135,872	21,940	119,626	52,493	255,498	41.8	46.8
Central America	13,030	111,665	8,794	89,698	21,824	201,364	40.3	44.5
South America	80,676	650,313	10,138	184,445	90,814	834,758	11.2	22.1
South Asia	143,427	492,718	120,707	563,161	264,134	1,055,879	45.7	53.3
Southeast Asia	69,413	331,755	27,464	191,890	96,876	523,645	28.3	36.6
China	66,715	617,460	124,731	909,561	191,446	1,527,021	65.2	59.6
North Africa	15,714	51,163	7,492	78,944	23,206	130,107	32.3	60.7
Sub-Saharan Africa	175,375	440,800	6,243	43,398	181,618	484,199	3.4	9.0
Rest of the world	3,813	47,467	1,094	23,931	4,906	71,398	22.3	33.5
Total	872,029	4,132,597	440,782	3,015,211	1,312,811	7,147,808	33.6	42.2
Sub-Saharan African crops								
Rice	6,015	6,117	965	1,606	6,979	7,723	13.8	20.8
Wheat	2,043	3,288	422	1,340	2,465	4,628	17.1	28.9
Cereal grains	65,723	65,912	2,394	3,286	68,117	69,197	3.5	4.7

(continued)

Table 44.1 (continued)

Description	Rainfed agriculture		Irrigated agriculture		Total agriculture		Share of irrigated agriculture in total	
	Area (thousand ha)	Production (thousand Mt)	Area (thousand ha)	Production (thousand Mt)	Area (thousand ha)	Production (thousand Mt)	Area (%)	Production (%)
Vegetables, fruits, nuts	31,570	224,570	1,111	9,846	32,681	234,415	3.4	4.2
Oilseeds	9,969	8,804	551	554	10,520	9,358	5.2	5.9
Sugarcane, sugar beet	822	35,280	309	25,614	1,131	60,894	27.3	42.1
Other agricultural products	59,235	96,830	490	1,153	59,725	97,983	0.8	1.2
Total	175,375	440,800	6,243	43,398	181,618	484,199	3.4	9.0

Source: Calzadilla, et al. (2009)
Mt metric tons

44.3 Objectives

The objective of the study is to determine the effects of marginal water in agriculture and food crisis in SSA and to facilitate policy interventions. This chapter, therefore, briefly reviews the current state of knowledge related to the condition of SSA land water resources and highlights the importance of linking degraded land and water management at local and landscape scales in order to address pressing issues.

44.4 Agricultural Water Management in Sub-Saharan Africa

As long as water demands are low relative to water availability, there is little competition for resources and little recognition of the connection between decisions about land and water. There are not enough new land or water sources that can be diverted for agricultural production without incurring huge environmental and social costs. A different path is needed that recognizes the multifunctional nature of agriculture in relation to food, water, and climate (Varghese 2009). Rainfed agriculture is practiced in the developing world, and 96% of rainfed agricultural land is in SSA. According to FAO paper in 2008, "Climate Change, Water and Food Security," "rain-fed systems will continue to offer the greatest scope of adaptation in terms of area, number of farmers and overall contribution to global food production." Far more vulnerable to climate-related stresses and accounting for more than 80% of agricultural land, rainfed agricultural systems not only require the greatest adaptation but have also been identified as pivotal to addressing the food crisis.

Table 44.1 shows summary of agriculture in SSA. Annual precipitation in SSA is estimated at an average of 815 mm. Given the wide range of climates in the region, there are consistent disparities between countries, subregions, and livelihood zones. Annual internal renewable water resources for SSA amount to more than 3,880 km^3. Madagascar is the richest country in terms of water resources (5,740 $m^3\ ha^{-1}\ year^{-1}$). They account for 49 and 24% of SSA's water resources, respectively. The Sudano–Sahelian subregion is the most deprived with only 186 $m^3\ ha^{-1}\ year^{-1}$, with Mauritania having only 0.4 $km^3\ year^{-1}$ (3.9 $m^3\ ha^{-1}\ year^{-1}$). Considering the availability of resources per capita, at country level, the most disadvantaged countries are Mauritania (130 m^3 inhabitant^{-1} year^{-1} in 2005) and Niger (272 m^3 inhabitant^{-1} year^{-1} in 2005), while Gabon, Congo, and Equatorial Guinea enjoyed almost 120,000, 57,000, and 50,000 m^3 inhabitant^{-1} year^{-1}, respectively, in 2005. There has been a decrease in internal renewable water resources per inhabitant since 1960.

From 1960 to 2005, owing to population growth, the average decreased from more than 16,500 to 5,500 m^3 inhabitant^{-1}, with an average decrease of more than 65%. Some countries have been particularly affected, such as Niger, Côte d'Ivoire, and Uganda, with decreases of about 75%.

In regard to water use, total annual withdrawal of water from rivers, lakes, and aquifers was about 121 $km^3\ year^{-1}$ in 2004, about 170 $m^3\ year^{-1}$ per capita. Agriculture is by far the main water user in comparison with domestic and industrial sectors, accounting for 87% of the total withdrawal, against 10 and 3%, respectively, for the other sectors. The average annual withdrawal from irrigated areas is about 15,000 m^3 per hectare of irrigation. Out of about 105 km^3 $year^{-1}$ from the agriculture sector, 48% is withdrawn in the Sudano–Sahelian subregion, which accounts for only 15% of domestic withdrawals. On the other hand, the southern area accounts for only 15% of agricultural withdrawals but 42% of domestic ones. In the last 20 years, water withdrawal has increased considerably in the entire region as population and irrigated agriculture have expanded. Agricultural withdrawals have risen by more than 90% on average in the entire region, apart from the southern subregion. Table 44.2 gives the basic agriculture and water-related data for the SSA region and for the world.

44.4.1 Problems of Agricultural Water Development in Sub-Saharan Africa

Water management is a key investment for diversification of agricultural income. Each 1% growth in agricultural yields brings about an estimated 0.5–0.7% reduction in number of poor people. Facing the food and poverty crises in developing countries will require a new emphasis on small-scale water management in rainfed agriculture involving the redirection of water policy and large new investments. Rainfed systems dominate world food production, but water investments in rainfed agriculture have been neglected over the past 50 years. Rainfed farming covers most of the world's cropland (80%) and produces most of the world's cereal grains (more than 60%), generating livelihoods in rural areas and producing food for cities. Estimates suggest that about 25% of the increased water requirement needed to attain the 2015 hunger reduction target of the Millennium Development Goal can be contributed from irrigation. The remaining 75% will have to come from water investments in rainfed agriculture.

Rainfed agriculture is practiced in many parts of the developing world and in temperate regions of the global north. Most rainfed agricultural land in the developing world is in sub-Saharan Africa (96% of cultivated land in the region). Upgrading rainfed agriculture promises large social, economic, and environmental paybacks, particularly in poverty reduction and economic development. Investments in rainfed agriculture have large payoffs in yield improvements and poverty alleviation through income generation and environmental sustainability. There has been less agricultural water development to date in SSA than in any other region. At just 4.9% of the total cultivated area of 183 million ha, the area developed is by far the lowest of any region of the world. Three countries (Sudan, South Africa, and Madagascar) account for two-thirds of the irrigable area developed. Expansion of irrigation has been slow.

Over the last 40 years, only 4 million ha of new irrigation have been developed in the region, far and away the smallest expansion of any region. The

Table 44.2 Water and agriculture in sub-Saharan Africa

Variable	Unit	Sub-Saharan Africa	World	Sub-Saharan Africa as % of the world
Total area	1,000 ha	2,428,795	13,442,788	18.1
Estimated cultivated area 2007*	1,000 ha	234,273	1,865,181	12.6
In % of total area	%	10%	14%	
Per habitant	ha	0.34	0.29	
Per economically active person engage in agriculture	ha	1.25	1.15	
Estimated total population 2004**	1,000 inhabitants	689,700	6,389,200	10.8
Population growth rate 2000–2004**	% $year^{-1}$	2%	1%	
Population density	Inhabitants km^{-2}	28.4	47.5	
Rural population as % of total population***	%	62%	51%	
Precipitation	km^3 $year^{-1}$	19,809	110,000	18.0
	mm $year^{-1}$	816	818	
Internal renewable water resources per	km $year^{-1}$	3,880	43,744	9.0
Inhabitant	m^3 $year^{-1}$	5,696	6,847	
Total water withdrawal	km^3 $year^{-1}$	120.9	3,818	3.2
Agricultural	m^3 $year^{-1}$	104.7	2,661	3.9
Water withdrawal	%	86.6%	70%	
Domestic	km^3 $year^{-1}$	12.6	380	3.3
Water withdrawal	%	10.4%	10%	
Industrial	km^3 $year^{-1}$	3.6	777	0.5
Total water withdrawal	%	3.0%	20%	
Internal renewable water resources	%	3.0%	9%	
Per inhabitant	m^3 $year^{-1}$	171	598	
Irrigation	ha	7,076,911	277,285,000	2.6
Cultivated area	%	3.0%	15.0%	

*Adapted from IIASA and FAO (2000)
**Adapted from UNDP (2006)
***FAO (2006) data

Comprehensive Assessment of Water for Agriculture (IWMI 2006) also recognizes the importance of rainfed systems to achieving food security and advocates investing in such systems, in addition to achieving water use efficiency improvements in irrigated agriculture. Intensive irrigation water use, in combination with industrial farming systems, has resulted in widespread soil and water contamination from pesticide and fertilizer runoff, affecting quality and quantity of water available for other uses and resulting in habitat degradation. Even where the potential gains from water investments in rainfed agriculture are the greatest, improving water management alone is not enough to achieve significant and sustainable increases in yield.

At the farming systems level, full response to water investments is achievable only if other production factors, such as soil fertility, crop varieties, and tillage practices, are improved simultaneously. Important yield improvements can be achieved through synergies, particularly when water management is linked to organic fertilization from agroforestry and livestock systems, for example. Attention to land tenure, water ownership, and market access is also needed to ensure the full benefits from water management interventions.

44.4.2 The Importance of Water to Food Security

Globally, irrigated agriculture accounts for almost 70% of total water withdrawn for human use from rivers, lakes, reservoirs, ponds, and aquifers (this does not include water used in rainfed farming systems or water used in food processing). Its share drops to approximately 40% in countries that import food and have a developed and diverse economy but rises to over 95% in many of the countries where agriculture is the prime economic activity. The needs of intensive industrial agriculture have driven a large number of massive water infrastructures and water diversions, damming rivers for irrigation, for hydroelectric power, and in some cases, for flood control (Varghese 2009).

Today, only 19% of the world's croplands are irrigated, but those lands yield some 36% of the global harvest. Irrigation makes the greatest contribution to global food security in Asia. Irrigated lands account for as much as 80% of food production in Pakistan, some 70% in China and over 50% in India and Indonesia.

As the world population increases and the climate changes, the pressure on the world's water will intensify. Irrigation increases crop yields two to three times than in dryland farming, promotes stabilization and reliability of crop production, and allows for crop diversification in farm production including the introduction of new crops that are not generally viable under dryland farming. Irrigated agriculture has also been critically important for poverty reduction in many countries. In Asia, the poverty head count is typically far lower in irrigated areas – in Vietnam, 18% against over 60% in rainfed areas. Without irrigation, the increases in yields and output that have fed the world's growing population and stabilized food production would not have been possible.

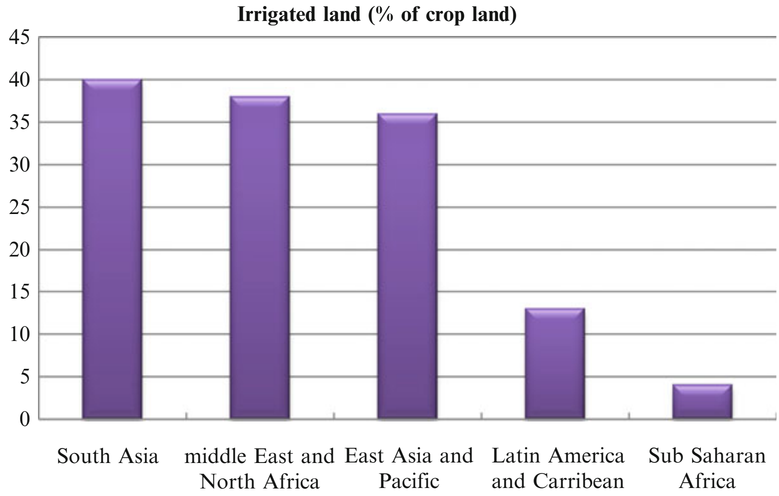

Fig. 44.1 Irrigated land (% cropland) in various regions

Irrigated land made up about 21% of total crop area in developing countries between 1997 and 1999 (Fig. 44.1) but produced 40% of total production and as much as 59% of production of staple cereals (FAO 2003). The distribution of irrigated land is strongly skewed toward a few countries and shows wide regional variations. Of 5% of arable land in SSA, only 3% is irrigated.

However, the history of irrigation in most countries within SSA in the last 30 years has not been good, and most existing schemes have considerable underutilized potential.

Until recently, investments in agricultural water in the SSA region have been declining. Levels and trends of donor financing are conventionally taken as a proxy for investment levels. Over the period 1996–2005, World Bank lending to SSA for irrigation and drainage was just 6% of the resources directed to irrigation and drainage in Asia. Investment in agricultural water has received only a small proportion of that for the water sector as a whole.

44.4.3 Agricultural Water and Land Degradation

The dominant water resource management challenge over the coming generations is how to secure water to cover food demands of a rapidly expanding world population. This applies especially to developing countries where 95% of the world's population growth occurs and most particularly to SSA, hosting the largest proportion of water scarcity-prone areas as well as the highest levels of malnutrition (Rockström et al. 2003). Effects including salinization, erosion, nutrient depletion, carbon loss, and loss of water holding and buffering capacity have resulted in reduced productive potential and abandonment of lands (Wood et al. 2000). Degrading and abandoning land is strip mining our agricultural land resources (Penning de Vries 2001). The preconditions to sustainable livelihood improvements are dynamic. The world is continuously experiencing social–ecological changes (Van Der Leeuw 2000; McIntosh et al. 2000) that can alter the capacity of ecosystems to generate goods (including food) and services on which society depends (Daily 1997). Land and water degradation occur in parallel and are interlinked. Mismanagement of land degrades water quality and reduces water productivity (Molden et al. 2003; Zwart and Bastiaanssen 2004). At the extreme, complete crop failure in rainfed systems reduces water use efficiency to zero. While this is often due to temporary or seasonal drought, it is also caused by soil nutrient and carbon depletion that reduce productivity and increase drought sensitivity. More commonly chemical and biological degradation of land results in incremental reductions in water productivity. Examples from northeast Thailand demonstrate that on tropical sandy soils, chemical and physical degradation strongly limits water productivity in both rainfed and irrigated systems (Noble et al. 2004). Water productivity can be increased 250% and over 500% in irrigated and rainfed systems, respectively, when soil amendments that alleviate chemical degradation are applied. Even in the relatively dry Sahel region, it is often the supply of nutrients not water as commonly assumed that limits farm productivity (Penning de Vries and Djiteye 1982; Breman 1998).

Mismanagement of water similarly contributes to degradation of land, such as increasing erosion, salinization, and waterlogging. Salinization of soil and water affects productive potentials, reduces water use efficiency, and results in loss of high-quality water to saline sinks and abandonment of previously arable lands. Estimates indicate that worldwide 20% of irrigated land suffers from salinization and waterlogging (Wood et al. 2000). Due to overuse and mismanagement of irrigation waters over the last 50 years, high levels of salinity and rising water tables affect significant areas of irrigated land with productivity losses exceeding 30% (US$1,750 million annually) (WEMP 2003). Currently, 47.5% of the irrigated land in Central Asia is affected by salinization, ranging from 95.9% in Turkmenistan to 11.5% in Kyrgyzstan. An area of 289,000 ha is affected by medium to high salinity levels, and approximately 405,000 ha are classified as sodic. It has been estimated that with improved on-farm water management system, between 20 and 25% of the annual available surface water in the region used for leaching could be delivered to the Aral Sea as increased environmental flow, and loss of productive land could be slowed (WEMP 2003).

44.4.4 Water Scarcity and Sustainable Agricultural Development

The dominant water resource management challenge over the coming generations is how to secure water to cover food demands of a rapidly expanding world population. This applies especially to developing countries where 95% of the world's population growth occurs and most particularly to SSA, hosting the largest proportion of water scarcity-prone areas as well as the highest levels of malnutrition (Rockström et al. 2003). Furthermore, it is becoming increasingly clear that diverting more water for agriculture may have serious implications for other water users and water-using activities and systems.

44.4.5 Promising Technologies Available to Farmers in Sub-Saharan Africa

The FAO recognizes "the vulnerability and food insecurity in poor countries that depend on rainfed production" and calls for specific efforts in these regions, such as adaptation techniques and capacity building. The Comprehensive Assessment of Water for Agriculture (IWMI 2006) also recognizes the importance of rainfed systems to achieving food security and advocates investing in such systems, in addition to achieving water use efficiency improvements in irrigated agriculture. There are a myriad of rainfed crops that are locally specific and that sustain communities living in marginal areas. In SSA, the current level of dependency on irrigated land is very low, and rainfed agriculture plays the central role in sustaining rural livelihoods and meeting food requirements. The challenge in this case is how to improve crop production per drop of rain. Rainfall is generally erratic, with intensive storms and intermittent dry spells even where the seasonal total is reasonable. Improving crop production therefore depends in part upon overcoming soil moisture problems, which can be categorized as those related to water entry and retention and those related to subsequent use by plants. The areas to address are the following.

44.4.5.1 Conservation Tillage

The effects of land mismanagement on crop growth are severe in semiarid and dry subhumid tropical landscapes. The resulting low yield levels are due in part to land degradation-induced low infiltration rates of surface soils. In combination with erratic, high-intensity rainfall events, this leads to excessive surface runoff, soil erosion, and deficient water for crop growth. A major cause of excessive land degradation in hot tropical regions with high-intensity rainfall events is conventional soil preparation by hoe or plow, which together with the removal or burning of crop residues leaves the soil exposed to rain, wind and sun. Farming practices or technology that will prevent this type of soil exposure and guarantee continuous covering of the agricultural land through appropriate planting of cover crops is required.

44.4.5.2 Rainwater Harvesting

Nonetheless, improved tillage practices are of little or no help to the farmer during dry spells and droughts. The challenge lies in the dry spells, when crops suffer from short periods of water stress (often less than 3 weeks long). An interesting option for such dry spells lies in the combination of soil and water conservation structures, conservation tillage, and optimal soil fertility management. With appropriate water-harvesting structures and supplementary irrigation, the crop can then survive on available water in the soil provided that soil fertility levels are adequate.

44.4.5.3 Integrated Soil and Water Conservation

Sustainable land management is a key to the sustainable management and conservation of water resources. Soil conservation has a fairly long tradition but has often been biased toward physical structures, such as bunds and terraces, with the prime aim of stopping further soil erosion. Currently, it is widely held that conservation must include both soil and water resources, that is, integrated soil and water conservation. Risk management is crucial in rainfed agriculture. The higher the risk for crop failure due to droughts and dry spells, the lower the likelihood that farmers will invest in other inputs, such as fertilizers, improved varieties, and pest management. Infield soil and water conservation contributes relatively little to reducing risks in rainfed agriculture. In order to substantially reduce risk of crop failure, supplementary irrigation needs to be combined with water harvesting. Supplementary irrigation is defined as the application of a limited amount of water to a crop when rainfall fails to provide sufficient water for plant growth in order to increase and stabilize yields. Technologies that reduce risk generally cost more and are more difficult to construct and manage.

44.5 Future Challenges

The challenge for the future is to raise yield levels for food crops, produced under both rainfed and irrigated conditions, to levels much closer to those attained as best practices in agriculturally developed countries. More widespread use of existing technologies for infield soil and water management can make substantial differences in yield levels, provided that they are combined with conservation tillage and appropriate levels of all other inputs, such as fertilizers, pest control measures, and good quality seed.

Food production needs to be increased substantially in both irrigated and rainfed agriculture, and the basic information to make it possible to be available. What is needed is to apply information about best practices as part of an integrated water resource management approach, which considers all uses of water and makes that information available to all stakeholders. Four areas identified are the following:

1. Provide policy support for governments in the priority setting of investments in agriculture, such that initiatives likely to lead to higher yields per unit of water or unit of land are being funded.
2. Collect data and information on best practices in water harvesting, supplementary irrigation, simple and cheap drip irrigation systems, infield soil and water conservation, and institutional arrangements for privatized irrigation systems, and disseminate that information as synthesized knowledge to water users.
3. Assess the performance, including cost–benefit analyses, of all measures that are likely to raise yields in farmers' fields. This should be done worldwide according to a common format to facilitate comparison among various measures and locations in order to identify the necessary conditions for successful introduction of the different measures.
4. Stimulate research in the following areas:
   (a) Integrated water resource management, with special attention to the management of groundwater and the effect on downstream water users of hydrological changes introduced elsewhere in the watershed.
   (b) The development of crops and crop species that grow well under conditions of limited water supply or saline conditions, by conventional plant breeding methods and through modern biotechnology.

44.6 Conclusions and Policy Recommendation

The challenge of producing food for a rapidly increasing population in semiarid agroecosystems in SSA is daunting. Future food security can be achieved only by delivering substantial increases in agricultural production, but this has important implications for water availability. Crop efficiency in converting water into biomass is essentially the same whether the crop is rainfed or irrigated. Some technical improvements may make it possible to increase this conversion rate, but it is inevitable that increased food production means increased water use by crop plants.

Every increase in food production upstream in a watershed will impact on water user and using systems downstream. Intensifying agriculture has in the past often been carried out with negative side effects in terms of land and water degradation. Water legislation is increasingly incorporating the requirement to safeguard a water reserve to sustain in stream ecology. Reversing global food and water insecurities is the preeminent social and environmental challenge of our time. Solutions to the water crisis and food security need to be considered in terms of fairness and equity, rights, responsibilities, and stewardship. Governments in SSA must act to:

1. Adopt a rights-based approach in national and regional water and agricultural policies and investment decisions. This would include:
   (a) Implementation of the right to food and the right to water. These two rights establish legally protected rights to water for poor people and all residents in a community to meet their basic needs, providing legally recognized access to water for practicing subsistence livelihood activities including food production.
   (b) Strengthened relationships with the UN special agencies and country missions to promote a rights-based approach.
2. Harmonize policy approaches to water, agriculture, and climate. This would include making these linkages at multiple fora such as the World Water Forum Ministerial, in meetings to develop the Global Partnership on Food and Agriculture, in the UN Task Force on the Food Crisis, and at the UN Commission of Sustainable Development and ensuring that water availability is prioritized for ecosystem needs and for basic needs of people.

Some examples include support for

(a) Locally managed soil moisture in rainfed areas.
(b) Rainwater-harvesting structures.
(c) Small-scale community-based irrigation.
(d) Improved irrigation systems.
(e) Available water for peri-urban producers and livestock production.

This chapter has outlined some of the challenges for the use of marginal water in agriculture and landscaping in (farmers in water scarcity-prone savanna agroecosystems) SSA. It argues that there are large opportunities to improve rural livelihoods through the adaptive adoption of smallholder system innovations in integrated land and water management. The Millennium Development Goals (MDGs) on poverty reduction, food security, and environmental security are key indicators of sustainability. It also indicates that sustainable water management and water productivity improvements constitute a necessary development investment to attain the MDGs and thus long-term sustainability.

References

Breman H (1998) Soil fertility improvement in Africa: a tool for or a by-product of sustainable production. Afr Fertil Mark 11(5):2–10

Calzadilla A, Zhu T, Rehdanz K, Tol RSJ, Ringler C (2009) Economy wide impacts of climate change on agriculture in sub-Saharan Africa, IFPRI discussion paper 00873. Environment and Production Technology Division International Food Policy Research Institute, July 2009

Daily G (ed) (1997) Nature's services: human dependence on natural ecosystems. Island Press, Washington, DC

Falkenmark M (1986) Fresh water-time for a modified approach. Ambio 15(4):192–200

Falkenmark M, Rockström J (2004) Balancing water for man and nature: the new approach to ecohydrology. EarthScan Publications, London

FAO (1996) Technical background documents 6–11: World Food Summit. FAO, Rome

FAO (2001) Crops and drops: making the best use of water for agriculture. FAO, Rome

FAO (2003) World agriculture: towards 2015/2030. FAO, Rome

FAOSTAT (2005) Database. Food and agriculture organization, Rome. http://faostat.fao.org/. Accessed Nov 2005

IIASA (International Institute for Applied Systems Analysis) and FAO (Food and Agriculture Organization) (2000) Global agro-ecological zones (global-AEZ). CD-ROM. Rome and Laxenburg, Austria. www.iiasa.ac.at/Research/LUC/GAEZ. Accessed Feb 2006

International Water Management Institute (IWMI) (2006) Resources on micro agricultural water management in Southern Africa. A CD based report, South Africa, IWMI, May 2006

Irz X, Roe T (2000) Can the world feed itself? Some insights from growth theory. Agrekon 39(3):513–528

McIntosh RJ, Tainter JA, McIntosh SK (2000) The way the wind blows: climate, history, and human action. Columbia University Press, New York

Millennium Project (2005) Investing in development: a practical plan to the millennium development goals, New York. www.unmillenniumproject.org. Accessed May 2005

Molden D, Murray-Rust H, Sakthivadivel R, Makin I (2003) A water-productivity framework for understanding and action. In: Kijne JW, Barker R, Molden D (eds) Water productivity in agriculture: limits and opportunities for improvement. CABI Publishing, Wallingford, pp 1–18

Noble AD, Ruaysoongnern S, Penning de Vries FWT, Hartmann C (2004) Large scale fluxes of plant nutrient in food cause environmental problems at the sources and at the sinks. In: Reversing land and water degradation: trends and ‘bright spot’ opportunities. Comprehensive assessment of water management for agriculture. CABI Publishing, Wallingford

Penning de Vries FWT (2001) Food security? We are losing ground fast. In: Noesberger J, Geiger HH, Struik PC (eds) Crop science: progress and prospects. CABI Publishing, Wallingford, pp 1–14

Penning de Vries FW, Djiteye MA (1982) La productivité des pasturages sahéliens: une étude des sols, des végétations et de l’exploitation de cette resource naturelle. Agricultural research report. Centre for Agricultural Publishing and Documentation (PUDOC) 918, p 525 Wageningen, The Netherlands

Rockström J (2000) Water resources management in smallholder farms in Eastern and Southern Africa: an overview. Phys Chem Earth 25(3):278–288

Rockström J, Barron J, Fox P (2003) Water productivity in rainfed agriculture: challenges and opportunities for smallholder farmers in drought-prone tropical agro-ecosystems. In: Kijne WJ, Barker R, Molden D (eds) Water Productivity in agriculture: limits and opportunities for improvement, Comprehensive assessment of water management in agriculture, No. 1. CABI Publishing, Wallingford, pp 145–163

Thirtle C, Lin Beyers L, Mckenzie-Hill V, Irz X, Wiggins S, Piesse J (2002) Impacts of changes in agricultural productivity on the incidence of poverty in developing countries. DFID report 7946. Department for UN, London

Van Der Leeuw SE (2000) Land degradation as a socio natural process. In: McIntosh RJ, Tainter JA, Mcintosh SK (eds) The way the wind blows: climate, history and human action. Columbia University Press, New York

Varghese S (2009) Integrated solutions to the water, agriculture and climate crises. The Institute for Agriculture and Trade Policy (IATP), Minneapolis

Water and Environment Management Project (WEMP) (2003) National and regional water and salt management plans. Regional report no. 3. GEF Agency of the IFAS Aral Sea Basin Program. Royal Haskoning, London

Wood S, Sebastian K, Scherr SJ (2000) Soil resource condition. In: Pilot analysis of global ecosystems (PAGE). IFPRI and World Resources Institute. Washington, DC, pp 45–54. World Resource Institute Publication, Baltimore, USA. Publication Director (Carol Rosen)

World Water Council (2000) World water vision: making water everybody’s business. EarthScan Publications, London

Zwart SJ, Bastiaanssen GM (2004) Review of measured crop water productivity values for irrigated Wheat, Rice, Cotton and Maize. Agric Water Manage 69(2):115–133

Part VIII
Water Quality, Soil and Water Management in Irrigated Agriculture

Chapter 45
Water Quality of Medjerda Wadi Used for Irrigation Purpose (Eastern Algeria)

Imen Guasmi, Fatiha Hadji, and Larbi Djabri

Abstract Waters of Medjerda wadi catchment (eastern Algeria) are one of the most important resources in Algeria. In this basin, waters are used for irrigation purposes. However, they collect domestic and industrial sewages and irrigation effluents exposing surface and groundwater to significant pollution. In this study water quality monitoring in Medjerda wadi has been completed. Longitudinal profiles of water quality were completed using the data from 14 sites. All sewages from agricultural and industrial discharges were included. The water samples were analysed for nutrients (NO_3^-, NO_2^-, NH_4^+ and PO_4^{3-}), biochemical oxygen demand (BOD_5) after 5 days and dissolved oxygen (DO). Chemical composition showed the waters in the Medjerda wadi are extremely polluted, especially, at the confluence with domestic releases of Souk Ahras city and downstream of industrial discharges and therefore present a serious risk for irrigation. This pollution is characterized by an increase in indicators of pollution (BOD_5, NO_3^-, NO_2^-, NH_4^+ and PO_4^{-3}), a very low rate of dissolved oxygen and high concentrations of heavy metals particularly iron.

Keywords Algeria • Irrigation • Medjerda wadi • Pollution • Water quality

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45.1 Introduction

Knowledge about the water quality of the rivers can be gained through quality monitoring of their network flow and available information. The ground and surface waters are collected to meet the demand of different agriculture uses (mainly for irrigation which represents nearly 30% of the total volume) and industry (with 4%), and 66% are reserved for human consumption.

In areas of semiarid climate, like Souk Ahras, the irrigation is needed as an unavoidable choice for improving agricultural productivity and well responding to the diverse needs of the population (Guasmi 2005, 2009).

The area for the present study is oriented for agriculture and has more than 270 ha of irrigated lands distributed mainly over the entire Medjerda valley (Guasmi 2009). However, the irrigation with waters of Medjerda wadi often leads to accumulation of salts in the soil causing soil salinization. High sodicity often changes soil permeability and alters aeration and subsequently affects plant growth and development. Moreover, wastewater discharges to these waters can disrupt the development of plant through the absorption of salts that affects the osmotic process or chemically by metabolic reactions such as those caused by toxic components. Such pollution has several origins, such as urban waste, industrial discharges and intensive use of fertilizers.

Given the magnitude of this problem, which continues to take over the farmlands of the region, present work has been devoted to assessing the quality of waters of wadi Medjerda and the possibility of their use to irrigate agricultural areas of the Medjerda valley.

45.2 Site Description

The study area is located in the north-eastern part of Algeria (Fig. 45.1). Souk Ahras region which is a part of the sub-watershed Medjerda is limited to north by El Tarf Wilaya, south by Tebessa, to the east by the Tunisian-Algerian border and then north-west by Guelma.

This is one of the largest wadis in north-eastern of Algeria. It starts in Khemissa city and crosses the Algeria territory in its upstream to flow into the Tunis Gulf. It covers an area of 1,411 km^2 and feeds Ain Dalia dam.

The Souk Ahras area which is a part of the geological Algerian Tell has been the subject of a detailed geological study by David (1956). Its structure is mainly due to tectonic movements of the Cenozoic Era (mainly Miocene). These geological systems are formed by Mesozoic, Cenozoic and Quaternary formations, generally represented by clay, marl, silt, sandstone and gravel (David 1956; Vila 1980). This region with its semiarid climate receives high annual average rainfall of 645 mm (Guasmi 2005, 2009). It is subject to an annual average temperature of about 16°C and an average potential evapotranspiration of 1,100 mm.

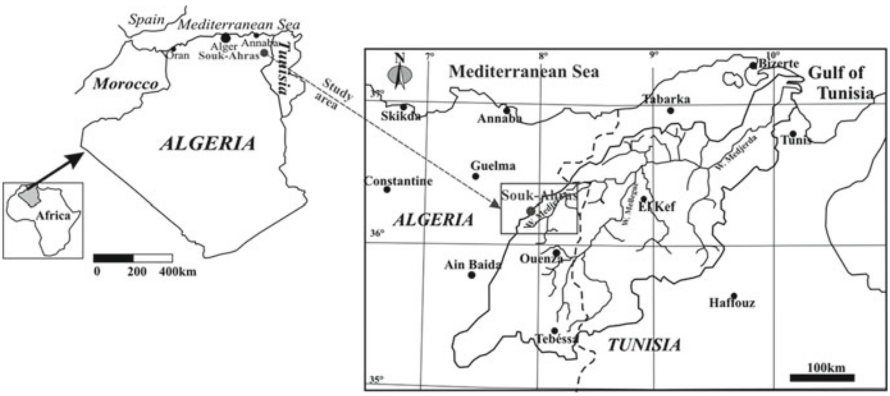

Fig. 45.1 Location of the study area

The agricultural region of the Medjerda valley is used for growing several varieties of crops requiring large quantities of water for irrigation purposes. These waters may affect physico-chemical properties of soils; the most important from plant growth point of view is the soil salinity. Agriculture is characterized by a wide variety of cereal crops, vegetables and tree (fig, apricot, apple, nectarine and walnut), watered with an irrigation system designed from the thresholds at two regions (Ouillen and Ouled Moumen) and also cattle pasture.

Given the high rate of urban, industrial and agriculture which are being developed in the study area, several forms of contaminants intakes have been detected in various forms (Guasmi et al. 2009).

45.3 Materials and Methods

To assess the water quality for irrigation, two physico-chemical campaigns of analysis were conducted during two periods along the mainstream and tributary confluences. They concerned a low-water period in August 2006 and a high water in April 2006. The samples were collected from 14 sites, and these sites were selected taking into consideration the various points of discharge of wastewater (Fig. 45.2). The water samples were analysed at the Central Laboratory of the ADE in Batna city for the following parameters:

- Physical parameters (pH, temperature, dissolved oxygen, electrical conductivity).
- Cations (Ca^{+2}, Mg^{+2}, K^{+}, Na^{+}, NH_4^{+}).
- Anions (SO_4^{-2}, Cl^{-}, HCO_3^{-}, CO_3^{2-}).
- Indicators of pollution (BOD_5, NO_3^{-}, NO_2^{-}, PO_4^{3-}).

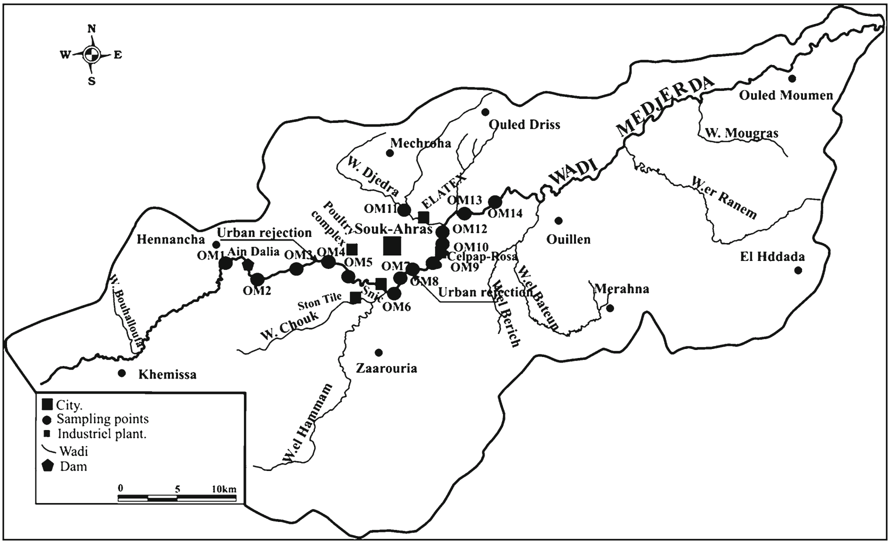

Fig. 45.2 Location of sampling points

The interpretation of results will allow the preparation of water suitability maps for irrigation in the region. Water temperature, electrical conductivity (EC) and dissolved oxygen (DO) were measured in situ using a multivariable WTW (MultiLine P3 PH/LF-SET) and oximeter (WTW, probe CellOx 325). The nutrients (nitrates, nitrite, ammonia and phosphates) were determined by spectrophotometry using a photoLab spectra, WTW. BOD_5 was measured by incubation of the water sample in the presence of a solution of phosphate and allylthiourea in darkness at 20°C.

Chloride contents were determined by the Mohr method under neutral conditions using a standard solution of silver nitrate in the presence of potassium chromate (Rodier 1982), sodium by the colorimetric method, sulphates by complexometry and Ca^{+2}, Mg^{+2} and K^{+} by atomic absorption spectrophotometer. Different parameters and methods were used to evaluate water quality of river Medjerda such as sodium adsorption ratio (SAR), % Na, residual sodium carbonates (RSC).

To understand the evidence of evolution of the global organic pollution of the waters, the organic pollution index (OPI) (Leclercq and Maquet 1987; Fawzi et al. 2001; Duong 2006) was calculated.

The OPI was developed by spreading the values of pollutants (BOD_5, ammonium, nitrites and phosphates) into five classes (Table 45.1). Following these analyses, we determined the class of analysed pollutants, which were then used to calculate the average of the number of classes (=OPI) of four properties according to the grid evaluation (Table 45.2).

Table 45.1 Class limits of pollutants

Classes	BOD_5 (O_2 mg L^{-1})	Ammonium (N mg L^{-1})	Nitrites (N µg L^{-1})	Phosphates (P µg L^{-1})
5	<2	<0.1	≤5	≤15
4	2–5	0.1–0.9	6–10	16–75
3	5.1–10	1.0–2.4	11–50	76–250
2	10.1–15	2.5–6.0	51–150	251–900
1	>15	>6	>150	>900

Leclercq (2001)

Table 45.2 Grid evaluation of organic pollution types

Limits of classes	Organic pollution level
5.0–4.6	None
4.5–4.0	Weak
3.9–3.0	Moderate
2.9–2.0	Strong
1.9–1.0	Very strong

Leclercq (2001)

45.4 Results and Discussion

Table 45.3 shows the minimum, maximum, mean and standard deviation values of the various parameters.

45.4.1 Nitrates

Nitrates are present in highly soluble forms. Their presence is associated with intensive use of chemical fertilizers (Lhadi et al. 1996; Fryar et al. 2000). In this form, nitrogen is a nutrient salt used by most plants.

Sensitive crops may be affected by nitrogen concentrations above 5 mg L^{-1}. Most other crops are relatively unaffected until nitrogen exceeds 30 mg L^{-1} (Ayers and Westcot 1985).

To evaluate the toxicity of waters of Medjerda wadi, we used the following classification (Isaac et al. 2009):

$$NO_3^- < 5\text{mg } L^{-1} : \text{No toxicity}$$
$$5 < NO_3^- < 30\text{mg } L^{-1} : \text{Moderate toxicity}$$
$$NO_3^- > 30\text{mg } L^{-1} : \text{Severe toxicity}$$

During high-water period (Fig. 45.3), concentration of nitrate of the Medjerda wadi ranged from 0 to 4 mg L^{-1} before OM_{10} sampling point (rejection of the paper

Table 45.3 Minimum, maximum, means and standard deviations of calculated parameters

		EC (µS cm^{-1})	NO_3^- (mg L^{-1})	Cl^{-1} (mg L^{-1})	OPI	[1]RSC	[2]SAR	%Na	Fe (mg L^{-1})	Mn (mg L^{-1})
April	Min	628	0	1.2	3.5	–40	3.71	20.47	0.16	0.3
	Max	1,596	27	12.98	4.75	0	17.09	47.88	0.42	0.6
	Mean	1,294.9	5.1	5.03	4.18	–9.29	11.01	36.36	0.26	0.39
	SD	283.7	8.81	3.37	0.37	11.24	4.61	11.02	0.08	0.11
August	Min	1,023	4	2.14	3.25	–23	9.57	35.15	0	0.0001
	Max	3,230	30	14.96	4.75	8	47.61	87.89	2.6	0.51
	Mean	2,174.6	17.14	6.53	3.98	–4.29	22.69	59.15	0.41	0.13
	SD	737.6	8.22	4.31	0.49	10.48	10.49	14.5	0.73	0.16

[1]RSC in meq L^{-1}; [2]SAR in (mmoles L^{-1})$^{0.5}$

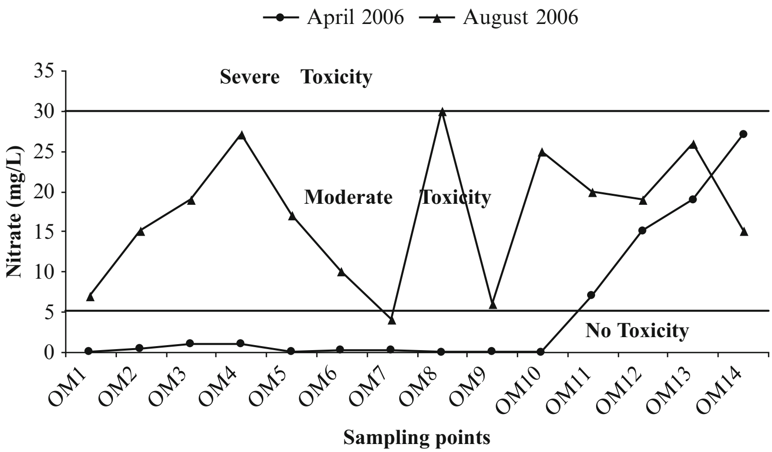

Fig. 45.3 Spatial evolutions of nitrates

mill and some spraying of agricultural land) and 7 to 27 mg L^{-1} between OM_{11} and OM_{14}, revealing moderate toxicity. For the high-water period, values varied between 4 and 30 mg L^{-1} showing moderate toxicity except for OM_7 sampling site.

45.4.2 Organic Pollution Index

Figure 45.4a clearly shows that pollution varies depending on the localities from moderate to strong. High values are localized at the waste discharges of the poultry complex and paint and paper plants at OM_5, OM_{10} and OM_6 sampling sites. For the other stations, it is due to the transfer of pollutants through the wadi by dilution and contribution of agricultural activities (use of fertilizers and pesticides) that end up in the wadi following spraying and leaching of agricultural land (Guasmi 2009).

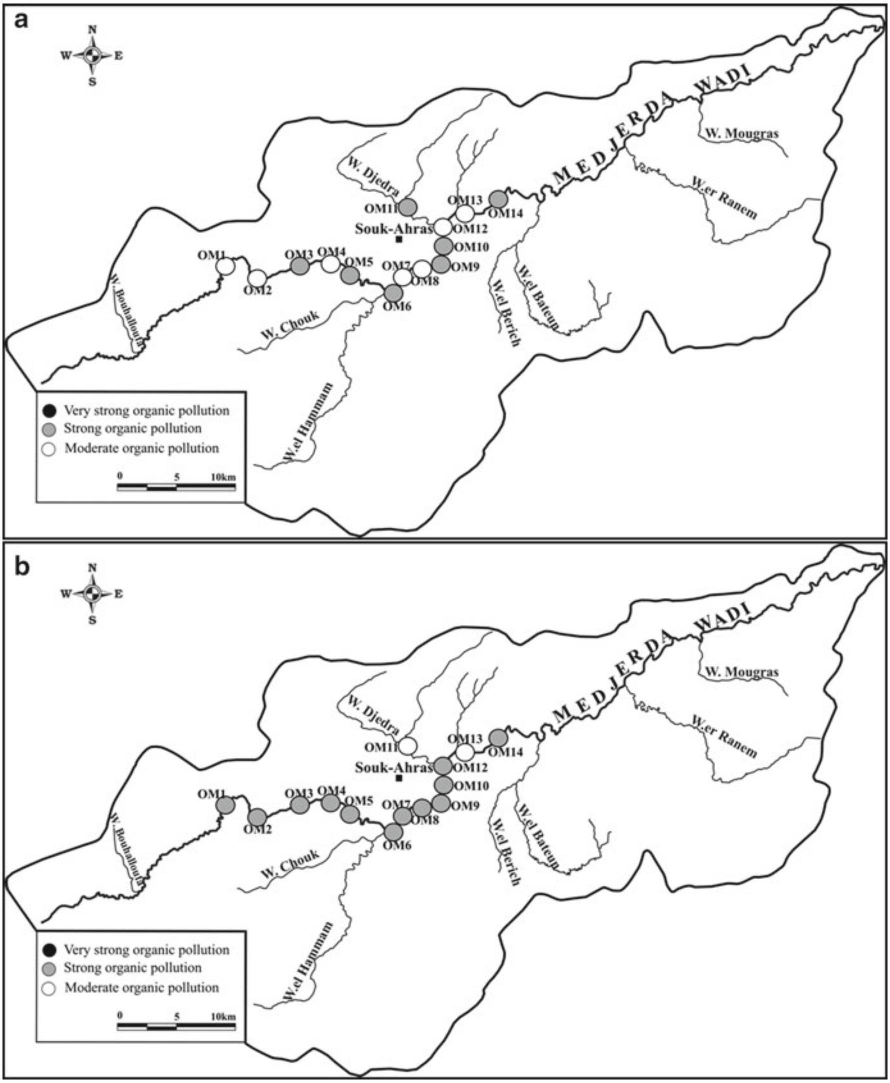

Fig. 45.4 Organic pollution index map. (**a**) April 2006; (**b**) August 2006

Figure 45.4b represents a very high rate of pollution across all sampling stations of the stream. This pollution is diverse as it is represented by urban discharges (OM_4 and OM_8), industrial wastes represented by the poultry complex (OM_5), paint factory (OM_6 and OM_7), paper mill plant (OM_{10}) and ELATEX (M_{12}) and finally other station along the tributaries which are situated in some agricultural lands such as OM_3, OM_{11} and OM_9 (Guasmi 2009).

The high concentration of organic pollution index makes the water unsuitable for irrigation uses.

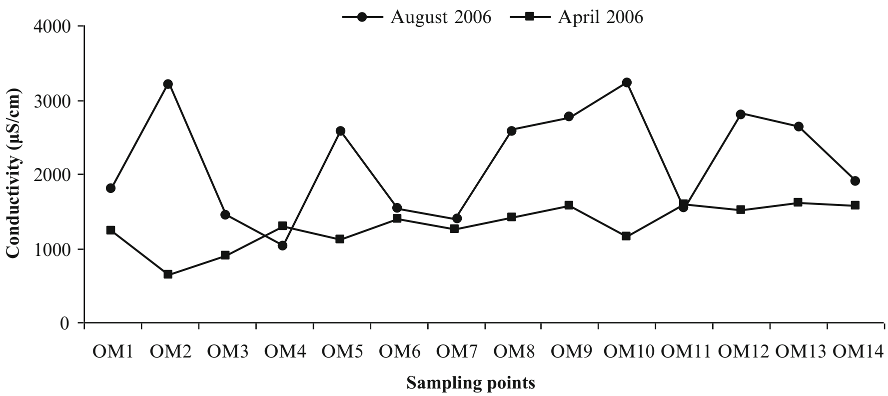

Fig. 45.5 Conductivity spatial evolution

45.4.3 Electrical Conductivity

Electrical conductivity is the most important parameter in determining the suitability of water for irrigation use. According to Langenegger (1990) and Bentoumi (1995), the measurement of EC is represented as salinity.

Irrigation using river water can add salt concentration to the soils, and a problem occurs if the added salt accumulates to a concentration that is harmful to the crop or landscape (Sundaray et al. 2009).

In order to have an idea about the electrical conductivity variation through the Medjerda wadi, a plot of spatial evolution has been drawn in Fig. 45.5.

Figure 45.5 shows the values of electrical conductivity ranging between 1,023 to 3,230 µS cm^{-1} and from 628 to 1,596 µS cm^{-1} during the high- and low-water periods, respectively. So, waters are considered permissible for the first period and permissible to unsuitable for the second one especially at the urban and industrial discharges.

45.4.4 Chlorides

Chlorides have a double origin. The geological one is due to the dissolution of evaporative formations (saline) and the other to anthropogenic activities in response to urban sewage discharged into the wadi. To highlight the water quality of Medjerda, the following classification (Sundaray et al. 2009) was used:

$$Cl^- > 10 \text{meq L}^{-1} : \text{Non toxicity}$$

$$4 < Cl^- < 10 \text{meq L}^{-1} : \text{Moderate toxicity}$$

$$Cl^- < 4 \text{meq L}^{-1} : \text{Severe toxicity}$$

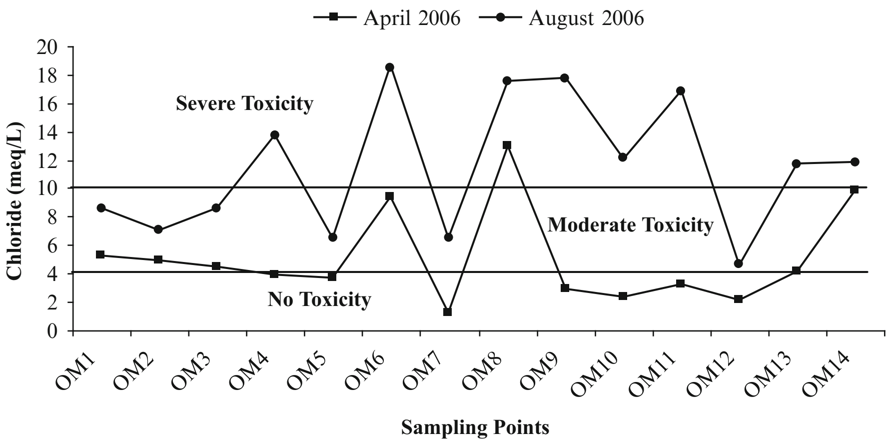

Fig. 45.6 Chloride spatial evolution

Figure 45.6 showed that during August waters are from moderate to severe toxicity and therefore are not suitable for irrigation at OM_4, OM_6, OM_8, OM_9, OM_{10}, OM_{11}, OM_{13} and OM_{14}.

45.4.5 Residual Carbonate Sodium

When total carbonate and bicarbonate level exceeds the total amount of calcium and magnesium (expressed in meq L^{-1}), the water quality may be diminished. When the excess carbonate (residual) concentration becomes too high, the carbonates combine with calcium and magnesium to form a solid material (scale) which settles out of the water (Isaac et al. 2009; Sundaray et al. 2009).

The RSC is expressed by the following equation:

$$\mathrm{RSC}\left(\mathrm{meq\,L^{-1}}\right)=\left(\mathrm{CO_3^{2-}}+\mathrm{HCO_3^-}\right)-\left(\mathrm{Ca^{2+}}+\mathrm{Mg^{2+}}\right)$$

If RSC value is above 2.5 meq L^{-1}, water is generally unsuitable for irrigation. If the value of RSC is between 1.25 and 2.5 meq L^{-1}, the water is marginally suitable, while a value below 1.25 meq L^{-1} indicates safe water quality.

It was observed from Table 45.1 and Fig. 45.7 that RSC values ranged, during low-water period, from −40 to 0 meq L^{-1} with a mean of −9.29 meq L^{-1} and from −23 to 8 meq L^{-1} during August with a mean of −4.29 meq L^{-1}. Values below 1.25 meq L^{-1} are observed at OM_6, OM_8 and OM_{10} sampling sites (Fig. 45.8).

On the basis of the RSC, waters are safe to irrigation use except at OM_6, OM_8 and OM_{10}.

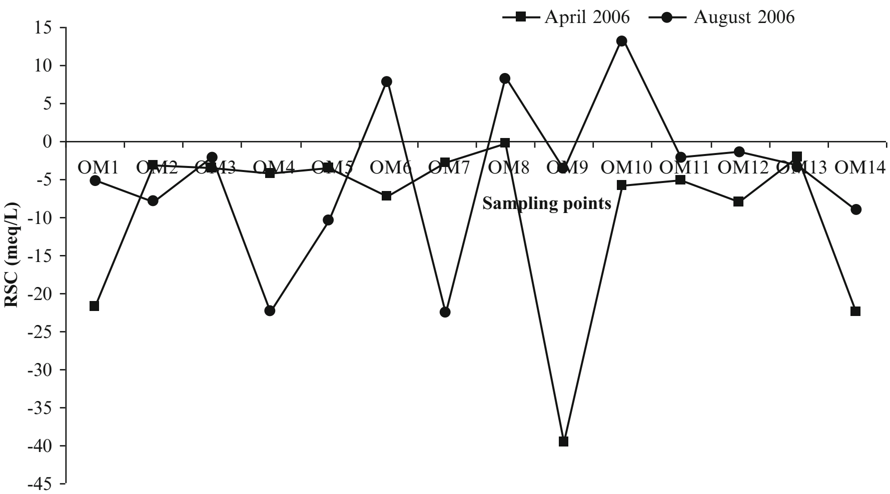

Fig. 45.7 Spatial variation of RSC values. (**a**) April 2006; (**b**) August 2006

45.4.6 Sodium Percentage

Generally, plants do not tolerate high sodium levels. Wilcox (1955) classification based on electrical conductivity and sodium content in water is expressed as percentage defined by the following relationship:

$$Na(\%) = \frac{Na}{Ca + Mg + Na + K} \times 100$$

Percent sodium (Fig. 45.9 and Table 45.3) varied from 20.47 to 47.88 during April and from 35.15 to 87.89 with a mean of 59.15 during August. During the low-water period, Na% values exceed 50% between OM_2–OM_9 and OM_{11}–OM_{13} and are therefore unsuitable for irrigation practices.

45.4.7 Sodium Adsorption Ratio (SAR)

The salinity may cause adverse effects to plants due to sodium and chlorides. The sodium then exerts a deleterious effect on vegetation indirectly by degrading the physical properties of soil. Under this action, the soil becomes compact and creates non-conducive condition for plant growth (Todd 1980). The concentration of soluble Na^+ ions in soil is important, as Na ions replace calcium more frequently from the soil exchange complex. A salt-laden water can cause this action (Schoeller 1962). The risk is determined from the adsorbed sodium values (Sodium Adsorption Ratio, SAR). For a given electrical conductivity, the risk of SAR effect on soil properties is higher.

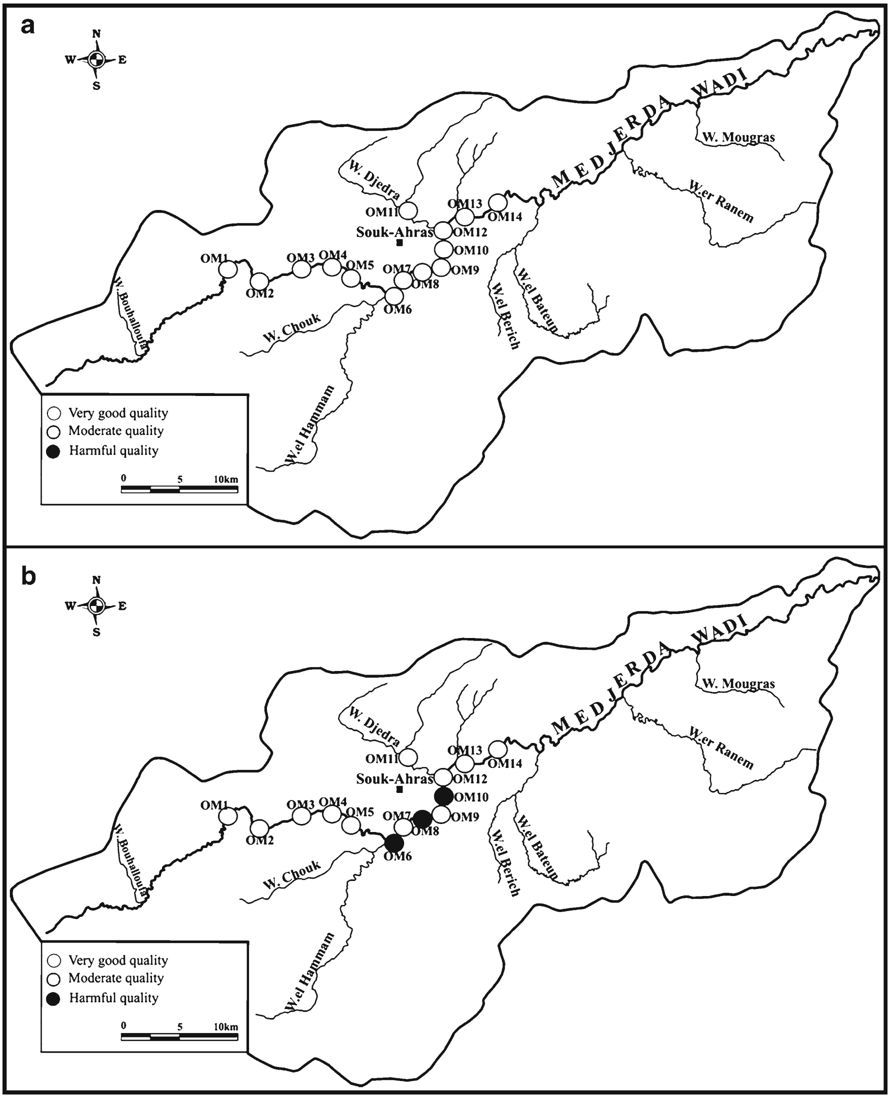

Fig. 45.8 Water irrigation suitability map using RSC. (**a**) April 2006; (**b**) August 2006

45.4.7.1 Effect of Sodicity and Salinity on Soil Permeability

In saltwater environments, irrigation practice is strongly influenced by soil permeability. Indeed, a soil rich with salt (NaCl) has good permeability due to clays being flocculated (Maas and Hoffman 1977). If irrigation water is loaded with sodium, the SAR is increased, and the high SAR disperses clay particles and clogs the conducting pores affecting the soil permeability significantly. High SAR also degrades soil

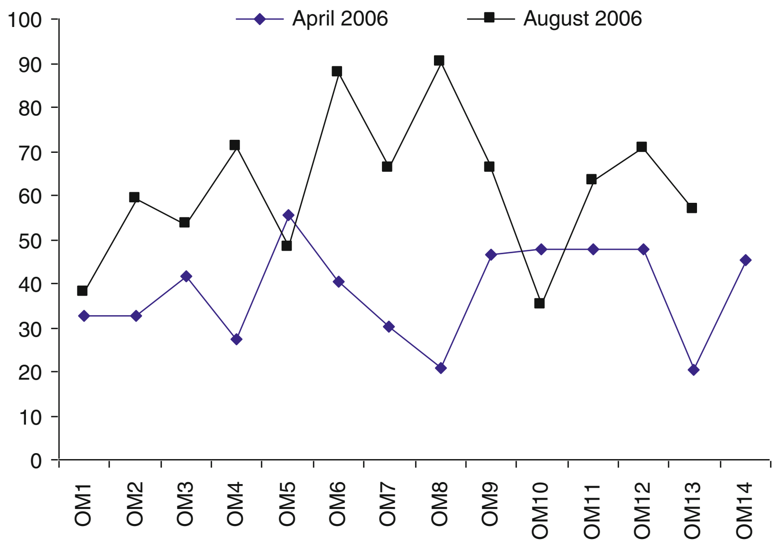

Fig. 45.9 Spatial variation plot of Na%

structure through swelling of clays (El Blidi et al. 2006). Under such degraded conditions, it is difficult to reclaim soils, as the drainage may then be completely stopped.

The sodium adsorption ratio (SAR) can be calculated by the following standard equation:

$$SAR = \frac{Na}{\left((Ca + Mg)/2\right)^{0.5}}$$

where the soluble Na, Ca and Mg are expressed in milliequivalents per litre and SAR is expressed as (mmoles $L^{-1})^{0.5}$.

The values of EC (microsiemens cm^{-1}) and SAR are then used to find water quality class using the diagram developed by the US Salinity Laboratory Staff (Richards 1954).

In order to find the water quality classes, we plotted EC and SAR (Fig. 45.10). Figure 45.10 shows the suitability of Medjerda waters.

Four classes appear in high-water period are moderate to poor except point OM_2. All points fall in C_3S_1, C_3S_2 and C_3S_3 classes each with its own characteristics (Table 45.4).

Waters pertaining to classes C_3S_1 and C_3S_2 are generally suitable for irrigation to salt-tolerant crops on drained soils. The sample (Table 45.4) points pertaining to the class C_3S_3 are in general highly mineralized and can be used for some species which tolerate salts on well-drained soils.

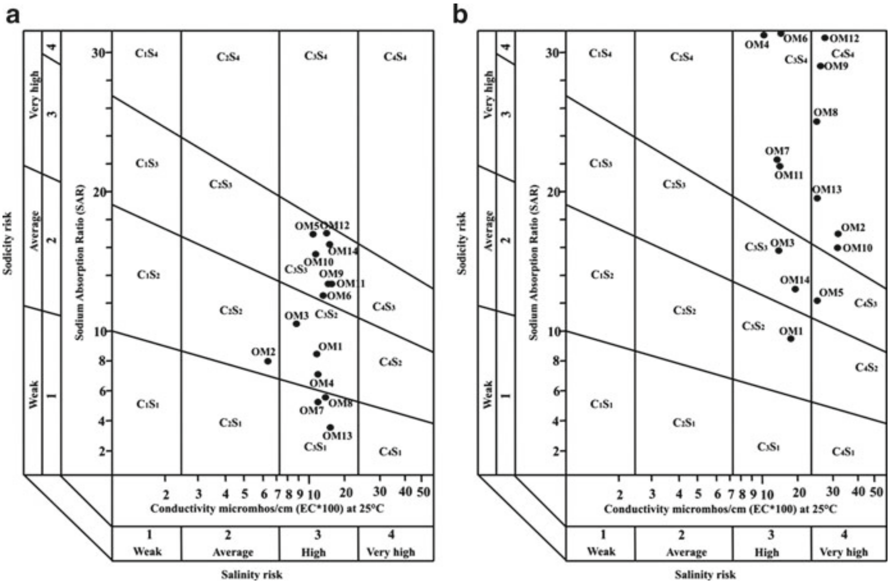

Fig. 45.10 SAR-EC plot. (**a**) April 2006 collection, (**b**) August 2006 collection

Table 45.4 Water quality classification for irrigation purpose

Degree	Quality	Class	April	August	Possibilities of utilization
1	Very good	C_1S_1	–	–	Safe to use water for irrigating most crops
2	Good	C_2S_1		–	In general, water can be used without special measures to irrigate moderately salt-tolerant crops on soils with good permeability
		C_2S_2	OM_2		
3	Moderate	C_2S_3			Generally, water suitable for irrigation of salt-tolerant crops on drained soils. Changes in salinity, however, must be controlled
		C_3S_1	OM_7, OM_8, OM_{13}	OM_1	
		C_3S_2	OM_1, OM_3, OM_4		
4	Poor	C_3S_3	OM_5, OM_6, OM_9, OM_{10}, OM_{11}, OM_{12}, OM_{14}	OM_3, OM_{14}	In general, highly mineralized water that may be suitable for some species to tolerate salts on soils well drained and leached
		C_4S_1			
		C_4S_2			
5	Harmful	C_4S_3		OM_5	Water unsuitable for irrigation but may be used under certain conditions: high soil permeability, good leaching plants, highly tolerant to salt
		C_4S_4		OM_2, OM_8, OM_9, OM_{10}, OM_{12}, OM_{13}	
		C_3S_4		OM_4, OM_6, OM_7, OM_{11}	

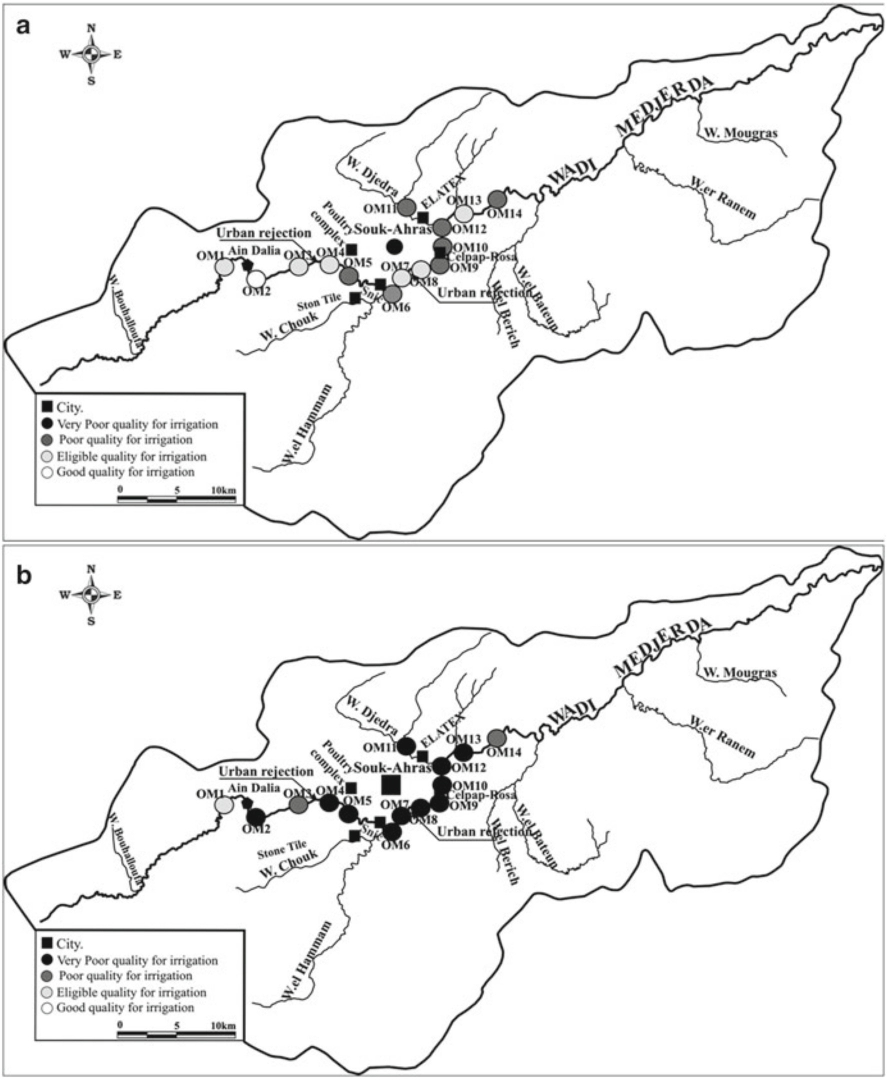

Fig. 45.11 Water quality suitability map for irrigation according to Richards classification. (**a**) April 2006 collection, (**b**) August 2006 collection

During the low-water period, the quasi-totality of sampling sites falls in the C_4S_3 and C_4S_4 (Table 45.4 and Fig. 45.11). Such waters are harmful and unsuitable for irrigation but can be used under certain conditions (high soil permeability, good leaching and plants highly tolerant to salt).

45.5 Conclusions

The surface water of Medjerda wadi has been evaluated for their suitability for irrigation uses. The investigation indicates, on the basis of the organic pollution index (OPI), that pollution varies depending on the localities from moderate to strong. Very high rate of OPI is across all sampling sites during the high-water period, and hence water cannot be used for irrigation practices.

Based on the SAR values and during the high-water period, waters are suitable for irrigation of salt-tolerant crops on drained soils at some site, and on the other sites, these can be used for some salt-tolerant species on well-drained soils.

During the low-water period, the quasi-totality of sampling sites falls in the C_4S_3 and C_4S_4 water quality classes. These waters are harmful and unsuitable for irrigation but can be used under certain conditions (high soil permeability, good leaching and plants highly tolerant to salts).

References

Ayers RS, Westcot DW (1985) Water quality for agriculture. FAO Irrigation and Drainage paper 29, Rev 1. FAO, Rome, p 174

Bentoumi O (1995) Transfert par infiltration de l'eau dans les sols fins compacts non saturés. Etude de la diffusivité et de la conductivité hydraulique. Thèse de doctorat, Institut National des Sciences Appliquées, Lyon

David L (1956) Etude géologique des Monts de la haute Medjerda. Thèse de doctorat, Université de Paris, paris, p 289

Duong TT (2006) Réponses des diatomées fixées aux pollutions organiques et métalliques dans les hydrosystèmes Nhue-Tolich (Hanoi, Vietnam) et Lot-Riou Mort (France). Thèse de Doctorat en "Sciences du vivant, Géosciences et Sciences de l'Environnement", University of Bordeaux I, p 261

El Blidi S, Fekhaoui M, Serghini A, El Abidi A (2006) Rizières de la plaine du Gharb (Maroc): qualité des eaux superficielles et profondes. Bulletin de l'Institut Scientifique, Rabat, section Sciences de la Vie 28:55–60

Fawzi B, Chlaida M, Oubraim S, Loukidi M, Sabour B, Bouzidi A (2001) Application of some diatom indices to a Moroccan water course: Hassar stream. Rev Sci Eau 14(1):73–80

Fryar AE, Macko SA, Mullican WF, Romanak KD, Bennett PC (2000) Nitrate reduction during ground-water recharge, Southern high plains, Texas. J Contam Hydrol 40:335–363

Guasmi I (2005) Dégradation de la qualité de l'eau dans le bassin versant de l'oued Medjerda (Souk-Ahras). Mémoire de Magister, University of El Hadj-Lakhdar, Batna, Algérie, p 90

Guasmi I (2009) Pollution des eaux et pouvoir auto-épurateur de l'oued Medjerda (Nord-Est Algérien). Thèse de Doctorat, University of Badji-Mokhtar, Annaba, Algérie, p 220

Guasmi I, Kherici-Bousnoubra H, Kherici N, Hadji F (2009) Assessing the organic pollution of surface water of Medjerda watershed (NE Algeria). Environ Earth Sci. doi:10.1007/s12665-009-0237-8

Isaac RK, Khura TK, Wurmbrand JR (2009) Surface and subsurface water quality appraisal for irrigation. J Environ Monit Assess 159:465–473

Langenegger O (1990) Ground water quality in rural areas of western Africa. UNDP project INT/81/026

Leclercq L (2001) Intérêt et limites des méthodes d'estimation de la qualité de l'eau. Station scientifique des Hautes-Fagnes, Belgique

Leclercq L, Maquet B (1987) Deux nouveaux indices chimiques et diatomiques de qualité d'eau courante. Application au Samson et à ses affluents (Bassin de la Meuse belge). Comparaison avec d'autres indices chimiques, biocénotiques et diatomiques. Institut Royal des Sciences Naturelles de Belgique, Document de travail 28:113

Lhadi EK, Mountadar M, Tounsi A (1996) Pollution par les nitrates des eaux souterraines de la zone littorale de la province d'el Jadida. (Maroc). Rev Hydrogéol 3:21–23

Maas EV, Hoffman GJ (1977) Crop salt tolerance – current assessment. Journal of Irrigation and Drainage Engineering, 103:115–134

Richards LA (ed.) (1954) Diagnosis and improvement of saline and alkali soils. US Salinity Laboratory Staff. USDA handbook no. 60. US Department of Agriculture, Washington, DC

Rodier J (1982) L'analyse chimique et physicochimique de l'eau. Dunod, Paris, p 699

Schoeller H (1962) Les eaux souterraines: hydrologie dynamique et chimique – Recherche, exploitation et évaluation des ressources. Masson, Paris, p 642

Sundaray SK, Nayak BB, Bhatta D (2009) Environmental studies on river water quality with reference to suitability for agricultural purposes: Mahanadi river estuarine system, India – a case study. J Environ Monit Assess 155:227–243

Todd K (1980) Groundwater hydrology, 2nd edn. Wiley, New York, p 510

Vila JM (1980) La chaîne alpine d'Algérie orientale et des confins algéro-tunisiens. Thèse de doctorat ès sciences naturelles. University of Pierre et Marie Curie, Paris, V, pp 282–296

Wilcox LV (1955) Classification and use of irrigation waters. US Department of Agriculture Circular 969. US Department of Agriculture, Washington, DC, p 19

Chapter 46
Exploring Soil Salinity Management in Entisols Using Trickle Irrigation System

M. Nurul Alam Akhand and Basel Al Araj

Abstract Entisols are common soils in the arid regions and have the potential for irrigated agriculture. However, when these soils are irrigated with brackish/saline water and the irrigation is poorly managed, the soils become saline. Maintaining desired saltwater balance in the potential root zone area is the key factor for growing agricultural, forestry, and landscaping plants under saline soil and water conditions. Irrigation management is one of the practices that can assist in achieving such a goal. In fact, irrigation methods along with better scheduling can manage the wetting-front movement and salt accumulation in the root zone. Micro-irrigation methods are usually desirable under water scarcity/salinity situations to facilitate water conservation and managing soil salinity. Among these irrigation systems, the trickle is commonly used for efficient soil salinity management and irrigation. In order to verify the above, field experiments on three emitter spacing (25, 50, and 75 cm) in two layout patterns (square and triangle) were evaluated on Entisols at the experimental farm of Dubai-based International Center for Biosaline Agriculture. Soil samples were collected at 0–25- and 25–50-cm depths and analyzed for EC of soil saturation extract to assess soil salinity development around the emitters. Results show that triangle pattern of emitters minimizes soil salinity development compared to salinity development in the square-type pattern through overlapping of wetting fronts and subsequent leaching. Similarly, close spacing of emitters also overlaps wetting fronts, and that helps in reducing salt accumulation. These preliminary findings may help formulate suitable irrigation management practices for growing different plants under saline environments.

Keywords Emitters • Emitter spacing • Irrigation • Salt accumulation • Wetting front

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46.1 Introduction

Salinity management is an important aspect of productive utilization of saline water resources in the crop production system. This is especially relevant in arid areas where freshwater is scarce, and this necessitates the use of brackish water to offset the water requirements of crops, and if this marginal water resource is poorly managed, the soils become saline leading to declined crop yields. It is, therefore, essential to take necessary measures to manage soil salinity in the potential root zone area (0–50 cm). For proper salinity management, it is essential to understand (1) how salts affect plant growth; (2) how soil physical, hydraulic, and chemical characteristics affect solute transport; and (3) how irrigation water quantity and quality influence salt accumulation in the root zone.

Irrigation management is one of the important options of salinity management for crop production system (Jensen 1983). Although the primary objective of irrigation is to supply water to meet crop water demand, appropriate irrigation application methods and irrigation scheduling help in managing soil salinity. Irrigation application methods which assist in salinity management include basin flooding, furrow, sprinkler, subsurface irrigation, and drip. Basin flood irrigation is good for leaching out salt from the root zone evenly if the land is level, though aeration and crusting problems may occur. Such problems can be minimized by using furrow irrigation, but salts tend to accumulate in the beds. If excess salts accumulate, crop rotation and periodic irrigation by sprinkler or flooding can solve the problem. The sprinkler method controls water quantity and distribution better (i.e., good leaching) but an appropriate quantity of water needs to be applied. This method, however, causes leave burn of sensitive crops. Subsurface irrigation with saline water is not generally advisable as it produces continuous upward soil water movement; thus regular leaching with low-salinity water is required. Drip irrigation performs better for localized salinity management because soils close to emitters have higher water content and low salt concentration, though salts accumulate in the periphery of the wetted area.

In drip Irrigation method, the layout pattern and spacing between emitters influence wetting-front movement and eventually salt accumulation (Shahid and Hasbini 2007). Different layout patterns determine the nature of wetting-front movement and distribution uniformity. The closely spaced emitters enhance salt dilution in the root zone in comparison with widely spaced emitters. In this study, two layout patterns and three spacing of emitters were evaluated with regard to salt accumulation in the potential root zone area.

46.2 Materials and Methods

46.2.1 Field Experiments

Field experiments were conducted at the experimental farm of the Dubai-based International Center for Biosaline Agriculture (ICBA) during 2008 and 2009. The experimental site location map is presented in Fig. 46.1.

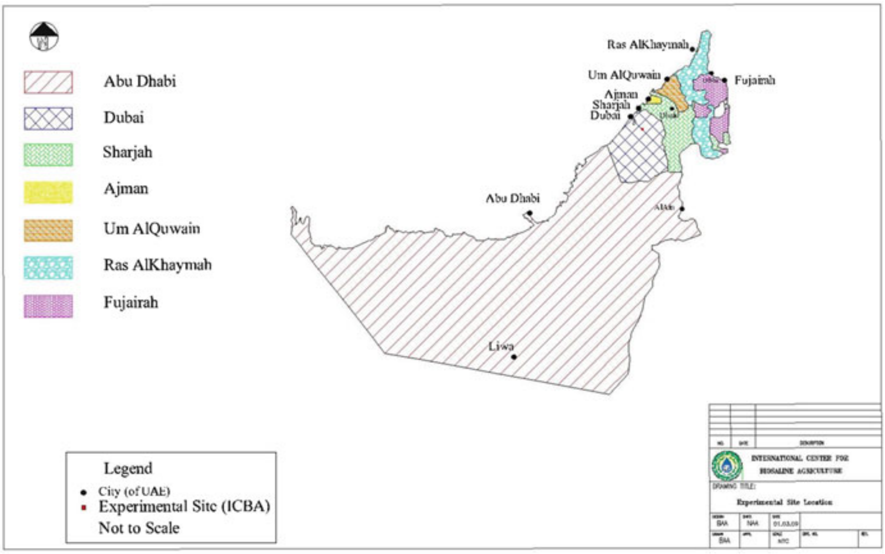

Fig. 46.1 Location of the experimental site in the United Arab Emirates

The experimental site was assessed for taxonomic class using the norms and standards of the United States Department of Agriculture "Soil Taxonomy" (Soil Survey Staff 1999, 2003). The soil of the site is calcareous and fine sand in texture "Entisols" (Shahid et al. 2009; Soil Survey Division Staff 1993). The infiltration capacity and unsaturated hydraulic conductivity of site soil is 30 mm h^{-1} and 2,000 mm day^{-1}, respectively. The soil is classified as *carbonatic, hyperthermic typic torripsamments* (Shahid et al. 2009). Where carbonatic is the mineralogy class, i.e., more than 40% $CaCO_3$ in fine earth fraction (<2 mm), hyperthermic is soil temperature regime (the mean annual soil temperature is 22°C or higher, and the difference between mean summer and mean winter soil temperature is more than 6°C at a depth of 50 cm from the soil surface). Typic torripsamment indicates typical desert sandy soil at soil subgroup level of USDA Soil Taxonomy. The soil type represents dominant sandy soils in the Gulf Cooperation Council Countries (GCCC).

The dimension of the plot was 30 m × 15 m, and a surface drip irrigation method was installed. The capacity of the pressure-compensating emitters was 4 L h^{-1}, and lateral pressure was maintained at 1.5 bars. The black PE laterals were 16 mm (outside diameter) with inside diameter of 13 mm. The initial soil salinity was 3.5 dS m^{-1} (0–25-cm depth). The irrigation water salinity was maintained at 22 dS m^{-1} throughout the experimental period.

Three emitter spacing (25 cm × 25 cm, 50 cm × 50 cm, and 75 cm × 75 cm) and two layout patterns (square and triangle) were used (Fig. 46.2) with three replications. The experiment was irrigated twice a day, morning and evening for 30 min each, and the experiment was continued for 4 months (15 October 2008–15 February 2009). At the completion of the experiment, soil samples were collected from two

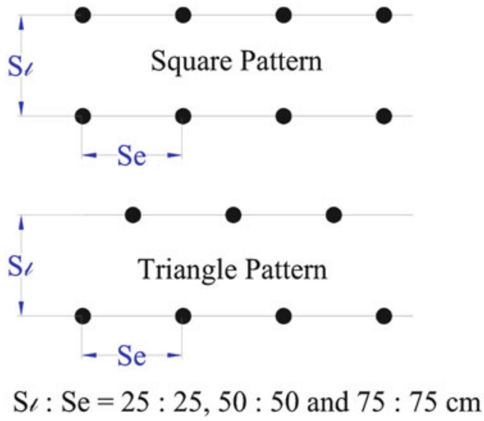

Fig. 46.2 Two experimental layout patterns, i.e., square and triangle. The spacing between the laterals and emitters were kept same in this experiment (S*l* lateral spacing, S*e* emitter spacing)

depths (0–25 and 25–50 cm) representing the area around the emitters. The soil samples were air-dried, sieved (<2 mm), and analyzed for EC of soil saturation extract at the Central Analytical Laboratory (CAL) of ICBA.

46.3 Results and Discussion

Table 46.1 presents mean soil salinity (EC_e) at two soil depths (0–25 and 25–50 cm) of three spacing (25, 50, and 75 cm) for square layout pattern. The mean values are the lowest with 25 cm and the highest with 75-cm spacing, whereas an insignificant difference in EC_e was recorded at 25–50-cm depth. The soil salinity values were higher at 0–25 cm relative to those at 25–50-cm depth. Such higher values are expected at surface due to the effect of evaporation that brings the salts to surface through capillary rise and subsequent evaporation and increasing surface salinity. Higher dilution effect could also help in decreasing salt concentration at 25–50-cm depths.

In a similar experiment at ICBA, Shahid and Hasbini (2007) reported similar pattern of salt accumulation. The less salt accumulation at 25–50-cm depth is due to wetting front hardly reaching at 50 cm based on saturated hydraulic conductivity. The observations on the salinity pattern around the emitters revealed maximum being in the central zone of the emitters (Figs. 46.3 and 46.4). This is due to the fact that the wetting front ends in the middle, and subsequently salts are accumulated at the edges of the wetting front. Such trend was observed in all spacing and at both depths.

The triangle layout pattern follows the same trend of salt accumulation of the square layout pattern although soil salinity values of the triangle layout pattern were lower (Table 46.2). The mean values of soil salinity at 0–25-cm depth were 8.34, 17.48, and 18.36 dS m^{-1} in 25-, 50-, and 75-cm spacing, respectively. In other words, the triangle layout pattern resulted in decreased soil salinity by 25, 16, and 30% at 0–25-cm depth in comparison with the square pattern. In case of 25–50-cm depth,

Table 46.1 Soil salinity (EC_e) for square layout pattern

	Average EC_e (dS m^{-1}) value			
	Soil depth (0–25 cm)		Soil depth (25–50 cm)	
Spacing (cm)	Range	Mean	Range	Mean
25	9.26–13.00	11.13	4.99–7.77	6.38
50	7.21–40.01	20.78	3.44–8.19	6.05
75	5.68–46.41	26.04	4.20–11.36	7.74

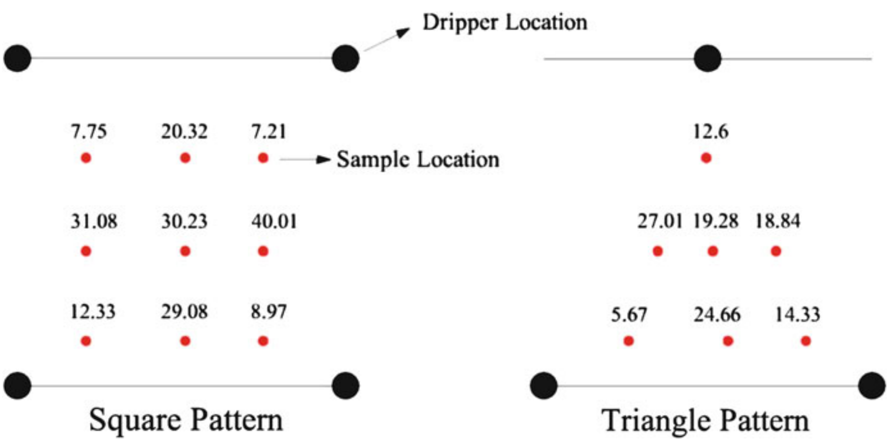

Fig. 46.3 Soil salinity (EC_e) values in two layout patterns at 0–25-cm depth of 50-cm spacing

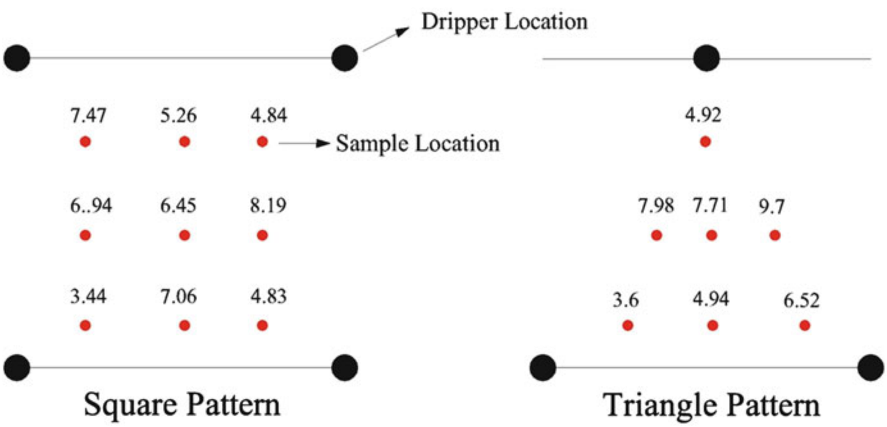

Fig. 46.4 Soil salinity (EC_e) values in two layout patterns at 25–50-cm depth of 50-cm spacing

Table 46.2 Soil salinity (EC_e) for triangle layout pattern

	Average EC_e (dS m^{-1}) value			
	Soil depth (0–25 cm)		Soil depth (25–50 cm)	
Spacing (cm)	Range	Mean	Range	Mean
25	7.61–9.08	8.34	3.64–8.87	6.25
50	5.67–27.01	17.48	3.60–9.70	6.48
75	8.00–26.71	18.36	4.79–11.97	8.38

the corresponding soil salinity values for the triangle pattern were 6.25, 6.48, and 8.38 dS m^{-1}.

These values are not much different than those of the square layout pattern although 25-cm spacing in triangular pattern showed a decreasing trend. These overall findings justify recommending triangle layout pattern over square layout pattern. This is due to more overlapping of wetting fronts and subsequently less salt concentration in the soils.

46.4 Conclusions

In drip irrigation, a significant amount of salt usually accumulates on the outer edges of the wetting front; thus choosing proper spacing will minimize salt accumulation in the potential root zone area (0–50 cm). In this study, the triangle layout pattern showed less accumulation of salts than the square layout pattern because of the greater overlapping of wetting fronts and leaching of salts from the soils. Decreased distance between the emitters and the laterals demonstrated less accumulation of salts. It is expected that such findings will help the farmers in proper designing drip irrigation method for better management of irrigation-induced soil salinity in the root zone.

References

Jensen ME (ed.) (1983) Design and operation of farm irrigation systems. Monogr Am Soc Agric Biol Eng, St. Joseph, Michigan 49085, USA

Shahid SA, Hasbini BA (2007) Optimization of modern irrigation for biosaline agriculture. Arab Gulf J Sci Res 25(1/2):59–66

Shahid SA, Dakheel AJ, Mufti KA, Shabbir G (2009) Automated *in-situ* soil salinity logging in irrigated agriculture. Eur J Sci Res 26(2):288–297

Soil Survey Division Staff (1993) Soil survey manual. USDA handbook no. 18. USDA-NRCS, Washington, DC

Soil Survey Staff (1999) Soil taxonomy: a basic system of soil classification for making and interpretation of soil surveys. USDA agriculture handbook no. 436, US Government Print Office, Washington, DC, p 869

Soil Survey Staff (2003) Keys to soil taxonomy, 9th edn. US Government Print Office, Washington, DC, p 331

Chapter 47
Suitability of Surface Water from Mouillah Wadi of Algeria for Irrigation Purposes

Fatiha Hadji, Imen Guasmi, and Larbi Djabri

Abstract Salinity is one of the most severe environmental factors limiting the productivity of agricultural crops. In this chapter, evaluation of water quality of Mouillah wadi was carried out in order to assess its suitability for irrigation purposes. Mouillah wadi is a subbasin of Tafna watershed which is situated in the north-west of Algeria. It feeds the Hammam Boughrara dam with a capacity of 177 Mm^3. This wadi has important sources of pollution contaminating water whose quality deterioration is a direct consequence of the discharge of the effluents of all categories in surface water (industrial and urban wastes). To evaluate the water quality, chemical parameters such as the residual sodium carbonate (RSC), the magnesium hazard (MH) and the permeability index (PI) using US Salinity Laboratory Staff salinity classification and the Wilcox diagram were determined, and seasonal variation diagrams were prepared. The electrical conductivity values show the dam waters to be of marginal quality. The waters of Mouillah wadi are of poor to harmful quality according to Wilcox classification. The calculated values of SAR and % Na plotted on SAR and Wilcox diagrams versus conductivity indicate a good to doubtful use of the dam water for irrigation. High salinity, % Na, Mg hazard and RSC values at Mouillah wadi limit the use for agricultural purposes.

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Keywords Algeria • Conductivity • Irrigation water quality • Mouillah wadi • Sodium adsorption ratio

47.1 Introduction

Soil salinity problems in irrigated agriculture appear worldwide (Greenlee et al. 1968; Halvorson and Rhoades 1976). Soil salinity refers to a situation in which the presence of salts renders the soil to be of marginal quality, whereas sodicity is caused by the specific effect of sodium ions adsorbed on the exchange complex of clay minerals. This leads to deflocculation/dispersion of soil colloids, translocated in the soil profile, blocks the conducting pores and reduces soil porosity (Vlek's et al. 2008).

Assessing soil salinity is complicated by the dynamic nature and its spatial and temporal variability (Rhoades and Ingvalson 1971). In irrigated agriculture, where irrigation is accomplished with saline/brackish water, the hazard of water salinity to soils and agricultural crops is a constant threat; unless salinity is properly managed through an integrated approach of soil reclamation, the formulation of which may be site specific. The suitability of surface water for agricultural purposes can be determined by evaluating some important physical and chemical characteristics as well as some calculated hydrogeochemical parameters and established graphical representations dealing water quality.

The quality indices determined are secondary in nature and are calculated by using concentrations of cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-}) in water and could be influenced by the type of soil or water (Hernández et al. 2003).

In the present study, the evaluation of the water quality of the Mouillah wadi (NW, Algeria) suitability for agricultural purposes has been attempted.

47.2 General Settings

Mouillah wadi is a sub-watershed of Tafna wadi located in the north-west of Algeria (Fig. 47.1). Its tributaries cross Zriga and Maghnia plains of Algeria and that of Angads of Morocco. Mouillah wadi represents the 4/5 of the inputs of the Hammam Boughrara dam of total capacity exceeding 177 Mm^3, and the waters are intended for the drinking water production and irrigation. The dam is the main outlet of Bou Naim wadi of Morocco, which took the name of Mouillah wadi in Algeria and whose catchment area covers 4,000 km^2 (Dahmani et al. 2008) on both sides of the Moroccan–Algerian border (2,100 km^2 in Algeria and 1,900 km^2 in Morocco). The agricultural, industrial and urban discharges generate significant pollution; the dam is receiving environmental problems and thus affects its water resources.

The study area is characterised by a semiarid climate with temperate winters. The average annual rainfall is 328 mm, the average annual temperature is 17.5°C

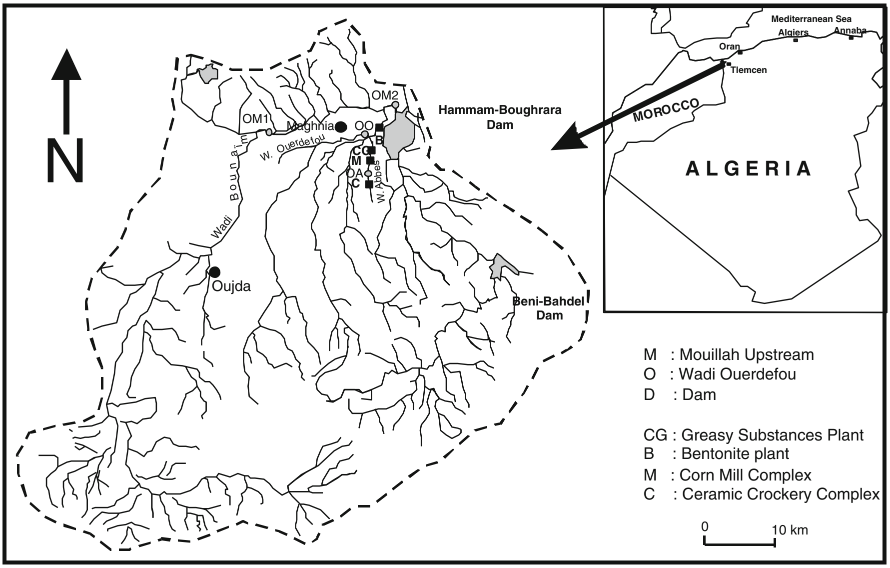

Fig. 47.1 Study area and location of sampling points

and evapotranspiration is of 875 mm (Boudieb and Braik 2003). The average monthly flow is highly variable: it varies between 1.6 $m^3 s^{-1}$ in March and 7×10^{-4} $m^3 s^{-1}$ in August.

The wadi Ouerdefou, whose main tributaries are Abbes, Méhaguène and Aouina wadis, presents a permanent flow downstream. It is fed by municipal wastewater from Maghnia City with industrial activities (mainly plant of manufacturing bentonite and bleaching earth) and those discharged by Abbes wadi.

The geological formations of the study area are represented by former Jurassic lands where carbonates predominate (limestone and dolomite strongly fissured and karstified) and Palaeozoic formations (clays, sandstone, shale, limestone and dolomite). Between these reliefs, depressions are occupied by Miocene lands (marl, sandstone and clay) and Plio-Quaternary formations represented by clay, coarse or fine sand, gravel and limestone.

Mouillah wadi basin receives municipal and industrial wastewater discharges from Oujda City and its vicinity, discharges of urban and industrial sewage (complex of greasy substance, complexes of ceramic crockery, mill Tafna, bentonite and bleaching grounds) and chemical fertiliser (Hadji et al. 2005).

47.3 Materials and Methods

The determination of water quality and the estimation of its pollution degree were made on the basis of multiple measurements of pollution indicators represented by the BOD_5, electrical conductivity and major anions and cations.

Table 47.1 Irrigation water quality classification for electrical conductivity, chloride and BOD_5

	Class I	Class II	Class III	Class IV	Class V
	Very good	Good	Moderate	Poor	Harmful
Electrical conductivity ($\mu S\ cm^{-1}$)	0–250	250–750	750–2,000	2,000–3,000	>3,000
BOD_5 ($mg\ L^{-1}$)	0–25	25–50	50–100	100–200	>200
Chlorides ($mg\ L^{-1}$)	0–142	142–249	249–426	426–710	>710

In Gunduz et al. (2006)

The intensity and nature of pollution vary according to locations; therefore, sampling points were selected on the basis of pollution sources (Fig. 47.1):

- Point (D) representing the Hammam Boughrara dam.
- Point (M) located upstream of Mouillah wadi and controlling urban and industrial wastewater of Moroccan kingdom.
- Point (O) on Ouerdefou wadi controlling discharges of urban wastewater from Maghnia City and industrial of bentonite plant.

In order to assess the suitability of surface water for irrigation use, electrical conductivity, biochemical oxygen demand (DBO_5), chloride content and the following computed equations were used.

47.3.1 Conductivity, BOD5 and Chloride

Table 47.1 presents irrigation water quality classification for electrical conductivity, biochemical oxygen demand (BOD_5) and chloride values

47.3.2 Sodium Hazard

Soils with a high concentration of Na^+ in solution are notorious for having a bad physical structure (Appelo and Postma 1993). Toxicity of Na^+ occurs with the accumulation of sodium in the plant tissues and exceeds the tolerance limit of crop. Any increase in the sodium adsorption ratio (SAR) of irrigation water increases the sodium of soil solution and ultimately increases exchangeable sodium of soil (Isaac et al. 2009).

The role of sodium in the classification of river water for irrigation was emphasised because of the fact that sodium accumulates on soil exchange complex and disperses soil structure, and dispersed clay translocates in soil profile and clogs the conducting soil pores, thereby reducing the permeability (Todd 1980; Domenico and Schwartz 1990; Nagaraju et al. 2006; Sundaray et al. 2009). The SAR can be calculated by the following equation:

$$SAR = \frac{Na^{+}}{(Ca^{2+} + Mg^{2+})^{0.5}}$$

where Na^{+}, $Ca^{2+} + Mg^{2+}$ are expressed in milliequivalents per litre and SAR as $(\text{meq L}^{-1})^{0.5}$

47.3.3 Sodium Percentage (% Na)

Percent sodium in water is a parameter computed to evaluate the suitability for irrigation (Wilcox 1948; Tiwari and Manzoor 1988a). The percentage of Na can be calculated by the following relation:

$$\%Na = \frac{100 \times (Na^{+})}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})}$$

where Na, K, Ca and Mg are expressed in milliequivalents per litre.

47.3.4 Permeability Index (PI)

The soil permeability is affected by long-term use of irrigation water. The sodium, calcium, magnesium and bicarbonate contents of the soil influence the permeability through changing soil physical and chemical properties.

Doneen (1964) classified irrigation waters based on the permeability index (PI) where

$$PI = \frac{Na + \sqrt{HCO_3}}{Ca + Mg + Na} \times 100$$

The PI values >75 indicate excellent quality of water for irrigation. If the PI values are between 25 and 75, they indicate good quality of water for irrigation. However, if the PI values are less than 25, they reflect unsuitable nature of water for irrigation (Al-Amry 2008).

47.3.5 Kelley's Ratio (KR)

Concentration of Na^{+} in irrigation water is considered to be in excess, thereby making the water unsuitable, if Kelley's ratio is >1. This ratio is represented by the concentration of Na^+ against Ca^{2+} and Mg^{2+} (Paliwal 1967). Kelly's ratio is calculated by using the following equation:

$$KR = \frac{Na}{Ca + Mg}$$

47.3.6 Residual Sodium Carbonate (RSC)

The quantity of bicarbonate and carbonate in excess of alkaline earths ($Ca^{2+} + Mg^{2+}$) also influences the suitability of water for irrigation purposes.

The empirical approach (Eaton 1950) which has been widely used to predict the additional sodium hazard associated with $CaCO_3$ and $MgCO_3$ precipitation involves calculation of the residual sodium carbonates (RSC).

When the sum of carbonates and bicarbonates is in excess of calcium and magnesium, the carbonates and bicarbonates are precipitated to the equivalent quantity of Ca and Mg; the excess of carbonates and bicarbonates will then react with Na to appear as RSC (Raghunath 1987). This approach is based on the equation:

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$$

where all the concentrations are in meq L^{-1}.

A high value of RSC in water leads to an increase in the adsorption of sodium in soil (Eaton 1950; Singh et al. 2008). If RSC exceeds 2.5 meq L^{-1}, the water is generally unsuitable for irrigation. If the value of RSC is between 1.25 and 2.5 meq L^{-1}, the water is marginally suitable, while a value less than 1.25 meq L^{-1} dictates safe water quality (USDA 1954; Shahid 2004).

47.3.7 Magnesium Hazard (MH)

The MH is the excess amount of Mg^{2+} over Ca^{2+}. Normally Mg^{2+} amounts are level with that of Ca^{2+}, and Mg^{2+} will thus be in a state of equilibrium. The excess Mg^{2+} affects the quality of soil resulting in poor agricultural returns. Where Ca is less than Mg, Mg behaves like Na and thus degrades soil structure. The MH value <50% makes the water suitable for irrigation while MH value >50% makes it unsuitable (Lloyd and Heathcoat 1985). Excess amount of Mg^{2+} reduces yield of crop.

This ratio proposed by Szabolcs and Darab (1964) is as below:

$$MH = \frac{Mg^{2+} \times 100}{Ca^{2+} + Mg^{2+}}$$

where all the concentrations are in meq L^{-1}.

47.4 Results and Discussion

Table 47.2 summarises the minimum, maximum, mean and standard deviation values of the various parameters

The total concentration of soluble salts in irrigation water can be adequately expressed in terms of electrical conductivity for purposes of diagnosis, classification and management.

In general, water having conductivity below 750 μS cm^{-1} is satisfactory for irrigation. Water having a range of 750–2,250 μS cm^{-1} is widely used, and satisfactory crop growth is obtained under good management and favourable drainage conditions, but saline conditions will develop if leaching and drainage are inadequate (Haritash et al. 2008).

In upstream Mouillah site, values of electrical conductivity (Table 47.1) vary between 1,550 and 2,670 μS cm^{-1} with a mean of 2,445.5 μS cm^{-1}, and continuous application of such water may lead to formation of saline soils (Fig. 47.2a).

According to the irrigation water classification (Table 47.1) and on the basis of the BOD_5 values represented as Fig. 47.2b, waters of the dam are considered to be good to moderate for irrigation purposes. For Ouerdefou wadi, all sampling points fall in classes III and IV and are classified as moderate to poor quality for irrigation. For Mouillah upstream, waters are classified as class V waters. Such waters are considered to be harmful and unsuitable for irrigation purposes.

The most common toxicity is from chloride in the irrigation water. If the chloride concentration in the leaves exceeds the tolerance of the crop, injury symptoms develop such as leaf burn or drying of leaf tissue. Normally, plant injury occurs first at the leaf tips (which is common for chloride toxicity) and progresses from the tip back along the edges as severity increases. Excessive necrosis (dead tissue) is often accompanied by early leaf drop or defoliation (Ayers and Westcot 1985).

Chloride contents present in the study area are within classes II and IV and are moderate and poor for irrigation use.

In Fig. 47.3, data from the study area are plotted on SAR versus EC diagram in order to categorise the suitability of watershed waters for irrigation activities. It appears in this graphical presentation that the quasi-totality of water samples of Ouerdefou wadi belongs to the C_2–S_1 class (medium salinity and low sodium content class); however, water that belongs to this class is also useful for almost all plants provided that moderate amount of leaching takes place or for plants with reasonable salinity tolerance without large practices for salinity control (Ayers and Westcot 1985).

For the Hammam Boughrara dam and upstream, the % sodium–EC diagram (Fig. 47.4) demonstrates that water samples fall in the fields of C_3S_1, C_3S_2 and C_4S_2. Samples belonging to the field of C_3S_1 and C_3S_2 reflect high-salinity and low-sodium water which can be used for irrigation on almost all types of soil with only a minimum risk of exchangeable sodium. The water of this type can be used for plants having good salt tolerance (Karanth 1987).

Table 47.2 Minimum, maximum, means and standard deviations of calculated parameters

		BOD_5 (mg L^{-1})	EC (μS cm^{-1})	Cl (mg L^{-1})	SAR	% Na	PI	KR	RSC	MH
Hammam Boughrara dam (D)	Min	9.0	983.0	273.0	3.74	42.2	56.4	0.69	−7.51	42.2
	Max	31.5	1,930.0	460.0	7.31	58.3	68.0	1.34	−3.35	82.6
	Mean	16.2	1,571.9	324.8	5.50	49.5	60.6	1.0	−4.5	61.1
	SD	6.6	278.7	70.3	1.10	4.8	3.8	0.19	1.13	10.7
Mouillah upstream (M)	Min	24.0	1,550.0	366.0	4.24	40.5	52.7	0.81	−4.44	54.0
	Max	125.0	2,670.0	551.0	9.19	58.8	66.4	1.35	2.20	80.5
	Mean	58.4	2,445.5	443.2	6.68	48.8	62	0.95	−1.48	65.3
	SD	31.9	404.9	73.8	1.46	5.2	5.09	0.21	1.96	8.5
Ouerdefou wadi (O)	Min	113.0	392.0	283.0	5.52	40.1	47.9	0.62	−10.4	40.5
	Max	1,127.0	1,120.0	508.0	11.77	71.3	83.3	2.31	10.13	80.0
	Mean	396.3	648.7	434.0	6.15	47.6	57.7	0.83	−3.77	63.5
	SD	368.6	257.2	73.3	2.09	9.9	12.3	0.51	6.78	12.4

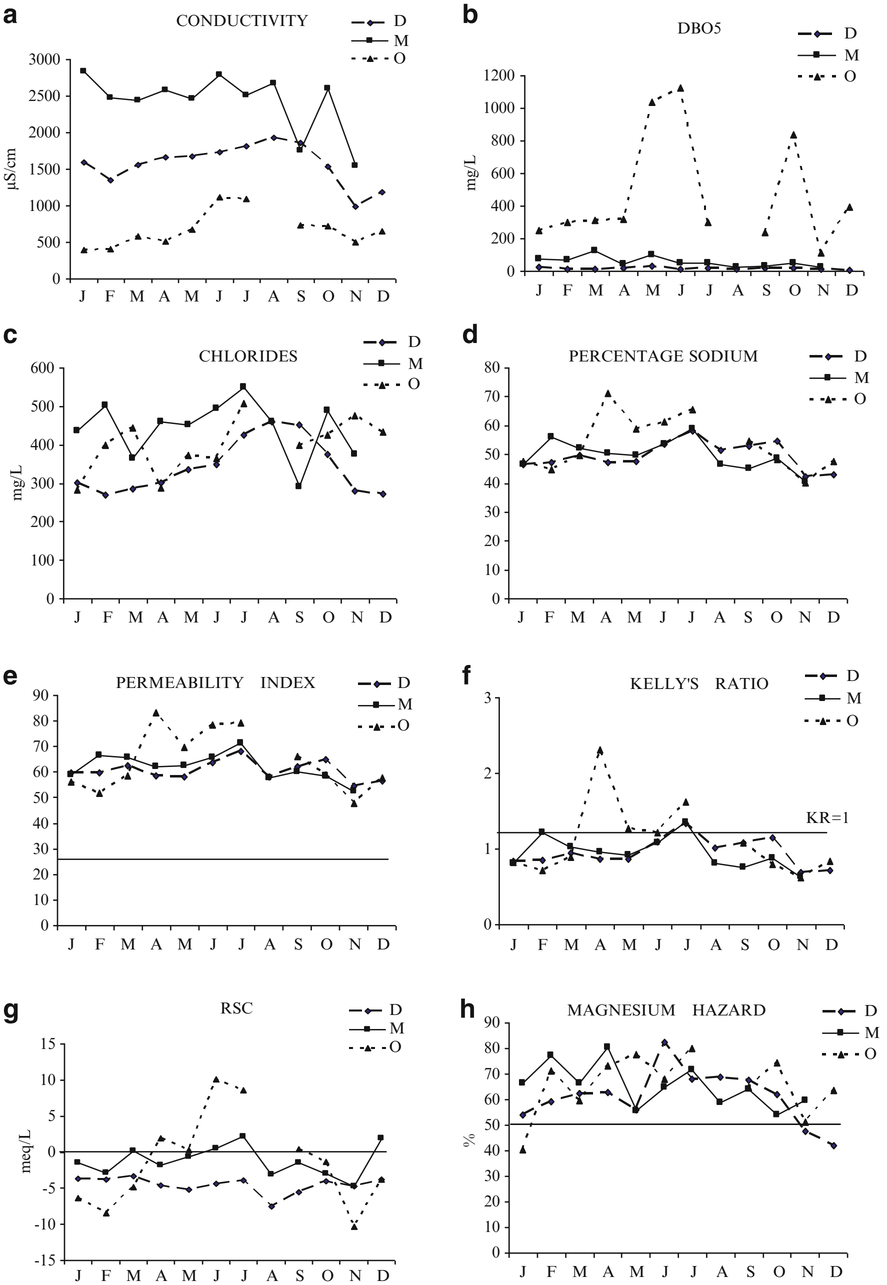

Fig. 47.2 Monthly variation of electrical conductivity (**a**), DBO_5 (**b**), chlorides (**c**), sodium % (**d**), permeability index (**e**), Kelley's ratio (**f**), RSC (**g**) and magnesium hazard (**h**)

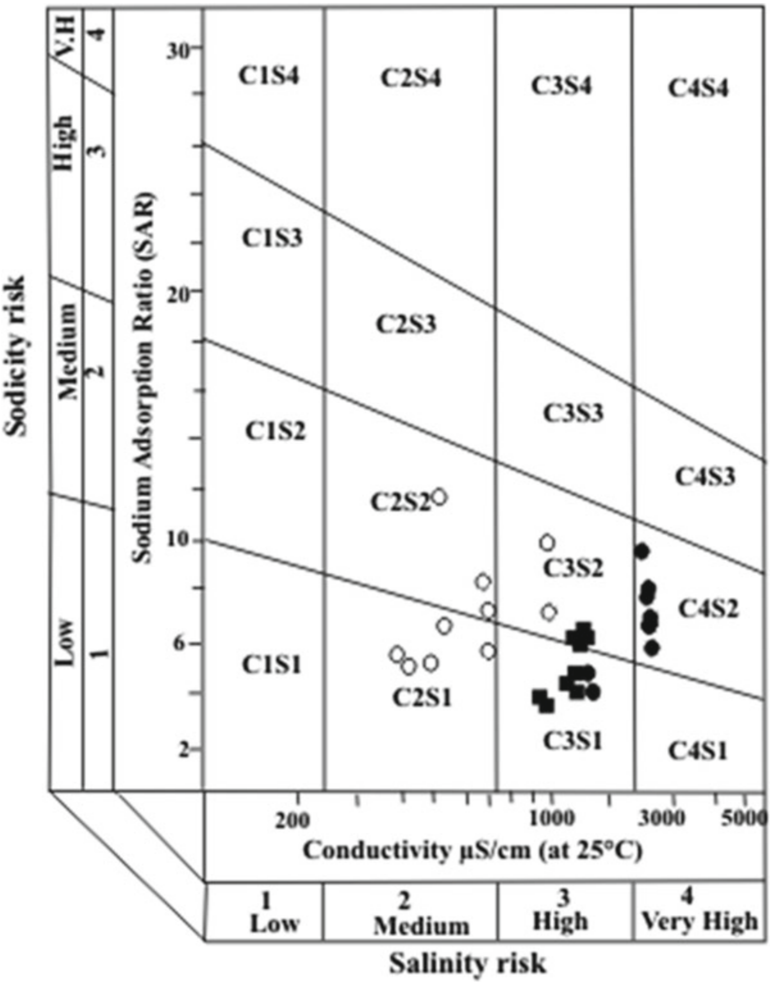

Fig. 47.3 Water quality with respect to SAR and EC

The permeability index (Fig. 47.2e) of the study area vary; in Hammam Boughrara dam, it ranges from 56.4 to 68.0, upstream of Mouillah wadi from 52.7 to 66.4 and in Ouerdefou wadi from 47.9 to 83.3.

On the basis of PI, 100% of the surface water samples collected during the study period record PI>47.9 (Fig. 47.2e), indicating the good quality of the water for irrigation purpose.

Values of Kelly's ratio (Fig. 47.2f) in the study area vary in Hammam Boughrara dam from 0.69 to 1.34, upstream of Mouillah wadi from 0.81 to 1.35 and in Ouerdefou wadi from 0.62 to 2.31. Therefore, according to Kelly's index, waters are, generally, unsuitable for irrigation during the summer period.

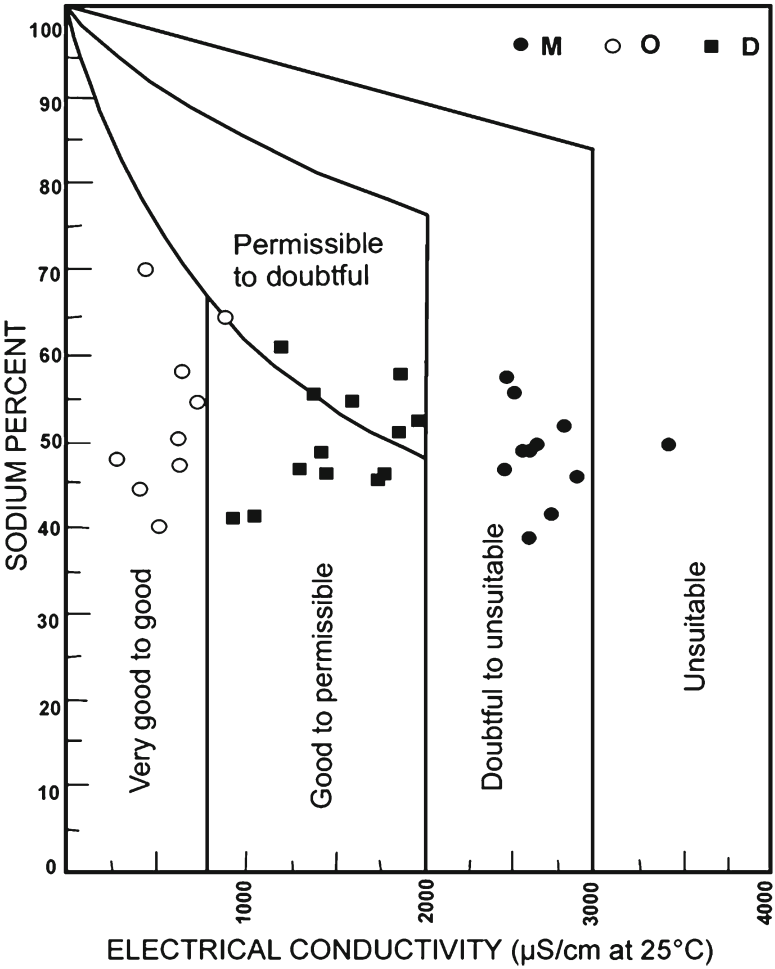

Fig. 47.4 Relationship between electrical conductivity and % sodium for rating irrigation water quality (Wilcox 1955)

The waters having a high concentration of bicarbonate have the tendency for calcium and magnesium to precipitate since the water in soil becomes more concentrated as a result of evaporation. This reaction ordinarily does not go to completion, but when it does, there is a reduction in the concentration of calcium and magnesium and a relative increase in sodium. The calcium and magnesium are precipitated as carbonates, and any residual carbonate or bicarbonate is left in solution as residual sodium carbonate (RSC) or bicarbonate hazard (Haritash et al. 2008).

Waters having RSC values greater than 5 meq L^{-1} are considered harmful to the growth of plants, while waters with RSC values above 2.5 meq L^{-1} are not considered suitable for irrigation purpose. In most of the analysed water samples, RSC values are below 2.5 meq L^{-1}; only two samples exceed 5.0 meq L^{-1} limits. They are from Ouerdefou wadi collected during the months of June and July (Fig. 47.2g).

Of all samples, 75.8% of the samples have negative RSC values and indicate that there is no complete precipitation of calcium and magnesium (Tiwari and Manzoor 1988b).

In most water samples, MH exceeds 50%, making waters unsuitable for irrigation purpose (Fig. 47.2h).

47.5 Conclusion

The hydrochemical analyses provide significant information on surface water quality for irrigation purposes in Mouillah sub-watershed. On the basis on the EC–SAR diagram, continuous application of water in the upstream of Mouillah wadi may lead to formation of saline soils. For the Hammam Boughrara dam, water reflects high salinity and low sodium concentration which can be used for irrigation on almost all types of soil with only a minimum risk of exchangeable sodium. The chloride contents are important at all the sampling sites. The use of such water can lead to plant injury which can cause early leaf drop or defoliation. The BOD_5 levels were high to very high at the sampling sites. This is due to wastewater discharged into the wadis. This problem can be overcome by installing a permanent treatment plant to treat the wastewater prior to wastewater discharge. The quasi-totality of water has negative RSC values, outside warm periods, and indicates that there is no complete precipitation of calcium and magnesium.

References

Al-Amry AB (2008) Hydrogeochemistry and groundwater quality assessment in an arid region: a case study from Al Salameh area, Shabwah, Yemen. Paper presented at third international conference on water resources and arid environments, Riyadh

Appelo CA, Postma D (1993) Geochemistry, groundwater and pollution. Balkema, Rotterdam

Ayers RS, Westcot DW (1985) Water quality for agriculture. FAO Irrigation and Drainage Paper 29 Rev 1, Rome, 174 p

Boudieb H, Braik F (2003) Etude hydrochimique des eaux de la plaine de Maghnia (NW algérien). Mem Ing, Univ Tlemcen, Tlemcen

Dahmani B, Hadji F, Benmegri MH (2008) Impact of ammonium content of Tafna wadi on water drinking supply. In: Proceedings of th 4th environmental symposium of German-Arab scientific forum for environmental studies, Fes, Morocco

Domenico PA, Schwartz FW (1990) Physical and chemical hydrogeology. Wiley, New York

Doneen LD (1964) Notes on water quality in agriculture. Water Science and Engineering, University of California, Davis

Eaton FM (1950) Significance of carbonate in irrigation waters. Soil Sci 69:123–133

Greenlee GM, Pawluk S, Bowser WE (1968) Occurrence of soil salinity in dry lands of southwestern Alberta. Can J Soil Sci 48:65–75

Gunduz O, Turkman A, Ulas D (2006) Alternative formulations for the reuse of treated wastewater in Menemen Plain irrigation scheme. In: Hlavinek P, Kukharchyk T, Marsalek J, Mahrikova I (eds). NATO, Springer, New York

Hadji F, Taleb KM, Yacouta-Nour A (2005) Pollution des eaux du bassin hydrographique de l'Oued Mouillah (N-W algérien). In: Proceedings of the $WATMED_2$ congress of water resources in mediterranean basin, Marrakech, Morocco

Halvorson AD, Rhoades JD (1976) Field mapping of soil conductivity to delineate dryland saline seeps with four-electrode technique. Soil Sci Soc Am J 40:571–575

Haritash AK, Kaushik CP, Kaushik A, Kansal A, Yadav AK (2008) Suitability assessment of groundwater for drinking, irrigation and industrial use in some North Indian villages. J Environ Monit Assess 145:397–406

Hernández JC, Orihuela DL, Marijuan I, Pérez S, Furnet NR (2003) Efecto de la modificación de cationes en columna de suelos calizos. In: Álvarez University of Salamanca Spain-Benedí J, Marinero P (eds) Estudio de la zona saturada del suelo, pp 99–104

Isaac RK, Khura TK, Wurmbrand JR (2009) Surface and subsurface water quality appraisal for irrigation. J Environ Monit Assess 159:465–473

Karanth KR (1987) Groundwater assessment, development and management. Tata McGraw-Hill, New Delhi

Lloyd JW, Heathcoat JA (1985) Natural inorganic hydrochemistry in relation to groundwater: an introduction. Oxford University Press, New York, 296 p

Nagaraju A, Suresh S, Killham K, Hudson-Edwards K (2006) Hydrogeochemistry of waters of Mangmpeta barite mining area, Cuddapah basin, Andhra Pradesh, India. Turkish J Eng Environ Sci 30:203–219

Paliwal KV (1967) Effect of gypsum application on the quality of irrigation waters. Madras Agric J 59:646–647

Raghunath HM (1987) Groundwater. Wiley Eastern Ltd., New Delhi

Rhoades JD, Ingvalson RD (1971) Determining salinity in field soil resistance measurements. Soil Sci Soc Am Proc 35:54–60

Shahid SA (2004) Irrigation water quality manual. ERWDA Soils Bulletin No 2, 31 p

Singh AK, Mondal GC, Kumar S, Singh TB, Tewary BK, Sinha A (2008) Major ion chemistry, weathering processes and water quality assessment in upper catchment of Damodar River basin. J India Environ Geol 54:745–758

Sundaray SK, Nayak BB, Bhatta D (2009) Environmental studies on river water quality with reference to suitability for agricultural purposes: Mahanadi river estuarine system, India – a case study Environ. J Environ Monit Assess 155:227–243

Szabolcs I, Darab C (1964) The influence of irrigation water of high sodium carbonate content of soils. In: Proceedings of the 8th international congress of ISSS, Trans, vol II, pp 803–812

Tiwari TN, Manzoor A (1988a) River pollution in Kathmandu valley (Nepal) suitability of river water for irrigation. Indian J Environ Prot 8(4):269–274

Tiwari TN, Manzoor A (1988b) Pollution of Subarnarekha River near Jamshedpur and the suitability of its water for irrigation. Indian J Environ Prot 8(7):49–497

Todd D (1980) Groundwater, 2nd edn. Wiley, New York, p 535

USDA (1954) Diagnosis and improvement of saline and alkali soils. US Salinity Laboratory Staff, handbook no. 60. Government Printing Office, Washington, DC

Vlek's PLG, Hillel D, Braimoh AK (2008) Soil degradation under irrigation. In: Braimoh AK, Vlek PLG (eds) Land use and soil resources book. Springer, New York

Wilcox LV (1948) The quality of water for irrigation use. US Department of Agricultural Technical Bulletin, 1962, Washington, DC

Wilcox LV (1955) Classification and use of irrigation waters. US Department of Agricultural Circulation 969, 19 p

Chapter 48
Water Use Efficiency for Leaching Saline-Sodic Clayey Soils: Case Study of Tina Plain Area of Egypt

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Abstract In Egypt, saline-sodic clayey soils represent approximately 109,200 ha of the delta. At present these areas are either of poor or low quality mainly due to salinity and sodicity problems. In Tina Plain area of North Sinai, there are about 6,300 ha of problematic saline-sodic clayey soils. Tina Plain area of North Sinai is one of the three regions of the reclamation areas under El-Salam canal development project. It represents the first region of the project. This project envisages the reclamation of an area of 170,000 ha. Therefore, it is important to measure the water use efficiency for leaching saline-sodic clayey soils in this area using irrigation water from El-Salam canal to evaluate the agro-economic value of this project. The study was conducted in an experimental field of saline-sodic clayey soils in Tina Plain area. The experimental field has an actual area of 25 ha. The soil is saline with heavy clay texture, poor drainage, shallow groundwater tables and 30-cm surface salt layer. From the site characteristics it is realistic that the most appropriate strategy for this stage of reclamation is to apply intermittent leaching and surface drainage. This strategy succeeded to remove the salt layer within 6 months of leaching. The study was extended for 1 year. The results indicated that 2.9 t of salts were leached for each hectare per day with irrigation water quantity of 223 m^3. The average soil salinity before leaching was 400 dS m^{-1} (0–50 cm) and 300 dS m^{-1} (50–150 cm). Leaching decreased the soil salinity at the surface layer to about 100 dS m^{-1} with leaching efficiency of 75%. For the other layer, EC decreased to 150 dS m^{-1} with leaching efficiency of 50%. The water table depth below ground surface was lowered from 0.16 m to about 0.86 m below ground surface. This indicates that the soil properties also improved due to the salt leaching process.

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Keywords Delta • Egypt • Leaching • Reclamation • Saline-sodic

48.1 Introduction

The ideal soil should have good water-storing capacity during dry periods and a good drainage condition during the rainy season. Such characteristics require soil to have sufficient pores and should resist to the disaggregating action of water. Clayey soils are some of the most productive soils in the world. They have a moderate to high fertility and a high water-holding capacity. They are often found in densely populated low-lying alluvial or coastal plains, making them particularly attractive for irrigated agriculture in arid and semiarid regions (Pannell 2001a).

In Egypt, the total agricultural land is about 3.36 million ha that are almost entirely depending on irrigation (Abu El Azz 1971). The Delta of the Nile is one of the most fertile and intensively cultivated regions in the world. Figure 48.1a shows the soil characteristics of the Nile Delta. The heavy clay soils represent approximately 109,200 ha of the delta, and in many instances, the saline and sodic problems are associated with heavy clay soils (DRI 2001). The saline-sodic clayey soils suffered from high groundwater table and high temperature that led to the salinisation of the soil profile to extremely high levels. The high salinity of the groundwater table led to the formation of salt crusts and increased the soil sodium content (Abdel et al. 2006). However, to face the increasing demands for food production, increased attention has been given to reclaim, improve and manage saline-sodic clayey soils to solve salinity problems and achieve optimal crop production (Sallam 2007).

Salinity in clayey soils is seen as one of the most serious environmental and resource management problems. It has many environmental, economic and social impacts. The adverse effects of salinity in agriculture include (Pannell 2001b) (1) significant losses of productivity in agriculture, with some land entirely out of production; (2) damaged soil structure and increasing content of toxic substances that may limit plant growth; and (3) more serious soil erosion, both by wind and by water, due to worsening of soil structure and reduction of vegetation cover.

The risk of soil salinisation is particularly acute in clayey soils, because there is no economical viable method for controlling salinity in this case. Therefore, there is an urgent need to establish the sustainable and economical limits for amelioration of saline-sodic clayey soils (Armstrong et al. 1996). There have been major government programmes aiming to increase farmers' adoption of management practices for salinity prevention. The long-term solution to salinity is to restore the balance of inputs and outputs of the soil-water system, by controlling the process of groundwater recharge. Treatment of salt-affected land is an important component of salinity management, and one of the most important factors in controlling salinity is an adequate supply of irrigation water such that a net downward water movement through the root zone is maintained. Therefore, leaching is the basic requirement for successful amelioration of saline-sodic clayey soils (Rycroft and Amer 1995).

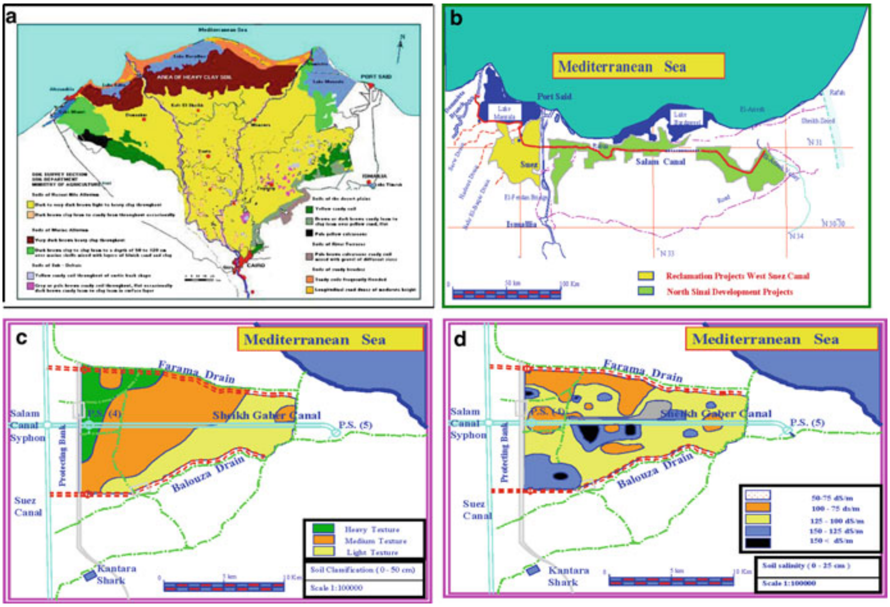

Fig. 48.1 Soil characteristics of the Nile Delta (**a**), the layout of El-Salam canal development project (**b**), soil classification map (DRI 1997) in Tina Plain area (**c**) and soil salinity map (DRI 1997) in Tina Plain area (**d**)

The selection of leaching method depends on soil type, soil salinity, leaching water quality and availability and climate. Application of leaching water can be applied as continuous ponding, intermittent ponding, border irrigation or sprinkler irrigation. Each of the former types has advantages and disadvantages according to the surrounding and prevailing conditions. Intermittent and continuous leaching processes are the main methods of salts leaching.

Continuous ponding is the traditional leaching method used all over the world, as it is used in surface irrigated fields. It depends on flooding the field plot, with water, and allowing the water level to rise up to several centimetres above the ground surface. The waterhead formed by the ponding depth is the driving force that is forcing the salts to dilute and to be drained easily. It is a common practice to perform land management with this type of leaching, such as land levelling, subsoiling and ploughing (Talsma 1967). It is considered the easiest leaching method as it does not necessitate many side activities.

Intermittent leaching is based on applying a set amount of water to the leaching plot and allowing this set amount to be drained completely to the drains. The idea is to give the water table the chance to draw down. Sometimes, intermittent leaching is combined with mulching to improve its performance (Keren 1990). Abdel et al. (2006) indicated that the two methods of leaching are effective for salt removal, with superiority for the intermittent leaching. The quantity of salts removed per unit quantity of water leached can be increased by intermittent sprinkling or frequent, small applications of surface water at average rates less than the infiltration rate of the soil. The intermittent leaching is also the optimum to improve soil physical properties such as pore size distribution and infiltration rate. It also saves more than 30% of the net applied water needed as compared to the continuous leaching method.

In arid and semiarid regions, the crop production is largely dependent on the availability of water for irrigation. In case of Egypt, about 98% of its fresh water resources come from outside its international borders (MWRI 2002). The main water resources in Egypt are represented with the Nile River which provides the country with more than 95% of its water requirements. The quota of Egypt from the Nile River water equals to 55.5 billion m^3 $year^{-1}$ (Allam 2004).

Nowadays, there is still a gap between the available water resources and water demand for agriculture purposes to meet the demand for food production. This is considered to be a main challenge for water policy and decision makers. Therefore, the main objective of this study is to measure the water use efficiency for leaching saline-sodic clayey soils using irrigation water from El-Salam canal to evaluate the agro-economic value of reclaiming these soils to increase its agricultural productivity for the changing face of population in Egypt.

48.2 Materials and Methods

The study was conducted in an experimental field of saline-sodic clayey soil characteristics of the Nile delta are given Fig. 48.1a. Tina plain area of North Sinai developing project is one of the three regions of the reclamation areas under El-Salam canal project and representing the first region of the project (Fig. 48.1b). This project envisages the reclamation of an estimated 170,000 ha. The soil texture in Tina Plain area as shown in Fig. 48.1c varies from sand to clay; the heavy clay soil area is only located at the north-western part of the area (DRI 1997). The soil salinity of Tina Plain area is represented in Fig. 48.1d. The soil salinity in the most area is ranged between 100 and 125 dS m^{-1}.

The experimental field was selected to represent the saline heavy clay soil in Tina Plain area. It has an actual area of 25 ha (about 60 feddans, 1 feddan = 0.42 ha). It is located in the western part of Tina Plain area. The main properties of the field (Table 48.1) indicated that it is characterised with saline heavy clay soil with average clay (56.43%) and soil salinity (EC 380 dS m^{-1}). Due to high clay content, it has poor drainage conditions, 30 cm of surface salt crust (Fig. 48.2a), and shallow saline groundwater (Table 48.2b). The high values of soil hydraulic conductivity ($K = 0.2$ m day^{-1}) and the infiltration rate (IR = 0.02 cm min^{-1}) could be attributed to the high soil salinity and the salt layer on the soil surface (DRI 2007).

Due to the main characteristics of the area, the recommended strategy followed for reclamation is to apply intermittent leaching with surface irrigation and surface drainage. The experimental area was divided into four units (A, B, C and D). Total area of Unit A is (37,195 m^2), Unit B (48,816 m^2), Unit C (39,160 m^2) and Unit D (49,720 m^2). The required network of surface irrigation canals and surface field

Table 48.1 Soil properties of the experimental area prior to leaching

Properties	Average value
EC_e (electrical conductivity of soil saturation extract in dS m^{-1})	380
SARs (sodium adsorption ratio of soil) (mmoles $L^{-1})^{0.5}$	83
K (soil hydraulic conductivity, m day^{-1})	0.2
IR (infiltration rate, cm min^{-1})	0.02
EC_{iw} (salinity of irrigation water, dS m^{-1})	1.5
WTD (water table depth, m)	0.1
EC_{gw} (EC of groundwater, dS m^{-1})	125

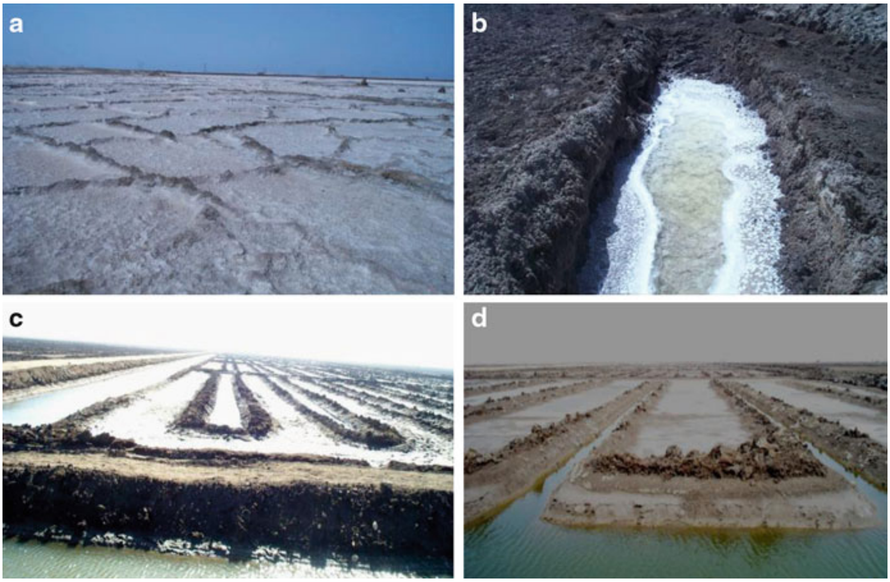

Fig. 48.2 Experimental area, surface salt crust (**a**), shallow groundwater table (**b**), leaching process (**c**) and after removing surface salt crust (**d**)

drains was constructed in the area as shown in Fig. 48.3. To apply the recommended reclamation strategy, each unit was provided with surface irrigation ditches and open field drains spaced at 10 m with depth of 100 cm.

The intermittent leaching was applied with irrigation water pumped from El-Salam canal (EC 1.5 dS m^{-1}). The El-Salam canal water is mixed water from reused agricultural drainage water and fresh Nile water (1:1). The leaching method was adopted to remove excess salts from the root zone or top soil layer through leaching water over the surface and applying of excess water, above that needed for evaporation, and allowing it to pass downwards to leach the soluble salts from the root zone through the field surface drains.

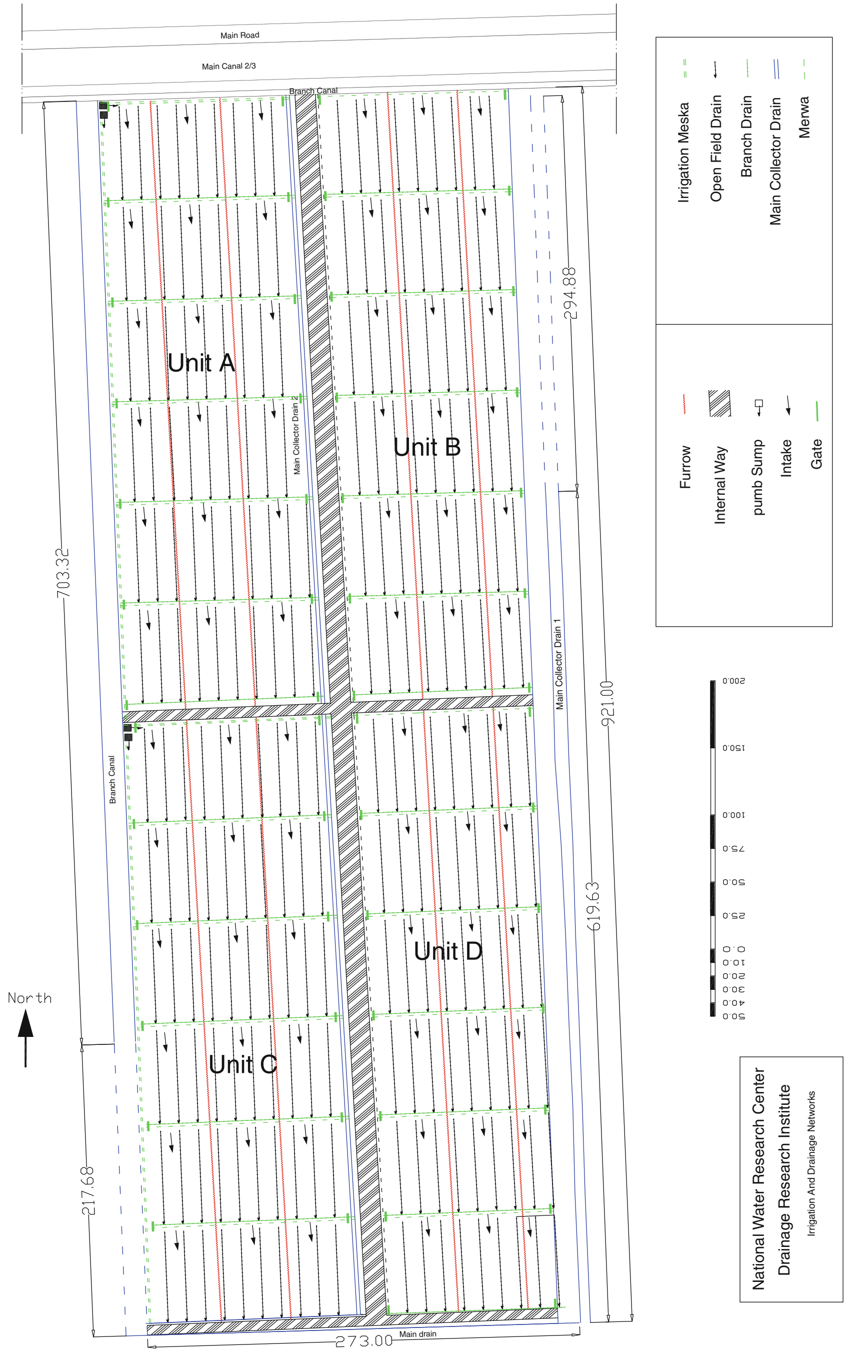

Fig. 48.3 Layout of the experimental field

The leaching proceeded in the area for about 1 year with thirteenth rotation of irrigation and drainage. The quantity of irrigation water that was pumped to each unit of the area was measured according to the drainage of the irrigation pumps in the area, and the quantity of the salts removed was calculated to determine water use efficiency in leaching saline-sodic clayey soils. Soil samples from each unit were collected after each rotation of leaching at 25-cm intervals to 150-cm depth. Soil samples were analysed to follow up the changes in soil salinity through the soil profile during leaching process. The groundwater table depth and some other soil physical characteristics such as the hydraulic conductivity and the infiltration rate for the surface soil layer treated with leaching were also determined to study the effect of leaching on these characteristics.

48.3 Results and Discussion

The leaching procedure comprises the water application and the drainage. Water was applied to the experimental area to saturate sufficient depth such as equivalent to the soil profile (Fig. 48.2c). The area was submerged with water for a period of about 10–15 days to permit the dissolution of salts. Then, the water is induced to flow through the soil profile, and as it does so, it leaches the excess salts away from the soil and transports it to the surface drainage system. The drainage process was extended for a period varied between 10 and 15 days. The leaching procedure with its two stages was repeated for thirteenth times (rotations) in the four units of the area over a period time of 1 year. The quantities of applied water for each leaching

Table 48.2 Applied water quantities for leaching process and loaded salts

	Unit A		Unit B		Unit C		Unit D	
Leaching rotations	IWQ (10^3 m^3)	Salts (t)	IWQ (10^3 m^3)	Salts (t)	IWQ (10^3 m^3)	Salts (t)	IWQ (10^3 m^3)	Salts (t)
1st rotation	26.6	25.1	Under construction		27.05	25.5	Under construction	
2nd rotation	27.3	20.6			26.66	20.1		
3rd rotation	27.7	22.7			27.44	22.4		
4th rotation	27.7	24.4			27.44	24.1		
5th rotation	27.7	24.4	28.5	25.9	27.05	23.8	28.39	26
6th rotation	27.7	26.1	28.06	28.7	26.66	25.1	29.39	27.4
7th rotation	26.6	25.1	27.08	27.7	25.48	24	28.39	26.5
8th rotation	27.3	22.4	26.1	25.3	26.66	21.8	29.88	22.1
9th rotation	27.7	22.7	25.62	22	27.44	22.4	25.91	21.7
10th rotation	27.7	24.4	26.59	24.6	27.44	24.1	26.90	24.3
11th rotation	27.7	22.7	28.55	25.3	27.44	22.4	29.88	24.2
12th rotation	27.7	22.7	28.55	25.3	26.66	21.8	29.88	24.2
13th rotation	28.4	21.5	29.52	23.3	27.44	20.7	29.88	23.1
Total	357.8	304.8	248.57	228.1	351.08	298.2	258.49	219.5

IWQ irrigation water quantity

Table 48.3 Drainage water quantities and removed salts during leaching process

Leaching rotations	Unit A DWQ (10^3 m^3)	Unit A Salts (t)	Unit B DWQ (10^3 m^3)	Unit B Salts (t)	Unit C DWQ (10^3 m^3)	Unit C Salts (t)	Unit D DWQ (10^3 m^3)	Unit D Salts (t)
1st rotation	23.6	586.6	Under construction		23.9	569.6	Under construction	
2nd rotation	23.2	584.5			22.7	555.3		
3rd rotation	24.0	624.6			23.1	594.1		
4th rotation	22.9	609.3			22.3	573.5		
5th rotation	23.2	626.7	28.5	640.8	23.1	608.6	23.9	855.2
6th rotation	24.0	678.8	28.0	673.7	23.1	478.2	23.4	767.7
7th rotation	23.6	629.6	27.0	669.8	22.7	615.1	24.4	794.4
8th rotation	24.0	564.4	26.1	593.9	23.1	630.3	23.9	749.3
9th rotation	24.7	543.5	22.6	1,019	24.3	963.2	22.9	1,046.4
10th rotation	24.3	489.3	22.2	858.5	23.9	418.2	22.4	851.5
11th rotation	24.7	465.8	24.6	657.3	24.3	451.1	25.9	621.2
12th rotation	24.3	428.1	24.1	646.8	24.7	449.3	25.4	620.1
13th rotation	25.8	422.3	25.6	618.6	24.7	418.3	25.9	618.5
Total	312.3	7,253.5	228.7	6,378.4	305.9	7,324.8	218.1	6,924.3

DWQ drainage water quantity

rotation and for each unit are shown separately in Table 48.2; Table 48.2 also presents the quantity of salts added to the soil with irrigation water. Moreover, the quantities of drainage water for each leaching period are also represented in Table 48.3, and consequently, the quantity of leached salts is calculated.

The results in Table 48.2 revealed the total quantities of water used for the thirteenth leaching rotations are 357,800, 248,570, 351,080 and 258,490 m^3 for Unit A, Unit B, Unit C and Unit D, respectively, with total amount of 1,215,940 m^3. This amount of water added salts quantity equals to about 304.8, 228.1, 298.2 and 219.5 t, respectively, with total amount of 1,050.6 t. On the other hand, the results shown in Table 48.3 indicated that the drainage water quantities for the different units are 312,300, 228,700, 305,900 and 218,100 m^3, respectively, with total amount of 1,065,000 m^3. The amount of salts removed with drainage water are 7,253.5, 6,378.4, 7,324.8 and 6,924.3 t for Unit A, Unit B, Unit C and Unit D, respectively, with total amount of 27,881.0 t.

Consequently, the net quantity of leached salts from the soil profile (Table 48.4) was calculated as the difference between the removed salts with drainage water and the added salts from irrigation water.

Table 48.4 and Fig. 48.4a indicated that the leached quantities of salts are equal to about 6,948.7 t for Unit A, 6,150.8 t for Unit B, 7,026.6 for Unit C and 6,704.8 for Unit D with total amount of 26,830.9 t. It could be concluded that about 2.9 t of salts were leached for each hectare per day with irrigation water quantity of 223 m^3.

The variations in soil salinity for Units A, B, C and D are shown in Fig. 48.4b–e, respectively. The soil salinity before leaching for the surface soil layer (0–50 cm) was ranged from 370 to 440 dS m^{-1} with an average value of about 400 dS m^{-1}. On the other hand, the soil salinity for the other layer (50–150 cm) was ranged from 260

Table 48.4 Quantities of leached salts from soil during leaching process

Leaching rotations	Removed salts (t)				
	Unit A	Unit B	Unit C	Unit D	Total
1st rotation	561.5	Under construction	544.1	Under construction	1,105.6
2nd rotation	563.9		535.2		1,099.1
3rd rotation	601.9		571.7		1,173.6
4th rotation	584.9		549.4		1,134.3
5th rotation	602.3	614.9	584.8	829.2	2,631.2
6th rotation	652.7	645	453.1	740.3	2,491.1
7th rotation	604.5	642.1	591.1	767.9	2,605.6
8th rotation	542	568.6	608.5	727.2	2,446.3
9th rotation	520.8	997.5	940.8	1,024.7	3,483.8
10th rotation	464.9	833.9	394.1	827.2	2,520.1
11th rotation	443.1	632	428.7	597	2,100.8
12th rotation	405.4	621.5	427.5	595.9	2,050.3
13th rotation	400.8	595.3	397.6	595.4	1,989.1
Total	6,948.7	6,150.8	7,026.6	6,704.8	26,830.9

to 340 dS m^{-1} with an average value of 300 dS m^{-1}. After leaching process, it was found that the soil salinity for surface layers is decreased to an average value of about 100 dS m^{-1} with leaching efficiency of 75% as shown in Fig. 48.4f. For the other layers, it was decreased to an average value of about 150 dS m^{-1} with leaching efficiency of 50% as shown in Fig. 48.4.

The data also revealed that the water table is lowered from 0.16 m to about 0.86 m below soil surface. This is attributed to the fact that the soil is improved due to the salt leaching from the soil and slight improvement in soil properties. It was also found that after leaching process, the hydraulic conductivity of the soil reaches to about 0.16 m day^{-1}, and the infiltration rate also ranges from 0.01 to 0.02 cm min^{-1}. This could be attributed to the removal of the salt layer from the soil surface (Fig. 48.2d) and retrieving the soil for its natural characteristics of heavy clay soil.

48.4 Conclusions

Large quantity of water requires leaching saline-sodic clayey soil to reduce surface soil salinity. The presence of salts in soil matrix restricts its removal through mechanical means before leaching process. Even though, the disposal of large quantities of salts may cause problem to other sites. We found that the intermittent leaching is the most recommended alternative available for the area. Moreover, though not tested but can be recommended to use gypsum amendment with leaching process to rectify sodicity problem. Different drainage technologies, surface drainage, subsurface drainage, mole drainage, deep ploughing and subsoiling can also be used

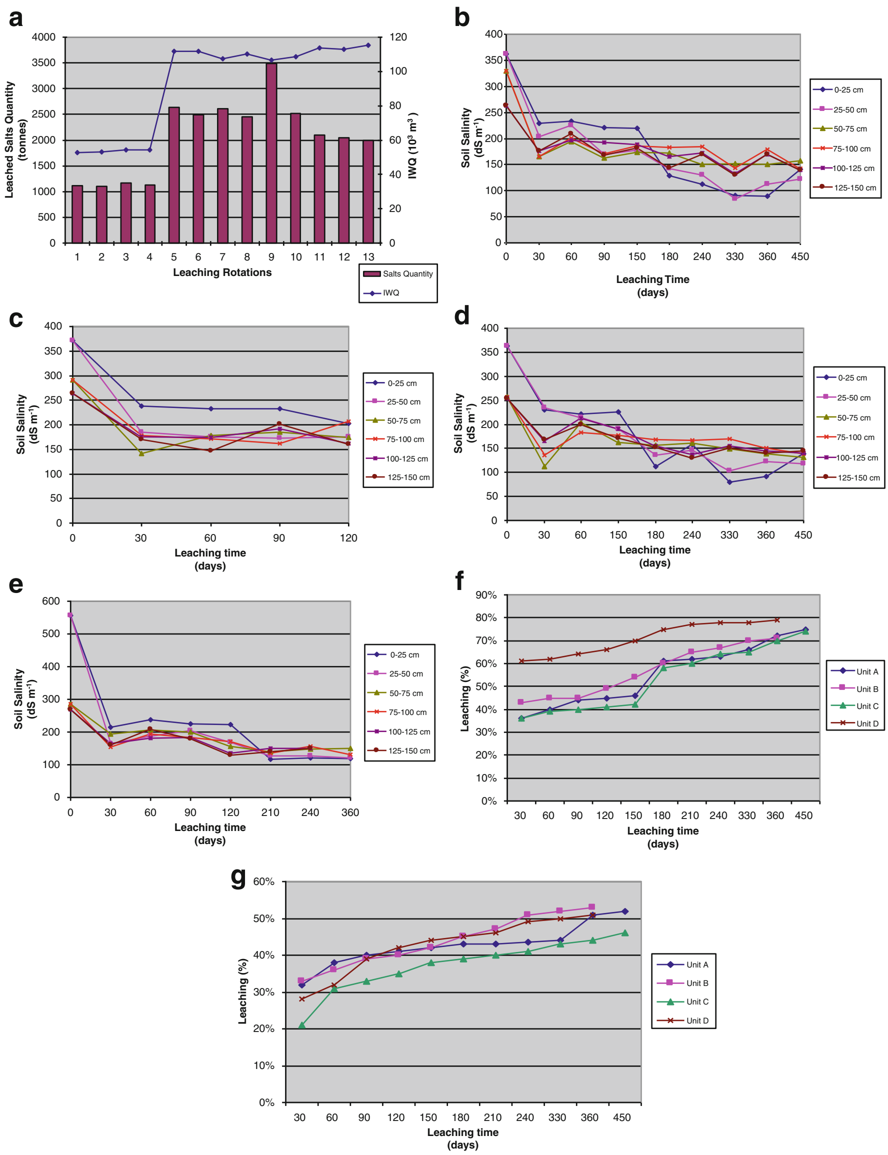

Fig. 48.4 Leaching rotation and quantity of leached salts (**a**), Variation of soil salinity for Unit A (**b**), Variation of soil salinity for Unit B (**c**), Variation of soil salinity for Unit C (**d**) Variation of soil salinity for Unit D (**e**), Leaching efficiency for surface layer (0–50 cm) (**f**), Leaching efficiency for lower layer (50–150 cm) (**g**)

based on site-specific conditions, where appropriate. It is recommended to provide farmers the guidelines for the reclamation of saline-sodic clayey soils in Egypt.

References

Abdel NG, Sallam GAH, Rashad M (2006) Improving the physical properties of salt affected clayey soils associated with leaching techniques in Tina Plain. In: Proceedings of the third Arab water conference, Cairo, Egypt, 9–11 Dec 2006, p 45

Abu El Azz MS (1971) Landforms of Egypt. The American University in Cairo Press, Cairo

Allam MNE (2004) Introduction to irrigation and engineering. Lectures, Faculty of Engineering, Cairo University, Cairo

Armstrong AB, Hughes EJ, Rycroft DW, Tanton TW, Perarce GR, Abbott CL (1996) Reclamtion of saline clay soils: a manual of horizontal leaching technique. Institute of Irrigation Studies, University of Southampton, Wallingford

DRI (Drainage Research Institute) (1997) Salt leaching and land reclamation study, Tina Plain – Sinai, Part I and III, Drainage Research Institute, El Kanater

DRI (Drainage Research Institute) (2001) Reclamation, improvement, management of clay soils for optimal crop production. DRP 2 technical report TR 118. Drainage Research Institute, El Kanater, p 105

DRI (Drainage Research Institute) (2007) Leaching process of the first experimental field of heavy clay soils in Tina Plain Area. DRI technical report (Arabic Reference). Drainage Research Institute, El Kanater, p 78

Keren R (1990) Reclamation of saline, sodic and boron affected soils: drainage for salinity control, agriculture salinity assessment and management, ASCE manuals and reports on engineering practice No. 71, Scientific Publishers, Jodhpur, pp 410–431

MWRI (Ministry of Water Resources and Irrigation) (2002) Adopted measures to face major challenges in the Egyptian water sector. From the Hague 2nd World Forum 2000 to The Kyoto 3rd World Water Forum 2003. A report presented to the World Water Council in the 3rd World Water Forum

Pannell DJ (2001a). Salinity policy: inevitable, inequitable, intractable. In: Presidential address, 45th annual conference of the Australian Agricultural and Resource Economics Society, Adelaide, 23–25 January 2001. SEA working paper 2001/01, Agricultural and Resource Economics, The University of Western Australia, Crawley

Pannell DJ (2001b) Dryland salinity: economic, scientific, social and policy dimensions. Aust J Agric Resour Econ 45(4):517–546

Rycroft DW, Amer MH (1995) Prospects for the drainage of clay soils. FAO irrigation and drainage paper. FAO, Rome

Sallam GAH (2007) Utilizing expert system for comprehensive management of saline sodic clay soils. In: Presentation at eleventh international water technology conference 2007, Sharm El-Sheikh, Egypt, 15–18 Mar 2007

Talsma T (1967) Leaching of tile drained saline soils. Aust J Soil Res 5:37–46

Chapter 49
The Performance of Sunflower, Turnip and Forage Corn in Uptaking Some Essential Elements and Cadmium Under Wastewater Irrigation

Hamid Molahoseini and Mohammad Feizi

Abstract The objective of the present study was to investigate the potential of some plants to uptake and accumulate some essential elements and cadmium in soils under wastewater irrigation. The study was performed in the farmer's field in 2005 at Varamin region located in the south of Tehran, Iran. The soil at the studied site belongs to Shahr-e-Ray Series and soil taxa "*Fluventic Camborthids*". The sunflower, turnip and forage corn were selected for the investigation. The wastewater was used for irrigation purpose. The experiment was laid out in a randomized block design (RBD), and treatments were triplicated. The sunflower, turnip and forage corn plants were harvested in 2005, and the plants were separated into roots and aboveground material. The results showed the highest concentration of nitrogen, phosphorus, zinc, copper and cadmium was 6.05%, 1.27%, and 97.27, 22.84 and 0.54 mg kg^{-1} in sunflower, respectively, and the most accumulations of nitrogen, phosphorus, zinc and copper were in grain and cadmium in the leaf. The concentration of potassium and nitrate was 5.79 and 8.26% in turnip, respectively, and the high accumulation of potassium and nitrate was in leaf. The highest concentration of iron and manganese was 349.56 and 144.78 mg kg^{-1}, respectively, in forage corn. The results suggest that the lands irrigated with wastewater with excessive amount of essential elements and cadmium can support sunflower cultivation through uptake of sufficient quantities by selected crops.

Keywords Elemental concentration • Forage corn • Soil remediation • Sunflower • Wastewater

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49.1 Introduction

The nutrient availability changes continuously due to the application of macro- and micronutrients and other trace elements through the application of fertilizers, biosolids, irrigation with wastewater or indirect sources (car exhausts, rainfall and atmospheric deposition from several sources, etc.). Soils, as filters of toxic chemicals, may adsorb and retain heavy metals from wastewater. However, when the capacity of soils to retain toxic metals is reduced due to continuous loading of pollutants or changes in pH, soils can release heavy metals into groundwater or soil solution available for plant uptake. The effects of wastewater irrigation on the availability of some micronutrients and heavy metals in calcareous soil in the south of Mosul, Iraq, showed that the concentration of Fe, Zn, Mn and Cu as micronutrients and Pb, Ni and Cd as heavy metal increased (Meani et al. 1993). Microbial decomposition of organics in wastewater can also release heavy metals into soil solution. But, because of their low solubility and limited uptake by plants, heavy metals tend to accumulate in surface soil and become part of the soil matrix (McGrath et al. 1994). With repeated wastewater applications, heavy metals can accumulate in soil to toxic concentrations for plant growth. The long-term effects of irrigation with wastewater in the south of Tehran, Iran, showed that the available concentration of organic carbon (OC), P, K, Zn, Cu, Cd, Pb and Ni was more than those in control soils (Molahoseini 2001) without significant decrease of wheat and forage corn yield. This practice can lead to reduce the amount of nitrogen, phosphorus and potassium required for crops to less than 75% of the recommended doze determined through soil tests in the laboratory (Molahoseini 2003, 2005).

The results of heavy metal contents of crops in the south of Tehran, Iran, showed that the maximum accumulative concentration of these metals occurs in the order of leaf > tuber > root > stem > fruit > seed. The greatest uptake was found in turnip, lettuce, radish (leaf), sugar beet (leaf) and spinach, while the least was in rice and wheat (grain) and beetroot (Shariati et al. 1998). Phytoremediation is one of the environmental friendly technologies that use plants to clean up soil from heavy metal and trace element contamination.

The uptake and accumulation of pollutants vary from plant to plant and also from species to species within a genus (Singh et al. 2003). Another agronomic principle, which has been neglected in phytoremediation research, is crop rotation. Because of the proliferation of weeds, predators and diseases, which can cause significant yield reduction, crops, including those used for soil remediation, must be rotated. In general, crops are rotated less frequently today than 30 years ago. From crop science, it can be extrapolated that short-term (2–3 years) monoculture (the use of the same species in consecutive seasons) may be acceptable for metal phytoremediation.

However, for longer-term applications, as most metal phytoextraction projects are anticipated, it is unlikely that successful metal clean up can be achieved with only one remediative species used exclusively in monoculture. Plant rotation is even more important when multiple crops per year are projected (Lasat et al. 2000). In general terms, the macronutrient and micronutrient concentrations for the three crops were lower than that showed by Plank et al. (1995). The normal range of nitrogen (N), phosphorus (P), potassium (K), Iron (Fe), Manganese (Mn), Zinc (Zn) and copper (Cu) was reported in the range of 3–5, 0.3–0.5 and 3–5% and 100–200, 50–100, 50–70 and 10–20 ppm in sunflower; 3–5.5, 0.35–0.8 and 3–5% and 80–370, 30–100, 20–70 and 3–10 ppm in turnip; and 3–3.5, 0.25–.045 and 2–2.5% and 30–200, 15–300, 15–60 and 3–15 ppm in forage corn, respectively (Plank et al.1995). The normal range of cadmium (Cd) was 0.2–0.8 ppm in all of the plants (Ross 1996), and normal range of nitrate (NO_3) ion was less than 0.45% (Maynard 1978).

The long-term effects of soils under wastewater irrigation in the south of Tehran, Iran, cause to increase the available concentration of OC, P, K, Zn, Cu, Cd, Pb and Ni more than control soils. This study was carried out to evaluate plant potential of sunflower, turnip and forage corn to uptake and accumulate some essential elements and cadmium in soils under wastewater irrigation located south of Tehran.

49.2 Materials and Methods

49.2.1 Study Site

The average annual rainfall in the study area is about 173 mm; therefore, it is situated in the arid zone (Table 49.1). Field experiment was conducted by irrigating the plots with wastewater. The experiment was conducted in the south of Tehran, Iran

Table 49.1 Climate data of the area of study

	Temperature °C		Precipitation	Relative humidity (%)		
Months	Av. maximum	Av. minimum	Total (mm)	03 GMT	09 GMT	Average
January	8	−1.4	31.6	75	53	64
February	20	0.2	33.8	66	41	53
March	16	4.7	35.2	60	35	47
April	21	9.5	22.2	55	30	42
May	28	15.4	15.2	42	21	31
June	33	19.7	2.6	32	16	24
July	36	22.7	1.8	32	17	24
August	35	22.0	1.8	30	16	23
September	31	17.9	1.3	31	18	24
October	25	12.1	7.9	44	26	35
November	16	5.5	24.3	61	35	48
December	10	0.6	25.8	70	45	57
Total			173.2			

Station name: Tehran-Mehrabad
Latitude 35 4; longitude 51 19; elevation 1,191 m
Year of record: 1975–2003
Climatic type: Xerothermomediterranean

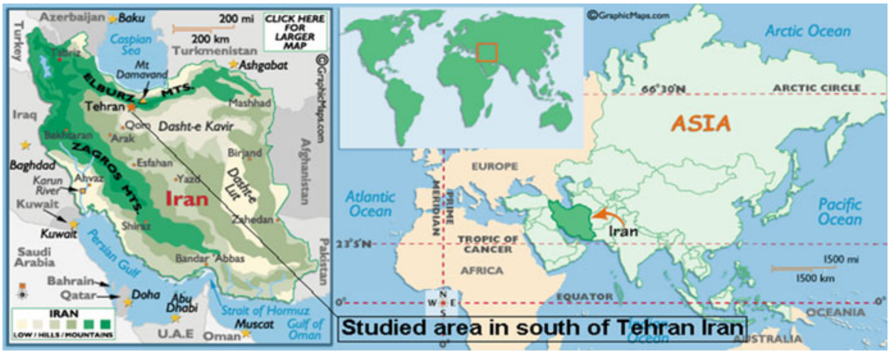

Fig. 49.1 Site location map

Fig. 49.2 View of experimental plots showing different crops

(Fig. 49.1). The general view of experiment is shown in Fig. 49.2. The soil at the study site belongs to Shahr-e-Ray Series (total area of Shahr-e-Ray Series is 3,290 ha). The soil profile displayed a cambic horizon in the upper 1 m from soil surface and has been located in River Alluvial Plain (Table 49.2). The soil taxa at soil family level based on USDA soil taxonomy is “Fine Mixed, Thermic, Fluventic Camborthids” (Iravani, 2000). The basic soil characteristics (0–30 cm) are given in Table 49.3. The studied site is slightly alkaline in reaction and silty clay loam in texture.

It is worth emphasizing that the selected site was previously used for wheat cultivation, where wheat was harvested in July. The site was properly prepared for the experiment. The sunflower, turnip and forage corn were planted to investigate the ability of the different parts of plants to accumulate some elements. The cultivars

Table 49.2 Soil profile description related to Shahr-e-Ray Series

Depth (cm)	Horizon	Texture	Sand (%)	Silt (%)	Clay (%)	Sp	ECe (dS m^{-1})	pH	OC (%)	Av. P (ppm)	Av. K (ppm)	$CaCO_3$ (%)
0–20	Ap	SiCl	14	52	34	49	1.6	7.9	0.6	11.7	340	18
20–60	B1	SiC	13	45	42	43	0.9	8.2	0.3	3.2	380	19
60–100	B21	SiC	11	46	43	48	1.3	8.1	0.2			15
100–150	B22	SiC	14	43	43	47	1.2	8.1	0.2			15

Depth (cm)	Horizon	SAR (mmoles L^{-1})$^{0.5}$	CEC ($cmol^{+}$ kg^{-1})	ESP
0–20	Ap	3.0	12	3
20–60	B1	2.0	15	2
60–100	B21	2.8	18	2
100–150	B22	2.5	17	2

SP saturation percentage, *ESP* exchangeable sodium percentage, *CEC* cation-exchange capacity, *SiCl* silty clay loam, *SiC* silty clay

Table 49.3 Soil characteristics (0–30 cm) of the experimental site

Soil characteristics	Units	Quantity
Organic carbon	%	1.26
EC	dS m^{-1}	1.5
SAR	(mmoles L^{-1})$^{0.5}$	3
ESP	%	3
CEC	$cmol^{+}$ kg^{-1}	12
Gypsum	%	0
Total N	%	0.013
Available P	mg kg^{-1}	72
Available K	mg kg^{-1}	287
Fe	mg kg^{-1}	21.6
Mn	mg kg^{-1}	9.1
Zn	mg kg^{-1}	10.0
Cu	mg kg^{-1}	7.5
pH (soil extract)	Slightly alkaline	7.5
Sand (2–0.05 mm)	%	14
Silt (0.05–0.002 mm)	%	49
Clay (<0.002 mm)	%	37
Textural class	Silty clay loam	–

of sunflower, turnip and forage corn were Hyson33, Native and Single Cross 704, respectively. The wastewater irrigation scheduling was with the interval of 6 days, and 10 cm (4 in.) water was applied per irrigation. The fertilizer was applied based on soil testing. The experiment was conducted during 2005 and 2006, using randomized block design, with three replications in a net plot size of 30 m^2.

49.2.2 Plant Sampling and Analysis

In the autumn of 2005, three plant samples per plot were collected. Each sample was a composite of two plants taken in the centre of the experimental plot. Each sample was separated into roots, aboveground materials (shoots, leaves, etc.) and grains, dried at 75°C in an oven, and then weighed, grounded, homogenized and a representative subsample analysed.

The samples were analysed for N using Kjeldahl apparatus; Olsen P was determined colorimetrically, and K was determined by using flame emission spectroscopy. The cadmium and trace elements (Cd, Cu, Fe, Mn and Zn) were extracted using DTPA (diethylenetriamine pentaacetic acid (DTPA)) and determined by atomic absorption spectrophotometer. In all cases, standard procedures described by Sparks et al. (1996) were used.

49.2.3 Statistical Analysis

All data were subjected to analysis of variance (ANOVA), and when significant differences ($p < 0.05$) were detected, Duncan's test was performed to allow separation of means.

49.3 Results and Discussion

49.3.1 Mineral Composition of Plant Components

The analysis of variance of N, P, K, Fe, Mn, Zn, Cu and nitrate ion in grains shows highly significant effect ($p < 0.01$), whereas cadmium has shown significant effect ($p < 0.05$). The analysis of variance of N, P, K, Fe elements and nitrate ion in leaf and root of the plant treatments had high significant effect ($p < 0.01$). The analysis of variance of N, P, K, Zn, Cu and Mn elements and nitrate ion in the stem of the plants had high significant effect ($p < 0.01$). The mean mineral composition of roots and aerial biomass (leaf, stem and grain) of each crop are shown in Tables 49.4 (macronutrients) and 49.5 (micronutrients).

49.3.2 Macronutrient Concentrations of Crops

The concentrations of the studied macronutrients N, P, K and NO_3 showed some differences according to the plant treatment and their components. The highest concentrations of N and P were in sunflower grain and K and NO_3 in the turnip leaves

Table 49.4 Macronutrient concentrations (%) in the plants and their components

Components	Crop	Nitrogen	Phosphorus	Potassium	Nitrate
Grains	Sunflower	6.05a	1.27a	1.39a	0.00a
	Turnip	0.00c	0.00c	0.00c	0.00a
	Forage corn	2.57b	0.44b	0.56b	0.00a
Leaves	Sunflower	3.46b	0.35b	5.41a	0.50b
	Turnip	4.98a	0.49a	5.79a	8.26a
	Forage corn	2.27c	0.25c	1.63b	0.05b
Stems	Sunflower	0.98a	0.11a	1.19b	2.27a
	Turnip	0.00b	0.00b	0.00c	0.00b
	Forage corn	0.80a	0.18a	1.91a	0.49b
Roots	Sunflower	0.49c	0.05c	1.92b	0.38b
	Turnip	5.14a	0.61a	5.56a	5.52a
	Forage corn	0.87b	0.12b	1.97b	1.29b

Means with different letter in each column are significantly different between treatments at $p<0.05$ Duncan's test

(Table 49.4). According to Plank et al. (1995), the macronutrient concentrations of N, P and K for leaves of the three crops were lower than normal value, but nitrate concentrations in turnip leaves were more than normal range as stated by Maynard (1978) (normal range 0.45%).

49.3.3 Soil Macronutrient Uptake by Crops

The highest uptakes of N and P were 376.1 and 65.5 kg ha^{-1}, respectively, by sunflower, and for K and nitrate ion were 294.2 and 347.3 kg ha^{-1}, respectively, by turnip (Fig. 49.3).

49.3.4 The Crops Micronutrient and Cadmium Concentration

The concentrations and accumulation of the micronutrients and Cd also showed differences between the plant treatments (Table 49.5). The highest concentration of Fe and Mn was in forage corn root and leaves, respectively. The highest concentration of Zn and Cu was in sunflower grain and Cd was in sunflower leaves. According to Plank et al. (1995), the concentrations of Fe in forage corn and sunflower leaves were more than normal values whereas Mn in forage corn was less than normal values, and in sunflower and turnip leaves was close to the normal values. The Zn was lower than normal range in leaves of the three plants, but the concentration of Cu and Cd was more than normal range in turnip leaves.

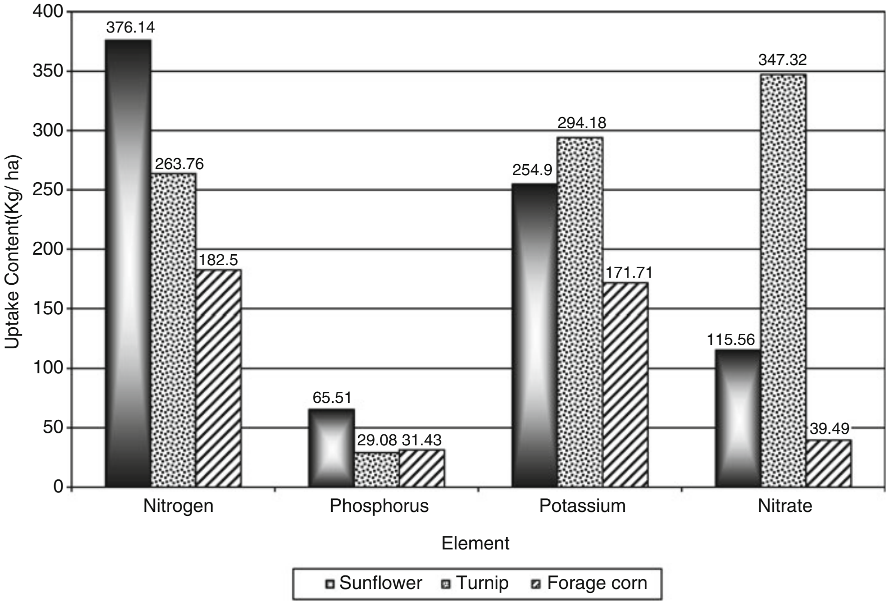

Fig. 49.3 The uptake of N, P, K and nitrate ions by sunflower, turnip and forage corn

Table 49.5 Micronutrient and cadmium concentration (mg kg^{-1}) in the plant components

Components	Crop	Iron	Manganese	Zinc	Copper	Cadmium
Grain	Sunflower	86.45a	39.27a	97.27a	22.84a	0.28a
	Turnip	0.00c	0.00c	0.00c	0.00c	0.00b
	Forage corn	27.45b	13.22b	29.44b	4.11b	0.06ab
Leaf	Sunflower	578.01a	107.27a	59.69a	20.49a	0.54a
	Turnip	278.22b	110.88a	42.11a	9.67a	0.00a
	Forage corn	349.56b	144.78a	54.89a	8.78a	0.00a
Stem	Sunflower	32.51a	14.53b	18.12a	10.24a	0.06a
	Turnip	0.00a	0.00c	0.00b	0.00c	0.00a
	Forage corn	84.43a	39.78a	16.55a	5.98b	0.00a
Root	Sunflower	1,025.11b	28.53b	24.37b	12.73a	0.00a
	Turnip	339.56c	48.22a	50.00a	10.55a	0.00a
	Forage corn	1,341.0a	50.84a	33.83ab	12.42a	0.00a

Means with different letter in each column are significantly different between treatments at $p<0.05$ Duncan's test

49.3.5 Soil Micronutrient and Cadmium Uptake by Crops

The highest uptake of Fe, Cu, Zn and Cd was 2.955, 0.643, 0.2, 0.003 kg ha^{-1} by sunflower, respectively, and Mn was 0.537 kg ha^{-1} by forage corn (Fig. 49.4).

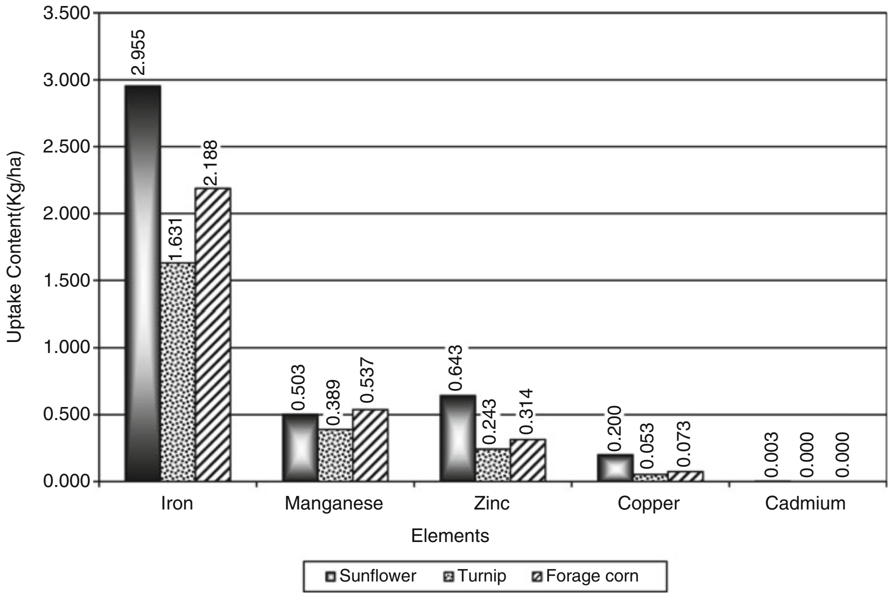

Fig. 49.4 Uptake of Fe, Mn, Zn, Cu and Cd elements by sunflower, turnip and forage corn

The results of this study showed that the plants of sunflower, turnip and forage corn have different potential to concentrate and accumulate essential elements and cadmium from lands under wastewater irrigation. Based on these results, the most concentration and accumulation of N, P, Zn and Cu were in sunflower grain and cadmium in sunflower leaf. The most concentration and accumulation of K and NO_3 were in turnip leaf. Finally, the most concentration and accumulation of Fe was in forage corn root, and Mn was in forage corn leaf. It is therefore concluded that the proper plant rotation and suitable plant selection could decrease pollution of land under wastewater irrigation. Overall, the lands under wastewater irrigation with excessive amount of essential elements and cadmium could recommend sunflower to uptake excessive content of N, P, Zn, Cu and Cd; turnip to uptake excessive content of K and NO_3; forage corn to uptake excessive amount of Fe and Mn without any yield decrease.

49.4 Conclusion

This study was carried out to evaluate the potential of sunflower, turnip and forage corn to uptake and accumulate some essential elements and cadmium in soils under wastewater irrigation in a site located south of Tehran. Based on the results of this experiment, lands under wastewater irrigation with excessive amount of essential elements and cadmium can support cultivation of sunflower to uptake excessive content of nitrogen, phosphorus, zinc, copper and cadmium; turnip to uptake excessive content of potassium and nitrate; and forage corn to uptake excessive content of iron and manganese without any yield decrease.

References

Iravani A (2000) The soil survey report of south of Tehran. Ministry of Agricultural Jeahad, Agricultural Research and Educational Organization, Soil and Water Research Institute, No. 616, Tehran

Lasat MM, Pence NS, Garvin DF, Ebbs SD, Kochian LV (2000) The use of plants for the removal of toxic metals from contaminated soil. American Association for the Advance of Environmental Science and Engineering Fellow, No CX 824823, Washington, DC

Maynard DN (1978) Potential nitrate levels in edible plant parts. In: Nielsen DR et al (eds) Nitrogen in the environment, vol 2, soil – plant nitrogen relationships. Academic, New York, pp 221–233

McGrath SP, Chang AC, Page AL, Witter E (1994) Land application of sewage sludge: scientific perspectives of heavy metal loading limits in Europe and the United States. Environ Rev 2:108–118

Meani AT, Juburi AL, Hamadany RH (1993) Effect of irrigation with wastewater on some micronutrients and heavy metals levels in calcareous soil Mij alat -Zira: 3at-al-ra: fidi: n (Iraq). Mesopotamia J Agric 25(4):27–35

Molahoseini H (2001) Investigation of intensive and beyond of soils pollution to heavy metal and plants under wastewater irrigation. In: Proceedings of the 7th Iranian soil science congress, Shahrekord University-College of Agriculture, Islamic Republic of Iran, 26–29 Aug 2001, pp 289–291

Molahoseini H (2003) Effect of N, P and K and plant population on quality and quantity characteristic of forage corn (704) under wastewater irrigation. In: Proceedings of the 8th Iranian Soil Science Congress, 26–29 Aug 2003, Rasht University-College of Agriculture, Islamic Republic of Iran, pp 289–291

Molahoseini H (2005) Effect of wastewater quality on supplying N, P and K for winter wheat cropping. In: Proceedings of the 9th Iranian Soil Science Congress, Karaj, Research Center of Watershed and Soil Conservation, Islamic Republic of Iran, 26–29 Aug 2005, pp 212–213

Plank CO, Granberry DM, Phatak S (1995) Plant analysis handbook for Georgia. Agricultural and Environmental Services Laboratories, Athens

Ross MS (1996) Toxic metals in soil-plant system. Wiley, Chichester

Shariati M, Farshi M, Nejad G (1998) Heavy metal contents of crops under wastewater irrigation in south Tehran. Proceedings of The 5th Iranian Soil Science Congress, pp 3–4

Singh OV, Labana S, Pandey G, Budhiraja R, Jain RK (2003) Phytoremediation: an overview of metallic ion decontamination from soil. Appl Microbiol Biotechnol 61:405–412

Sparks DL, Page AL, Helmke PA, Loeppert RA, Soltanpour PN, Tabatabai MA, Jhonston CT, Sumner ME (eds) (1996) Methods of soil analysis, part 3, chemical methods, 3rd edn. ASA, Madison, p 1390. ISBN ISBN-089118-072-9

Chapter 50
Sustainable Agriculture Through Integrated Soil Fertility Management on Degraded Lands

Muhammad Aamer Maqsood, Shahid Hussain, Tariq Aziz, and Muhammad Ashraf

Abstract The use of natural resources to meet people's requirements, currently and in the future, is sustainable agriculture. In order to uphold the growing rural and urban population in the developing world, considerable development in the efficiency of agricultural systems is required. Intensification of current production systems via increasing cropping intensity and by increased use of external inputs is often the only way to increase agricultural production. However, a major portion of the currently cultivated land is being lost through soil degradation. Degradation includes soil erosion, nutrient depletion, desertification, deforestation, salinization and overgrazing. As agricultural areas become even more crowded, arable land has come under increasing pressure. Agricultural yields are at risk of serious decline as soils are becoming more degraded, putting the livelihoods of millions of subsistence farmers at risk. Integrated soil fertility management (ISFM) is the key in raising productivity levels while maintaining the natural resource base. The main purpose of this integrated approach is to restore soil nutrient pools, maximize on-farm recycling of nutrients, reduce nutrient losses to the environment and improve the efficiency of inputs. Soil fertility can be built up by progressive and steady modification of the natural resources including soils, vegetation and water by crop fallowing, grazing, selecting crop species, deep ploughing to break the plough pan, subsoiling, organic fertilizing, transferring crop residues and fodder. Therefore,

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ISFM is a viable tool to rebuild the degraded soils. Conclusively, ISFM can play a major role in improving farm output from degraded lands and ultimately in sustainable agriculture for the poor farmers.

Keywords Degraded land • Eroded soil • Nutrient • Soil fertility • Sustainable agriculture

50.1 Introduction

Land refers to soils, plants and water resources essentially required for crop production. Soil being the natural medium for growth provides air, water and anchorage to plants. It is also the hub of mineral nutrients required by plants for normal growth and development. Agricultural soils of the world are being intensively used to grow crops for human consumption. Soil, therefore, play a fundamental role in human food chain (Oliver 1997). However, non-judicious use of this precious natural resource has seriously deteriorated its quality and productivity. Deterioration of biophysical environment of land by human-induced processes resulting in reduced soil productivity is called land degradation (Dregne 2002). The main causes of land degradation are (1) intensive cultivation, (2) deforestation, (3) poor quality irrigation, (4) unbalanced fertilization and (5) industrialization. It is estimated that up to 40% of the world's total agricultural land is seriously degraded and 24% of the productive areas are under continuous degradation (Bai et al. 2008). According to the Land Degradation Assessment in Drylands (LADA 2010) project executed by FAO, apart from the increased cost of fertilizer, land degradation is costing about US$40 billion annually. However, losses are much more if cost of losing the biodiversity is also considered.

Highly degraded lands are found especially in semiarid areas (sub-Saharan Africa, Chili), areas with high population pressure (China, Mexico, India) and regions undergoing deforestation (Indonesia) (Fig. 50.1). Governments and scientists are trying to save the precious ecosystem for poor farmers who are totally dependent on these lands. At least now, the consensus has developed to judiciously use the land for continuous high productivity.

Sustainable increase in agricultural produce is a necessity to feed the ever growing population of the world. Sustainable agriculture assures human food and fibre needs, enhanced environmental quality, efficient use of nonrenewable and on-farm resources, and economic viability of farm operations and enhanced quality of life for farmers and for the society as a whole. Soil fertility degradation has been described as the second most important constraint to food security in Africa and other least developed countries (Swift and Shepherd 2007). Maintenance and improvement of soil fertility is an essential step towards sustainable agriculture. Application of inorganic fertilizers is still below their recommended rates in most of the developing countries. Thereby, application of mineral fertilizers will increase yields. However, their increasing costs, decreasing efficiencies and severe environmental impacts need to be addressed. Organic farming seems to be a sustainable

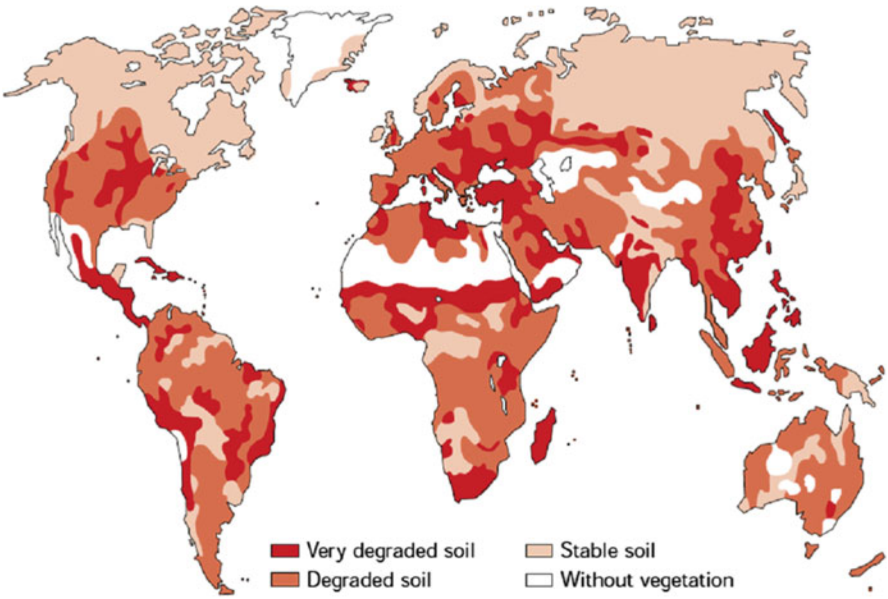

Fig. 50.1 Severity of land degradation in the world (UNEP 2002)

solution over the long term. However, there are also several environmental and yield-related concerns that put emphasis on integrated use of all possible resources in an efficient way (Mäder et al. 2002).

Integrated Soil Fertility Management (ISFM) combines the use of both organic and inorganic sources to increase crop yield, rebuild depleted soils and protect the natural resources (Evans 2009). Organic amendments increase the efficiency of inorganic fertilizers through positive interactions on soil biological, chemical and physical properties. The ISFM optimizes the effectiveness of fertilizer and organic inputs in crop production. This approach can rehabilitate degraded soils and restore their sustainable productivity. Therefore, ISFM is an effective strategy for sustainable agriculture on degraded soils.

Replenishment of soil nutrient pools, on-farm recycling of nutrients, reducing nutrient losses and improving the efficiency of inputs on degraded soils are much more important than on normal soils. In this chapter, we have presented ISFM for eroded, nutrient-depleted and salt-affected soils. Special emphasis is given to degraded drylands. In the end, possible conclusions are drawn for sustainable productivity on degraded lands by ISFM.

50.1.1 Land Degradation Processes and Soil Fertility

Under increased human population pressure, agricultural yields could fall as land becomes more degraded, putting the livelihoods of millions of subsistence farmers at risk. Much of world's cultivated land is being degraded by soil erosion, nutrient depletion, desertification, deforestation, salinization, contamination and overgrazing (Bai et al. 2008). Degraded lands are categorized as less productive. The main reason behind low productivity is reduced soil fertility. There are several human activities that significantly reduce soil fertility. Amongst the major land degradation classes, water and wind erosion are irreversible degradation while salinization and compaction are reversible. Most of the vegetation degradation, also called desertification, is irreversible in the drylands.

Deforestation for farming or timber needs has seriously increased soil erosion and nutrient depletion of fertile lands (Irshad et al. 2008). Accelerated soil erosion and destruction of soil structure including loss of organic matter are other consequences of the same mismanagement. Increased but unbalanced fertilization of crops has led to different environmental and economic concerns. Intensive farming on poorly managed agricultural lands has further depleted soil nutrients because of poor farming practices (Gruhn et al. 2000). Artificial irrigation system has led to salt-affected and waterlogged soils. Soil contamination by industrial waste is another outcome of artificial irrigation. Overgrazing, on the other hand, has also resulted in reduced soil productivity. This is due to loss of soil cover, resulting in loss of soil organic matter and loss of moisture-holding capacity and nutritional status of soils. This can lead to massive erosion especially by water. As soils' productivity decline, farmers move on to clear more forests, where the same cycle begins again (Fig. 50.2).

50.1.2 Eroded Soils and Fertility Management

Soil erosion is a complex process that depends on soil properties, ground slope, vegetation, land use and intensity and amount of rainfall (Montgomery 2007). In most cases, soil erosion is outcome of mankind's unwise activities of overgrazing, deforestation and unsuitable cultivation. These practices leave the land unprotected and vulnerable for erosive rainfall and windstorms (Kelley 1983). Sheet erosion is most common type of erosion that removes soil at roughly the same rate as soil is formed. However, net losses of soil are much faster in accelerated soil erosion due to human intervention. The detachment, transportation and deposition of soil from one place to another place significantly reduce its productivity potential. Use of powerful agricultural implements, in intensive mechanical agriculture, has compacted soils. This is known as tillage erosion.

Soil surface layer has more organic matter and nutrients than subsoil. Soil erosion peels away this surface layer. Consequently, soil continues to be deteriorated and becomes unproductive. The goals of soil fertility management on eroded soils are to provide sufficient nutrients to the crop grown, maintain and improve the soil condition and minimize erosion. Proper ISFM approaches rely on cover crops and organic matter application to strengthen the soil against erosive forces. Most crops grow best in soils with organic matter contents between 2 and 5%. Optimum organic

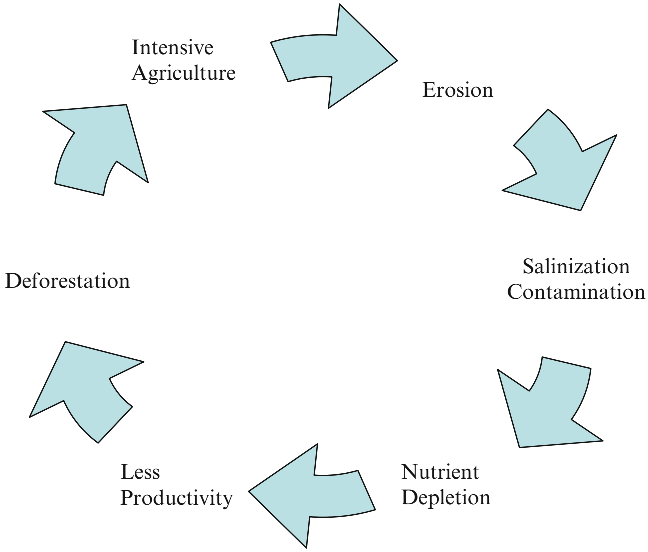

Fig. 50.2 Land degradation from deforestation to deforestation

matter in soils provides several beneficial functions such as minimize soil temperature fluctuations, provides essential nutrients, buffers the soil to changing pH, increases the ability of the soil to hold nutrients and thereby resists soil erosion (Mondini and Sequi 2008).

A combination of available organic and inorganic fertilizers will promote plant growth in these soils. Soil application of P is more effective when applied as enriched composts. Microbial activity and localized acidity in manures and composts can increase the availability of the P. However, total NPK requirements cannot be fulfilled by organic materials alone. Different organic sources and amendments are complementary to mineral fertilizers. Green manuring with legumes adds N to soil, suppresses weeds, scavenges nutrients left in the soil and increases the soil organic matter content. Legumes establish mutualistic relationships with *Rhizobia* that are capable of fixing atmospheric N. Seed inoculation with crop-specific *Rhizobia* strain has proved economical in both soil and food quality long since (Gaur et al. 1980).

50.1.3 Nutrient-Depleted Soils and Fertility Management

Prior to introduction of high-yielding varieties, farmers were using organic sources of nutrients. However, due to inorganic fertilizer application for intensive farming, the use of organic nutrient sources has greatly reduced. Since the introduction of high-yielding and fertilizer-responsive genotypes, use of mineral fertilizers has dramatically increased (Fig. 50.3). Realizing reduced fertilizer-use efficiencies, increased environmental pollution hazards and important benefits of organic

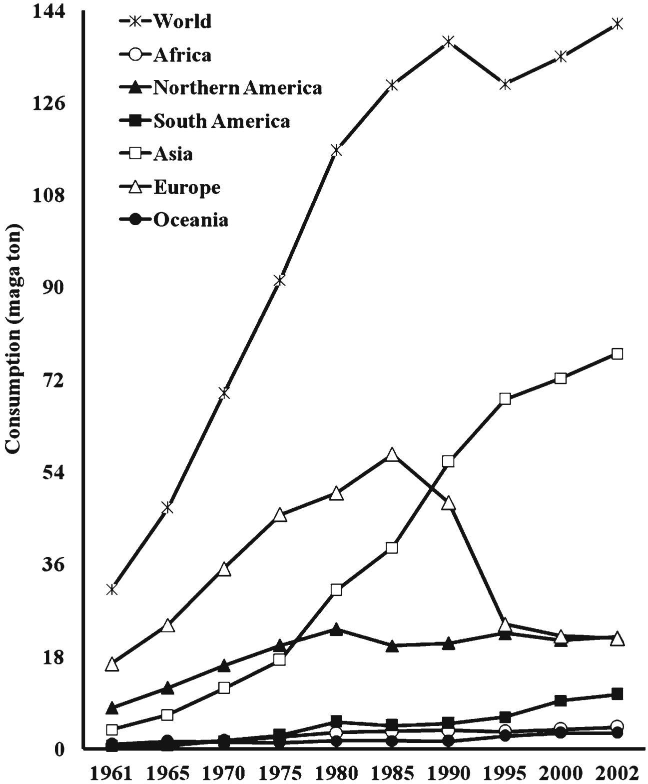

Fig. 50.3 Inorganic fertilizers consumption from green revolution to present (FAO 2010)

amendments, fertilizer use in European countries is decreasing. However, nutrient inputs are generally less than removal. This is particularly true in developing countries where fertilizer application rates are below optimum. Moreover, continuous high yields from intensive agriculture require application of inorganic fertilizers.

Unbalanced application of inorganic fertilizers has deteriorated soil productivity. Moreover, their use efficiency has decreased over time with significant increase in input costs. Sustainable agriculture and ISFM is vital tool for the restoration of soil fertility and productivity. Using plant growth promoting rhizobacteria and their substrates as biofertilizers is also a convincing strategy. For example, seed inoculations with such as atmospheric N-fixing bacteria are viable options for resource-poor farmers of the humid tropics and must be exploited to its fullest potential. For example, the amount of N fixed by legumes can range from 20 to 200 kg ha^{-1} $year^{-1}$ and saves lots of money. Addition of FYM, rice husk and green manures was reported to enhance the plant-available Fe and Mn in soils by 10–15 times. Through an effective ISFM approach, we can produce sustainable yields and can improve fertility status of soils.

50.1.4 Salt-Affected Soils and Fertility Management

Secondary salt accumulation in fertile lands has significantly reduced their productivity potential. This is a problem of arid and semiarid regions where agriculture is dependent on artificial irrigation with poor-quality water. Net precipitation in these areas is less than net evapotranspiration resulting in accumulation of salts on soil surface. Actually, salt problem is one of the major abiotic stresses to the world's agriculture covering 10% of total land surface of the world and about 30% of irrigated soils. On the basis of salinity and sodicity, salt-affected soils are categorized as saline, sodic and saline-sodic soils. Reclamation of severely salt-affected soils is a prerequisite for full yield potential. However, mostly, the conditions are not suitable for reclamation or soils are only marginally salt-affected. Therefore, one has to live with salinity. Efficient, balanced and integrated nutrient management is an integral part of saline agriculture or more comprehensively the *biosaline agriculture*.

Crops in sodic soils invariably suffer from inadequate N supply. High pH and exchangeable Na effects N transformations, thereby affecting the efficiency of applied N. Ammonium is the form of mineral N that accumulates and is subjected to major loss (10–60% of applied fertilizers) through volatilization (Lin et al. 2007). Sodic soils are highly deficient in organic matter and N, and about 25% more N is recommended than normal soil. In general, N efficiency is low in sodic soils due to high losses. Under such situations N-use efficiency can be increased by integrated use of organic and inorganic sources of N. In sodic soils, single superphosphate is a better source of P than other phosphatic fertilizers because it contains appreciable amount of calcium in the form of gypsum ($CaSO_4{\cdot}2H_2O$). Continuous use of fertilizer P, green manuring and FYM to crops significantly enhanced the yields and improved available P status of soils (Singh et al. 2009). Therefore, it is extremely important to integrate the use of organic resources and chemical amendments for sustainable higher production from sodic soils.

Excess soluble salts in the soil solution adversely affect the availability of nutrients to crops. Ionic imbalance and/or nutrient stresses are important limiting factors for crop production. Split application of N as urea should be followed to overcome losses. Both P and K fertilization of crops in saline soils help in alleviating adverse effects of salinity and improving water and N-use efficiency. Saline soils are well supplied with secondary nutrients, and crops do not require further application. In general micronutrient deficiencies have not been widely reported in saline soils. However, Zn is reported deficient in saline soils, and its application helps the crops to alleviate salinity stress. Application of FYM, pressmud, poultry manure and Sesbania green manure mitigates the Zn deficiency to greater extent (Abrol et al. 1998). However, integrated use of Zn and poultry manure is more effective in ameliorating Zn deficiency as compared to Zn sulphate alone, root dipping, Zn sprays and zincated urea (Holb and Nagy 2009). Saline soils under sub-surface drainage may require application of micronutrients. Green manuring in saline soils provides essential nutrients and restores soil physical and chemical properties. Continuous cropping with balanced use of organic and inorganic nutrients will increase yields per hectare.

50.1.5 Degraded Drylands and Fertility Management

Drylands are scattered across about 100 countries covering over 40% of the earth's land surface. People living in drylands of developing countries, about two billion, are amongst the poorest in the world (IUCN 2003). Land degradation in the drylands is an obvious problem. For United Nations Environmental Program (UNEP), desertification refers to a collection of land degradation processes: (1) vegetation degradation, (2) water erosion, (3) wind erosion, (4) salinization, (5) soil compaction and (6) soil fertility decline (UNEP 2002). Therefore, desertification is land deterioration in arid, semiarid and dry subhumid areas resulting from various factors, including climatic variations and human activities (UNCED 1992). Large proportion of dryland areas have low inherent fertility and exhibit a variety of constraints such as nutrient deficiency, low organic matter, moisture stress and high erodibility.

Dryland degradation is widespread in both developing and developed countries. Rangeland degradation is a centuries-old problem in Africa, Asia and the Mediterranean zone of Europe (Dregne 2002). Similarly, dryland salinity is a severe problem in Australia, Canada and the United States (Pannell and Ewing 2006). Wind and water erosion are worse in the semiarid and dry subhumid climatic zones than in the drier regions. Soil compaction, on another hand, undoubtedly reduces crop yields. Improved utilization of the better dryland cropping areas will allow climatically marginal cropland to be returned to good grazing land. Therefore, green drylands are requirement of the time (Lee and Schaaf 2009).

The ISFM balances chemistry, physics and biology in the soils via improved organic carbon content, appropriate mineral balance and a diverse and abundant soil life (Lal 2006). This helps to stabilize the fragile soils. The farming system is intended to enhance biological activity in soil, enabling a balanced supply of required minerals for effective plant growth, providing energy to plants and grazing animals. Active management of the soil food web, remineralization and substantial increase of soil organic carbon are essential to reaching ecologically sustainable production and a sustainable agriculture system. Such a system produces healthy food with good taste and structure (i.e. availability of calcium and silica) and extended shelf life.

50.2 Conclusion

Fertile soils with good physical properties to support plant growth are essential for sustainable agriculture. However, human-induced soil degradation processes has significantly reduced crop productivity of soils. Main reasons of low productivity are poor fertilizer and water management, soil erosion, drylands and salinization. Degraded lands are the sources of food and fibre for a major part of the world. Continuous cropping and inadequate replacement of nutrients removed in harvested materials, lost through erosion, leaching and gaseous emissions have further depleted

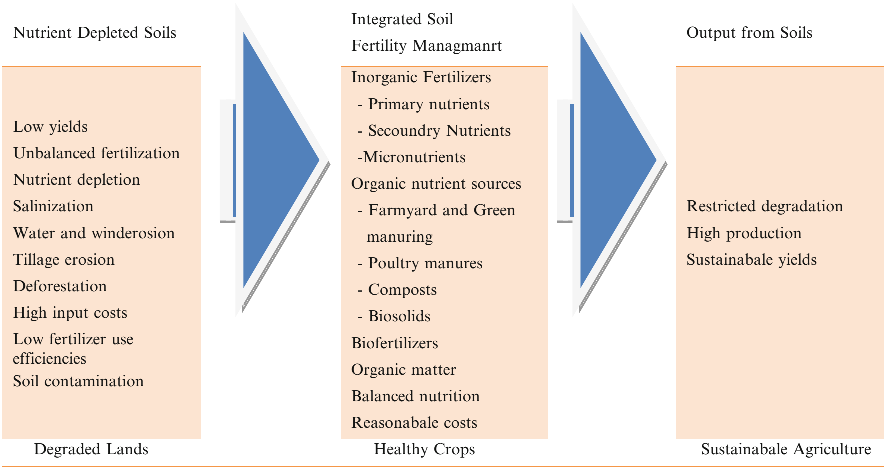

Fig. 50.4 A simplified way towards sustainable agriculture through integrated soil fertility management on degraded lands

fertility. This has led to reduced soil organic matter for optimum plant growth levels. Integrated soil fertility management combines both organic and inorganic materials, used with close attention to timing and placing of the inputs to maximize nutrient-use efficiency on sustainable basis. The road map of ISFM is simple but requires lot of efforts (Fig. 50.4).

The ISFM approach is much more important for degraded lands than for normal soils. However, research in optimum utilization of resources at local level is suggested. The ISFM should base on soil fertility status and valuable local inputs available, thereby increasing the income with high value to cost ratio for sustainable higher yields. Conclusively, ISFM can play a major role in improving farm output from degraded lands and ultimately in sustainable agriculture for the poor farmers.

References

Abrol IP, Yadav JSP, Massoud FI (1998) Salt-affected soils and their management. Food and Agricultural Organization of the United Nations, Rome

Bai ZG, Dent DL, Olsson L, Schaepman ME (2008) Proxy global assessment of land degradation. Soil Use Manage 24:223–234

Dregne HE (2002) Land degradation in the drylands. Arid Land Res Manage 16:99–132

Evans A (2009) The feeding of the nine billion global: food security for the 21st century. A Chatham house report. The Royal Institute of International Affairs, London

FAO (2010) FAO database. Online at http://faostat.fao.org/site/422/default.aspx#ancor. Accessed Feb 2010

Gaur YD, Sen AN, Rao NSS (1980) Improved legume-rhizobium symbiosis by inoculating preceding cereal crop with rhizobium. Plant Soil 54:313–316

Gruhn P, Goletti F, Yudelman M (2000) Integrated nutrient management, soil fertility, and sustainable agriculture: current issues and future challenges. International Food Policy Research Institute, Washington, DC

Holb IJ, Nagy PT (2009) Availability of calcium, magnesium, sulfur, copper, zinc, and manganese in the plant-soil system of integrated and organic apple orchards. Comm Soil Sci Plant Anal 40:682–693

Irshad M, Yasuda H, Inoue M (2008) Agricultural land degradation and its sustainable restoration. Ecocity world summit 2008, academic and talent scouting sessions, University of California, Berkeley, 22–23 Apr 2008

IUCN (2003) Sustainable drylands management: a strategy for securing water resources and adapting to climate change. International Institute for Sustainable Development, Winnipeg

Kelley HW (1983) Keeping the land alive: soil erosion, its causes and cures. Food and Agriculture Organization of the United Nations, Rome

LADA (2010) Land degradation assessment in drylands. Online at http://www.fao.org/nr/lada/. Accessed Feb 2010

Lal R (2006) Enhancing crop yields in developing countries through restoration of the soil organic carbon pool in agricultural lands. Land Degrad Dev 17:197–209

Lee G, Schaaf T (2009) The future of drylands. In: International scientific conference on desertification and drylands research, Tunis, Tunisia, 19–21 June 2006

Lin DX, Fan X, Hu F, Zhao H, Luo J (2007) Ammonia volatilization and nitrogen utilization efficiency in response to urea application in rice fields of the Taihu Lake Region, China. Pedosphere 17:639–645

Mäder P, Fliebach A, Dubois D, Gunst L, Fried P, Niggli U (2002) Soil fertility and biodiversity in organic farming. Science 296:1694–1697

Mondini C, Sequi P (2008) Implication of soil C sequestration on sustainable agriculture and environment. Waste Manage 28:678–684

Montgomery DR (2007) Soil erosion and agricultural sustainability. PNAS 104:13268–13272

Oliver MA (1997) Soil and human health: a review. Eur J Soil Sci 48:573–592

Pannell DJ, Ewing MA (2006) Managing secondary dryland salinity: options and challenges. Agric Water Manage 80:41–56

Singh G, Qadar A, Yaduvanshi NPS, Dey P (2009) Enhancing nutrient use efficiency in problem soils. Central Soil Salinity Research Institute, Karnal

Swift MJ, Shepherd KD (2007) Saving Africa's soils: science and technology for improved soil management in Africa. World Agroforestry Center, Nairibi

UNCED (1992) Agenda 21. United Nations Conference on Environment and Development, United Nations, New York

UNEP (2002) Global environment outlook 3. United Nations Environment Programme, Nairobi

Chapter 51
Use of Conservation Tillage System in Semiarid Region to Ensure Wheat Food Security in Pakistan

Ijaz Rasool Noorka and Shabbir A. Shahid

Abstract To help bridge the gap between food demand and supply, Pakistan requires an optimum, sustainable, and best adopted strategies to maintain the momentum of the agriculture sector. Investments need to be made in agricultural education, research and development, extension, soil and water resources, and allied infrastructural development which will lead to increase the food production and improve soil and water conservation. Wheat-rice cropping system in Pakistan, particularly in the areas where late-maturing fine-rice varieties are grown, the late-season harvesting of rice crop coupled with conventional land preparation leads to significant delay in wheat sowing and extra usage of irrigation water, and preparatory tillage operations result in a reduction in wheat yields. These practices not only increase the costs of production but also degrade the soil structure and organic matter availability. Conservation tillage technology including earlier wheat plantation, improved water use efficiency which can help to resolve this yield decline when compared with conventional tillage practices in both canal and ground water command areas. In an attempt to test these technologies, a comparative study on the soil and water conservation is tested using four wheat varieties in randomized complete block design (RCBD). Analysis revealed significant differences in all noted parameters including yield-contributing traits due to conservation tillage system compared to where this was not used. It was concluded that out of four exotic and local wheat varieties, the genotype Inqalab-91 proved best yielder in seedling as well as across tillage operation conditions. Additionally, the energy conservation was also done

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by adopting an integrated, holistic, and pragmatic approach to ensure staple food especially in competitive areas of semiarid regions.

Keywords Agriculture • Conservation • Conventional • Cost of production • Pragmatic approach

51.1 Introduction

Pakistan presents diversified topographic features including vast plains of fertile land. Most of the area remained under water stress due to lack of irrigation water and insufficient rainfall, even with average annual rainfall of 254–356 mm against the essential demand of 1,778 mm (Khan 2003). This condition leads to widening the gap between production and consumption (Anonymous 2007). Pakistan is facing a serious threat of rapidly growing population at the alarming rate of 2.7% per annum. It seems a dream that Pakistan had only 32.4 million peoples at the time of independence in year 1947. In the next five years, we saw a significant population increase to 138 million in 1952 and 170 million in 2010, and projectile population will be 208.06 million in year 2025 (PWP 2007).

To feed this burgeoning population, the pressure was exerted to local agriculture production having two cropping patterns, rice-wheat and cotton-wheat. The rice is grown on 2.2 million ha area, of which 62% area exists in Punjab province. In Punjab, most of farmers prefer to grow rice despite of low productivity and high delta of water, leading to 78 of rice area under fine-rice varieties enabling Punjab province to house 96% of total rice production in Pakistan (Sarwar and Goheer 2007). The rice-wheat cropping belt of Pakistani Punjab is considered as the food basket of fine grain length and aromatic rice, which contributes significantly toward the foreign exchange earnings and projects Pakistan throughout the world.

Wheat is another major crop best fitted in rice-wheat cropping system and has a prime position in national agricultural policies (FAO 2002). World food programs are under severe threats due to water scarcity, poor germination rates, less emergence rate, late sowing and harvest, and postharvest losses particularly in most of the Asian countries. These areas used almost 90% of total diverted fresh water for their agricultural needs (Huaqi et al. 2002).

Pakistan has a rich source of wheat germplasm having the ability to withstand water stress, drought, heat, and salt stress. In our crop improvement programs, the major problem is poor germination and late sowing or a combination of any two or three. Seedling trait is an important aspect which depicts the final crop stand. Various factors, such as seed germination, emergence, seedling vigor, energy of emergence, growth rate, mean emergence time, and water stress tolerance, exert their impact directly on the yield of a crop (Crosbie et al. 1980; Farooq et al. 2006). Due to late sowing, fulfilling physiological maturity periods and late harvesting of the crop rice-wheat cropping system are suffering significantly, depicting a low yield which is insufficient to feed burgeoning population (Iqbal et al. 2002). Due to this serious concern, wheat yields are affected badly, i.e., up to 50 kg ha^{-1} day^{-1} (Agriculture Information 2009).

Table 51.1 Area, production, and yield of wheat

Year	Area (000 ha)	Production (000 t)	Yield (kg ha^{-1})
2002–2003	8,034	19,183	2,388
2003–2004	8,216	19,500	2,375
2004–2005	8,358	21,612	2,568
2005–2006	8,448	21,277	2,519
2006–2007	8,578	23,295	2,716
2007–2008	8,550	20,959	2,451
2008–2009	9,046	24,033	2,657
2009–2010	9,042	23,864	2,639

Source: Ministry of Food and Agriculture, Federal Bureau of Statistics, Government of Pakistan

Looking at the ecosystem in broader perspective, it has a water cycle where addition of new water is impossible, and hence, we have to manage our agriculture within available resources. Definitely farmers and researchers are doing their best to find the possible ways to minimize the water use and to maximize the crop production with economical cost/benefit ratio in wheat production. It has also been shown that crop stand is improved in wheat if sown under conservation tillage operation system as compared to conventional systems of crop grown (Du et al. 2000).

The conservation tillage system is an improved and integrated approach to tackle the problem of wheat yield stagnation in the rice-wheat zone and to overcome late sowing, eliminating land preparation, direct seeding of next crop, and enhancing fertilizer application efficiency and consumptive use of water (Hammel 1995; Noorka et al. 2011). Conventional tillage is inducing deleterious effects on agriculture by increasing runoff, soil erosion, and nutrient depletion. In the changing face of climatic conditions, the conditions may even become worse. In comparison to conventional tillage, the conservation tillage avoids soil disturbance, improves soil moisture conditions, and improves soil structure (Jiao et al. 2004). To achieve maximum benefits, a conservation tillage technique is used to sow wheat after successful maturity of rice crop. This technique not only saves time but increases yield and improves soil quality and water saving (Rijsberman and Molden 2001).

According to the economic survey, the year-wise area, production, and yield of rice and wheat are increasing year by year in Pakistan (Table 51.1).

Keeping in view the shortage of irrigation water, increasing cost of inputs, and poor germination to compare the exotic and local germplasm, this study was initiated to explore increase in crops yields that may lead to bridge gap between supply and demand, a way forward to address food security for generations to come.

51.1.1 Conservation Tillage

The soil preparation for crop production is commonly accomplished by using mechanical and other means for plowing, digging, overturning, shoveling, hoeing, and raking. Small-scale farmers use conventional hand tools and often tools pulled by animals; however, farmers are now diverting their preferences toward the use of tractors and other machinery. The overall goal of conservation tillage is to increase crop production while conserving resources (soil and water) and protecting the environment (IBSRAM 1990). Conservation tillage, a progressive approach, presents innovative strategies and methods to tackle the remnants of ex-crop's residues, which can be used to get extra benefits, remained on the soil surface. This extra benefit depicts in slowing the water movement, which ultimately reduces the amount of soil erosion and nutrient depletion. Conservation tillage is suitable for a range of crops. Literature suggests there is great potential to use conservation tillage technology in Africa, Asia, and Eastern Europe, although limiting factors have to be taken into account (Derpsch 2001; GTZ 1998). The most common conservation tillage practices are no-tillage, ridge-tillage, and mulching-tillage. In fact, no-tillage is a way of growing crops without disturbing the soil as preparatory operation. This practice involves leaving the residue from last year's crop undisturbed and planting directly into the residue on the seedbed. Conversation tillage does not require specialized seeding equipment designed to plant seeds into undisturbed crop residues and soil. Cover crops – "green manure" – can be used in a conservation tillage system to help control weeds. Cover crops are usually leguminous which are typically high in nitrogen and have the ability to increase soil nitrogen. In ridge-tillage practices, the soil is left undisturbed for some period from harvest to planting, and then the crop is planted by making raised ridges. Planting usually involves the removal of the top of the ridge. Planting is completed with sweeps, cultivator, disk openers, and row cleaners. Residues are left on the surface between the ridges. Weeds are the serious threat to field crops and are controlled with cover crops, by applying herbicides and/or by integrated approach of hoeing and cultivation. Ridges are rebuilt in this process during row cultivation. Mulch-till technique involves soil disturbance between the times of harvesting of one crop and the planting of the next crop but leaving around a third of the soil covered with residues after seeding. Implements used for mulch-till techniques include chisels, sweeps, and field cultivators.

51.1.2 How the Technology Contributes to Climate Change Adaptation

Unpredictability of rainfall and an increase in the mean temperature may affect soil moisture levels leading to severe damages and the totally failures in crop yields. Conservation tillage practices reduce risk from drought by reducing soil erosion, enhancing moisture retention, and minimizing soil compaction. In combination, these factors improve resilience to climatic effects of drought and floods (Smith 2009). Improved soil nutrient recycling may also help combat crop pests and diseases (Holland 2004).

51.1.3 Advantages of Conservation Tillage

Conservation tillage benefits farming by minimizing erosion, increasing soil fertility, and improving yield. Plowing definitely loosens and aerates the soils which ultimately facilitate the roots to go deeper and deeper. Tillage is also believed to be helpful to boost up the growth of microorganisms and their mixing with crop harvest residues and soil organic matter. Conservation tillage helps the farmers to reduce fuel consumption as well as soil compaction and labor fatigue. In turn, this can increase time available for additional farm work or off-farm activities for livelihood diversification. Also once the system is established, requirement for herbicides and fertilizers can be reduced. According to Sorrenson et al. (1998), the total economic benefits as the outcome of no-tillage technique in small farms of generally less than 20 ha in Paraguay have reached around $941 million.

51.1.4 Disadvantages of Conservation Tillage

In case of conservation tillage operation, there are chances of weed infestation which require the application of herbicides, particularly in the transition phase, up to the establishment of the new balance of weed populations (Malik et al. 2000). The conservation tillage over a period of time may lead to soil compaction; however, this can be prevented with chisel plows or subsoilers. Initial investment of time and money along with purchases of equipment and herbicides will be necessary for establishing the system. There is a strong relationship between this technology and appropriate soil characteristics. This is detrimental in high clay content and compact soils.

51.1.5 Objectives

- To study soil and water conservation through conservation tillage in rice-wheat cropping system.
- To check the seedling behavior (germination percentage, emergence index, etc.) and yield response of four diverse wheat genotypes in conservation tillage compared to conventional tillage operation.
- To study the effect of different exotic and local wheat genotypes on the growth and yield under the given set of soil and water conditions.
- To demonstrate the value of innovative conservation technology to students and farmers through their active participation particularly at sowing and harvesting.

51.2 Materials and Methods

The study was conducted during 2008–2009 at the research area of the University College of Agriculture, University of Sargodha, Pakistan. The research station is situated in area known for rice-wheat cropping pattern. The agriculture and land use map of Pakistan is shown in Fig. 51.1a, presenting major rice growing areas in the provinces of Punjab and Sindh.

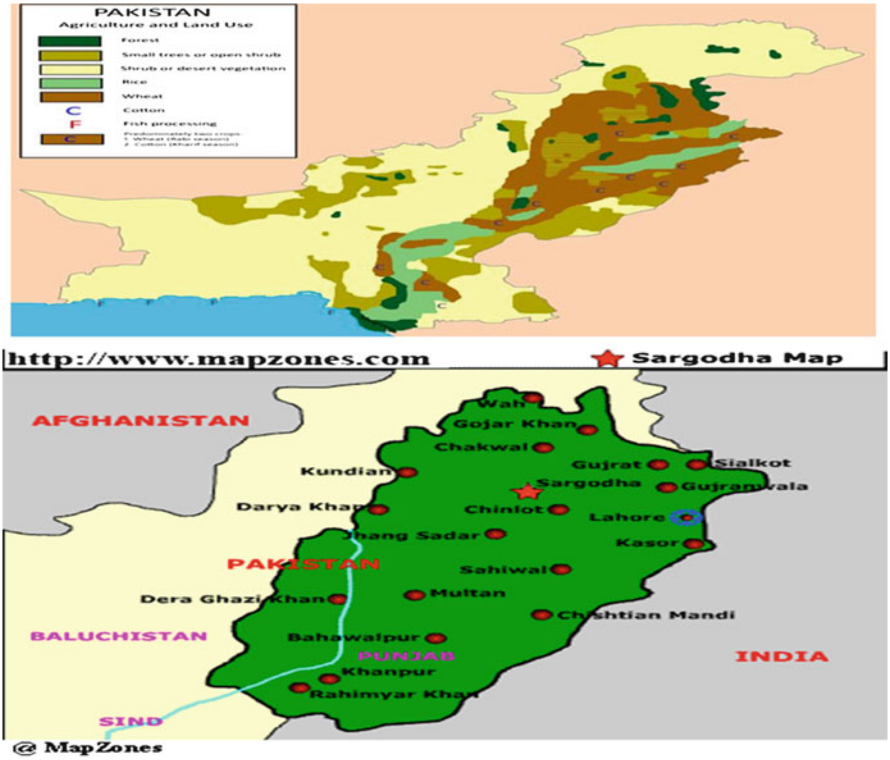

Fig. 51.1 (**a**) Map of Pakistan showing agriculture and land uses. (**b**) Map of Punjab showing Sargodha (experiment location). Courtesy of Map zones Pakistan

The Sargodha District lies at 32° 03′ N latitude and 72° 40′ E longitude and at an altitude of 187 m. Mean monthly maximum temperature varies from 20.2 to 41.7°C and minimum from 3.6 to 27.2°C. Mean annual rainfall in the area is about 435 mm. Wheat is a staple food predominantly grown in large area of Pakistan. The Punjab province of Pakistan is considered as the food basket; currently, Punjab shares 76.64% of total wheat production in Punjab (GOP 2010).

51.2.1 Soil Analysis of Experimental Area

The soil samples were collected from 0 to 15 cm, 15 to 30 cm, and 30 to 60 cm depths and analyzed using standard procedures (Chapman and Pratt 1961; Watanabe and Olsen 1962). Soil pH was measured in saturated soil paste (SSP) using pH meter, and electrical conductivity of soil saturation extract (ECe) was measured by standard EC meter and expressed as dS m^{-1}. The pHs is in neutral range (pH 7.15), and the soil was nonsaline (EC_e 0.28 dS m^{-1}) with very low organic matter content

(0.78%). Soil texture was determined by standard Bouyoucos hydrometer methods and % distribution of sand (2–0.05 m), silt (0.05–0.002 mm), and clay (<0.002 mm) determined. These values were then used on USDA textural triangle to determine soil textural class. Soil texture is sandy clay loam.

51.2.2 Experimental Details

The experiment is comprised of two treatments: (1) treatment 1 (T1) conservation tillage and (2) treatment 2 (T2) conventional tillage. In conservation tillage, the seeds were planted in existing rice field after harvesting without removing stubbles and plowing the fields. Seeds were sown with hand-pore drill due to plot being in small size. In conventional tillage, the rice field was plowed and then seeds were sown with hand-pore drill as used in conservation tillage.

Four diverse exotic and local wheat varieties, namely, Nesser (V1), Inqalab-91 (V2), Sarsabz (V3), and Sehar-08 (V4), were used in a randomized complete block design (RCBD) with three replications in a plot (6 m×6 m) for both treatments. The sowing was accomplished on 15 November 2008. Prior to sowing, the seeds were treated with fungicide Vitavex-200 @ 0.25% to protect from soilborne diseases. Seeds were sown by hand-pore drill. Plant-to-plant distance (2 cm) was maintained by thinning.

Urea, single super phosphate (SSP), and sulfate of potash (SOP) were used as source of NPK nutrients, respectively. The fertilizers were applied at the recommended rates to both the treatments (NPK 52:46:25 kg ha^{-1}) (GOP 2010). One-third of urea, full dose of SSP, and SOP fertilizers were broadcasted before sowing the wheat crop, while the remaining two doses of urea were used at tillering stage (22 days after planting the wheat) and flowering and grain making stage (90 days after planting).

The canal irrigation water was applied to both treatments. Three irrigations were given, first at 22 days after sowing (when seedling phase data was recorded) and the second at 60 days and third after 90 days after sowing. The flooded irrigation method was used to irrigate the experimental area. From each plot, ten plants are selected randomly at initial and maturity stages. The traits (plant height, number of tillers per plant, spike length, number of grains per spike, grain yield per plant) were recorded and analyzed statistically (Tables 51.2–51.4).

During the seedling phase, only one row of each treatment and each replication was selected. A total of 200 seeds per line were sown. Data collection was started immediately upon the emergence of first seedling in any of the plot. The counting/measurements were made on daily basis at 1,600 h for instant updates, and a number of visible seedlings were recorded. Data collection remained continued until there was no further emergence of the seedling. The trait emergence percentage was calculated according to the formula given by Smith and Millet (1964) and Noorka and Khaliq (2007):

$$\text{Emergence (\%)} = \frac{\text{Total number of seedlings emerged 18 DAS} \times 100}{\text{Total number of seedlings grown}}$$

Table 51.2 Wheat genotypes and their origin

Genotype	Origin of genotype
V1 = Nesser	CIMMYT, Mexico
V2 = Inqalab-91	Punjab Province, Pakistan
V3 = Sarsabz	Sindh Province, Pakistan
V4 = Sehar	Punjab Province, Pakistan

where DAS = Days after sowing.

Emergence index (EI) is the estimate of emergence rate of seedlings, which was calculated as per AOSA (1983):

$$\mathrm{EI} = \frac{\text{No. of seeds emerged at first count} + \cdots + \text{No of seeds emerged at final count}}{\text{Days of first count} + \cdots + \text{days of final count}}$$

The emergence rate index for each treatment and replication was calculated as follows:

$$\mathrm{ERI} = \frac{\text{Emergence Index}}{\text{Emergence percentage}}$$

The energy of emergence was computed according to the method outlined by Ruan et al. (2002). It is the percentage of emerged seedlings 3 days after sowing.

The mean emergence time was calculated in accordance with the equation of Ellis and Roberts (1981) as below:

$$\mathrm{MET} = \frac{\Sigma Dn}{\Sigma n}$$

where n is the number of seeds germinated on day D and D is the number of days counted from the beginning of emergence.

51.3 Results and Discussion

Among the one exotic and three local genotypes, the emergence percentage ranged between 82.40 and 90% under conservation tillage (T1), while in conventional tillage (T2) operation, the emergence percentage was 80.95–91.50%. Maximum value of emergence index was depicted by the genotypes Inqlab-91 (6.879) while minimum (5.623) in genotype Nesser in conservation tillage, while under conventional operation, maximum emergence index was depicted by the genotype Sarsabz (6.753). The data is illustrated in Table 51.3.

A magnitude of variability was observed in all seedling traits like energy of emergence and mean emergence time in both conditions (Table 51.3).

Table 51.3 Mean values of emergence percentage (EP), emergence index (EI), emergence rate index (ERI), energy of emergence (EOE), and mean emergence time (MET) in days at seedling phase

Treatments	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2
Genotypes	EP	EP	EI	EI	ERI	ERI	EOE	EOE	MET	MET
Nesser	90.00	89.50	5.623	5.745	0.062	0.062	46.67	44.54	1.996	2.001
Sarsabz	82.50	80.95	6.694	6.753	0.081	0.083	44.33	45.23	1.943	1.998
Inqalab 91	87.90	90.20	6.879	6.457	0.078	0.071	50.00	52.12	1.919	1.897
Sehar	82.40	84.60	5.850	6.564	0.070	0.077	43.76	43.96	1.945	1.945

T_1 conservation tillage and T_2 conventional tillage

Earlier and rapid emergence was observed in genotypes with maximum energy of emergence and emergence rate index (Noorka et al. 2007). In both conditions, the genotype Sarsabz and Inqalab-91 gained top position for emergence rate index and energy of emergence, respectively. A relationship was found among emergence percentage, emergence index, energy of emergence, and mean emergence time. The higher the emergence percentage, emergence index and energy of emergence and lower mean emergence time indicated earlier and rapid germination of the genotype. In this experiment, the genotype Inqalab-91 remained at the top by securing maximum emergence percentage in conventional tillage, emergence index under conservation tillage, maximum energy of emergence, and minimum mean emergence time under both tillage operation techniques. These findings are supported by similar findings (Zheng et al. 1994; Nayyar et al. 1995; Noorka and Khaliq 2007; Hameed et al. 2010).

To differentiate cost and benefit and associated morphological traits and tillage operation system, data from both conservation tillage and conventional tillage were used. The mean data on growth and yield traits are given in Table 51.4.

Table 51.4 illustrates significant difference among genotypes. Both treatments showed most of the yield, and yield-contributed traits behaved best in conservation tillage operation. It was noted that direct sowing of wheat in the rice stubbles has minimized the time invested to prepare the seedbed preparation, water used to do preparatory irrigation (locally called *Rouni*), tillage operation, energy in shape of tractor, and tube well diesel through conservation techniques. The results are also supported by other researchers (Aslam et al. 1993; Du et al. 2000; Iqbal et al 2002).

All genotypes showed significant difference under both tillage operations. Plant height is an important trait for crop improvement. The shorter the height, the plant will be best suited to bear climatic conditions as well as contribute better to crop yield. Most of the genotypes achieved maximum height in conventional tillage as compared to conservation tillage. Among genotypes, the exotic (CIMMYT) genotype Nesser showed minimum plant height and second best yielder under both tillage conditions. In this way, T1 (conservation tillage) behaved better compared to T2 (conventional tillage).

Regarding the number of tillers per plant, the genotype Sehar-08 attained maximum number of tillers per plant under T1, while Inqalab-91 attained maximum number of tillers per plant under T2 condition. As the treatments are concerned, T1 (conservation tillage) once again performed well as compared to T2 (conventional tillage) by topping three genotypes. In spike length measurement, the exotic genotype Nesser ranked number one under T1, while the genotype Sarsabz attained maximum spike length under T2 conditions.

In case of the treatments' performance, T1 (conservation tillage) and T2 (conventional tillage) remained equal. The exotic genotype Nesser attained maximum number of grain per spike in both tillage operations; however, T1 (conservation tillage) performed the best than T2 (conventional tillage).

The genotype Sehar attained maximum thousand grains weight in T1, while in T2, the genotypes Nesser showed best performance; however, T1 (conservation

Table 51.4 Comparative mean values of morphological traits under conservation and conventional tillage of four diverse wheat genotypes at maturity stage

Treatments	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
Genotypes	PH	PH	NT	NT	SL	SL	NGS	NGS	TGW	TGW	GY	GY
Nesser	85.80	93.87	9.45	7. 40	13.33	12.04	52.30	49.50	25.38	31.01	21.10	20.60
Sarsabz	104.50	100.50	9.50	9.30	11.90	12.80	48.90	44.76	26.43	25.65	14.90	15.50
Inqalab-91	97.50	106.04	11.02	11.40	12.50	10.30	44.30	40.80	22.83	21.54	22.66	18.00
Sehar-08	101.30	105.50	11.25	11.00	11.02	11.90	44.90	41.32	28.90	28.50	22.30	21.34

T_1 conservation tillage, T_2 conventional tillage, plant height (PH) in cm, no. of tillers/plant (NT), spike length (SL) in cm, no. of grains/spike (NGS), 1,000-grain wt (TGW) in grams, grain yield/plant (GY) in grams tillage) and T2 (conventional tillage) performed similarly. The grain yield per plant has prime importance for farmers; the genotype Inqalab-91 attained maximum grain yield per plant in T1 condition, while under T2 condition, Nesser remained at top. Overall the T1 (conservation tillage) once again performed better compared to T2-conventional tillage.

In general, the performance of Inqalab-91 proved the best in both tillage operations. Today's agriculture is going very costly. The poor farmers are not able to afford much agricultural costs particularly in tillage operation and seed selection. If germplasm is properly screened we can select the best genotype whose emergence percentage and mean emergence time will be outstanding. In the same way, conservation tillage is taking momentum. It is adopted by the farmers so that they can avoid 4–5 land preparation cultivation which costs almost 3,500–4,000 Pakistani rupees (38–43 US$) per acre. Additionally, soil structure is also disturbed, organic matter is exposed and dried at high temperature in summer, and the microbial population is disturbed that have deleterious effects on soil properties leading to poor land services for agriculture.

As discussed earlier, the wheat cultivation time was delayed mainly due to late harvesting of rice. If the conservation tillage operation system is adopted, then timely sowing of wheat may be done. It is a best sign in agriculture that farmers are going to prefer conservation tillage. Earlier researchers (Uri et al. 1999; Holland 2004) reported that conservation tillage reduced runoff and erosion and improved the soil structure. By less cost, maximum hazards of environment can be overruled. The results of this study revealed that crop stand is improved for wheat under conservation tillage. The conservation tillage technology is increasing the crop production and net income of farmers, given the condition that it is properly used by the farmers and area under conservation tillage will increase to ensure food security (Jeffrey et al. 2002; Zhanxing 2008).

51.4 Conclusions

It is concluded that farmers and eco-friendly policies are needed to provide economical ways to farming communities for land preparation to achieve high yields and conserving their precious soil resources ultimately paving the way forward to ensure food security, through bridging the gap between national food demand and supplies. Conservation tillage system creates such a type of sustained and most appropriate soil environment to the crops to get maximum growth of a crop that may conserve soil and water, save energy resources by minimizing the intensity of tillage to minimize structure destruction, and preserve plant residues for beneficial outcomes. This study concluded that emergence and related attributes criteria have vital role to discriminate the genotypes as well as treatments (tillage operation). This study also revealed that exotic and local wheat varieties showed diverse behavior to different tillage operation systems. The genotype Inqalab-91 proved best and can play a significant role in meeting food demand. However, further research is needed to transfer the findings to other areas where conditions similar to Sargodha semiarid zones may be existing in other parts of Pakistan.

References

Agriculture Information (2009) Wheat production technology. Zarat Nama, Department of Agriculture, Govt of the Punjab, Pakistan

Anonymous (2007) An overview of economy 2007. Ministry of Food, Agriculture and Livestock (MINFAL), Federal Bureau of Statistics, Islamabad

Aslam M, Majid A, Hashmi NI, Hobbs PR (1993) Improving wheat yield in the rice-wheat cropping system of the Punjab through zero tillage. Pak J Agric Res 14(1):8–11

Association of Official Seed Analysis (1983) Seed vigor testing hand book. Contribution no. 32 to the handbook on seed testing. Association of Official Seed Analysis, Spring Field, p 93

Chapman HD, Pratt PF (1961) Methods of analysis for soils, plants and waters. University of California, Berkeley

Crosbie TM, Mock JJ, Smith OS (1980) Comparison of gains predicted by several selection methods for cold tolerance traits of two maize populations. Crop Sci 20:649–655

Derpsch R (2001) Keynote: Frontiers in conservation tillage and advances in conservation practice. In: Stott DE, Mohtar RH, Steinhart GC (eds) Sustaining the global farm. Selected papers from the 10th international soil conservation organisation meeting at Purdue University and the USSA-ARS National Soil Erosion Research Laboratory, 24–29 May1999

Du BJ, Jian D, Wenying L, Zhixi L (2000) Field experiments for comparison of winter wheat conservation tillage and conventional tillage. J China Agric Univ 5(2):55–58

Ellis RA, Roberts EH (1981) The quantification of ageing and survival in orthodox seeds. Seed Sci Technol 9:373–409

FAO (2002) Food outlook bulletin no. 1. FAO, Rome

Farooq M, Basra SMA, Tabassum R, Afzal I (2006) Enhancing the performance of direct seeded fine rice by seed priming. Plant Prod Sci 9(4):446–456

Government of Punjab (2010) Agriculture Marketing Information Service, Lahore

GTZ (1998) Conserving natural resources and enhancing food security by adopting no-tillage. An assessment for the potential for soil-conserving production systems in various agro-ecological zones of Africa. GTZ Eschborn, Tropical Ecology Support Programme, TÖB Publication, Eschborn

Hameed A, Goher M, Iqbal N (2010) Evaluation of seedling survivability and growth response as selection criteria for breeding drought tolerance in wheat. Cereal Res Comm 38(2):193–202

Hammel JE (1995) Long term tillage and crop rotation effects on winter wheat production in northern Idaho. Agron J 87:16–22

Holland JM (2004) The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agric Ecosyst Environ 103:1–25

Huaqi W, Bouman BAM, Zhao D, Changgui W, Moya PF (2002) Aerobic rice in northern China: opportunities and challenges. Workshop on water wise rice production, 8–11 April IRRI, Los Banos, Philippines

IBSRAM (International Board for Soil Research and Management) (1990) Organic-matter management and tillage in humid and sub-humid Africa. IBSRAM proceedings No 10. IBSRAM, Bangkok

Iqbal M, Khan M, Azeem MA, Zubair M (2002) Zero-tillage technology and farm profits: a case study of wheat growers in the rice zone of Punjab. The Pakistan Development Review 41(4 Part iii):665–682

Jeffrey SJ, Douglas LY, William FS (2002) Economics of conservation tillage in a wheat fallow rotation. Agron J 94:527–531

Jiao Y, Hendershot WH, Whalen JK (2004) Agricultural practices influence dissolved nutrients leaching through intact soil core. Soil Sci Soc Am J 68(6):2058–2068

Khan SRA (2003) Water resource development potential. Pakistan water gateway. www.waterinfo.net.pk/articlesrizo2.htm. Accessed on 25 Apr 2012

Malik RK, Ashola Y, Bonga RS, Samar S (2000) Zero tillage wheat sowing and alternate herbicides resistant Phalaris minor in rice–wheat cropping system. Indian J Weed Sci 32(3):220–222

Nayyar H, Walia DP, Kaishta BL (1995) Performance of bread wheat (*Triticum aestivum* L.) seeds primed with growth regulators and inorganic salts. Indian J Agric Sci 65:112–116

Noorka IR, Khaliq I (2007) An efficient technique for screening wheat (*Triticum aestivum* L.) germplasm for drought tolerance. Pak J Bot 39(5):1539–1546

Noorka IR, Khaliq I, Kashif M (2007) Index of transmissibility and genetic variation in spring wheat seedlings under water deficit conditions. Pak J Agric Sci 44(4):604–607

Noorka IR, Shahid SA, Rouf S (2011) Principal component analysis for soil conservation tillage vs. conventional tillage in semiarid region of Punjab, Province of Pakistan. Iran J Earth Sci 3:204–208

Pakistan Water Partnership (2007) The framework for action for achieving the Pakistan water vision 2025. The national coordinator for frame of action. Pakistan Water Partnership, Pakistan

Rijsberman FR, Molden D (2001) Balancing water uses: water for food and water for nature. Thematic back ground paper. In: International Conference on Freshwater Water, Bonn, Germany, p 18

Ruan S, Xue Q, Tylhowska K (2002) The influence of priming on germination of rice (*Oryza sativa* L.) seeds and seedlings emergence and performance in flooded soils. Seed Sci Technol 30:61–67

Sarwar MN, Goheer MA (2007) Adoption and impact of zero tillage technology for wheat in rice-wheat system – water and cost saving technology. A case study of Pakistan (Punjab). Centre for Research on Poverty Reduction and Income Distribution, Islamabad

Smith P (2009) Agriculture and climate change: an agenda for negotiation in Copenhagen, synergies among mitigation, adaptation and sustainable development. Focus 16(B9). International Food Policy Research Institute, Washington, USA

Smith PG, Millet AH (1964) Germinating and sprouting responses of tomato at low temperature. J Am Assoc Hort Sci 84:480–484

Sorrenson WJ, Duarte C, López-Portillo J (1998) Economics of non-till compared to conventional cultivation systems on small farms in Paraguay, policy and investment implications. Report Soil Conservation Project MAG-GTZ, August 1998

Uri ND, Atwood JD, Sanabria J (1999) The environmental benefits and costs of conservation tillage. Environ Geol 38(2):111–125

Watanabe FS, Olsen SR (1962) Colorimetric determination of phosphorus in water extracts of soils. Soil Sci 93:183–188

Zhanxing H (2008) Research on the technique of conservation tillage in various areas in Shanxi Province. Shanxi Provincial Administration Bureau of Farm Machinery, Taiyuan

Zheng GH, Wilen RW, Slinkard AE, Gusta LV (1994) Enhancement of canola seed germination and seedling emergence at low temperature by priming. Crop Sci 34(15):89–1593

Chapter 52
Effect of Salinity and Bentonite on the Characteristics of Mineral Soil and Behavior of Leguminous Plants (*Vicia faba* L.)

Houcine Abdelhakim Reguieg Yssaad and Bachir Bouyadjra Amine

Abstract To rehabilitate the degraded soils and to improve the quality of agricultural product, especially leguminous plants (*Vicia faba* L.), we used bentonite to ameliorate the physical and chemical properties of sandy soil. To evaluate the ecological advantage of bentonite, we studied the effect of increasing amounts of bentonite on the physical and chemical characteristics of analyzing pH, EC (electrical conductivity), total calcareous, active calcareous, total phosphorus, organic carbon, organic matter, total nitrogen, and cation-exchange capacity. In Algeria, the drought has increased salts in the rhizosphere in the soils of semiarid and arid areas. The objective of this study was to assess the response of leguminous plants (*Vicia faba* L.) to increasing levels of salts, the combined effect of bentonite/salts to certain metabolic activities, mineral contents, and morphophysiological behavior of the plant response to abiotic stress. It is observed that variability exists in the physical and chemical characteristics and morphological growth of the plant according to the bentonite amount mixed in the sandy soil sample.

Keywords Bentonite • Leguminous plants • Physical and chemical characteristics • Rehabilitation • Salty soil

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52.1 Introduction

The progressive reduction of vegetation cover in arid and semiarid areas, due to desertification and soil erosion, becomes a major problem in ecosystems degradation of these regions (Martinez et al. 2005). The salinity is a worldwide growing environmental problem, particularly the Mediterranean Sea and North Africa; this is considered an abiotic factor. Salinity is the most important limiting factor to plants productivity (Khan and Panda 2008; Munns 2002; Tester and Davenport 2003). Over 40% of cultivated land in the arid and semiarid areas is affected by salinity (Hamdy 1999). The water scarcity in these regions (Munns et al. 2006) and expansion of irrigated areas cause salinization of soils (Ben Naceur et al. 2001; Rochdi et al. 2005; Araujo et al. 2006). The salinity is not only related to climate conditions (Djili and Daoud 2000) but also to poorly controlled cultivation practices, such as irrigation which leads to a secondary salinization process (Hamdy 1999) due to the use of large quantities of poor quality water (Mouhhouche and Boulassal 1999; Belkhodja and Bidai 2004). The excessive use of chemical fertilizers to increase yields also causes soil salinity (Zid and Grignon 1991; Smith and Compton 2004; Qadir and Oster 2004). The presence of excess salts in the soil does not only limit crop production but also causes an ionic, osmotic, and nutritional stress (Levigneron et al. 1995). When the plants are exposed to these environmental constraints, they develop tolerance and adjustment reactions resulting in changes in metabolic, physiological, and morphological nature (Jacoby 1994; Qian et al. 2001; Xianan and Vance 2003; Alberto et al. 2005). One major mechanism of adaptation to ionic and osmotic stresses results in the accumulation of K^+ and Na^+ (Wang et al. 2002; Parida and Das 2005), Cl^- (Munns et al. 2006; Teakle et al. 2007), and certain amino acids such as proline (Belkhodja and Bidai 2004; Kartashov et al. 2008). For a sustainable agriculture, it is important to choose a sound management of cultivated lands, based on a deep understanding of biological interactions and using available natural resources. It is in this perspective, the cultivated land is amended with bentonite clay, that ultimately improved the cation-exchange capacity of the soil (Petr 1985; Dejou 1987). Other authors reported that the addition of bentonite in sandy soil improved the physical properties (Benkhalifa and Daoud 1998; Halilat and Tessier 2006) leading to high water- and nutrient-holding capacity. The aim of the work was to study the influence of some different rates of bentonite, coupled with salinity constraints to legume (bean *Vicia faba* L.) commonly grown in Algeria; the mineral analysis of bean leaves and roots allows the understanding of the combined effects of salinity and bentonite on the mineral nutrition of this species.

52.2 Materials and Methods

52.2.1 *Plant Material*

A local variety of bean (*Vicia faba* L.) is used in the experiment. The bean seeds were obtained from the Institute of Development Crops, Sidi Bel Abbès (Fig. 52.1). The seeds were disinfected for 5 min with 8% bleach and rinsed several times with

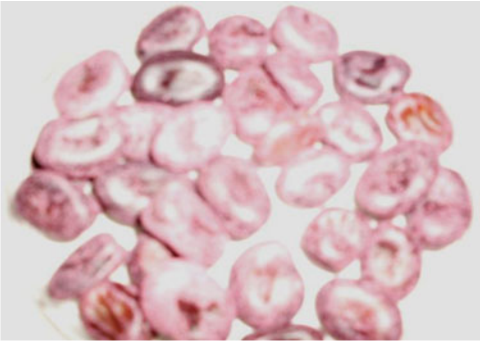

Fig. 52.1 The seeds of *Vicia faba* L.

distilled water to remove traces of chlorine. The germination tests were performed in plastic trays wrapped in moist filter paper and placed in an oven at 22°C for 7 days.

52.2.2 Methods

52.2.2.1 Substrate Culture

The bentonite sand was collected along the beach of Sidi Mansour. This sand has undergone several successive operations; first, the sand was sieved to eliminate wastes and coarser material then washed repeatedly with tap water to eliminate all carbonates and chlorides. Finally, the sand was air-dried. A confirmatory test was made by adding silver nitrate solution to check the purity of the substrate and to confirm no salts such as those of chlorides were present in the washed sand. The bentonite in its natural granular form was milled using an electric grinder and sieved through a 2-mm-opening sieve. The prepared substrate consists of two volumes of sand and one volume of peat. Four doses of bentonite are used: 3, 5, 7, and 10%. The quantity of bentonite added to the treated soil matches with doses expressed in percentage of soil dry weight (Table 52.1). This substrate was vigorously mixed manually to obtain a homogeneous substrate. The used pots are made of plastic. The bottom of each pot was covered with a layer of gravel to ensure good drainage. Each pot was filled with 600g of mixed substrate. The experimental treatments were arranged in randomized complete block design using five replications.

52.2.2.2 Experimental Plan

After germination, one seedling was carefully transferred to each pot and placed in a greenhouse located at the University of Oran, where temperature, humidity, and wind factors were controlled. Irrigation was preceded at 60% of the substrate

Table 52.1 Weight of each dose of bentonite used compared to substrate dry weight

Bentonite concentration (%)	3	5	7	10
Dry weight of bentonite used (g)	18	30	42	60

Table 52.2 Composition of the nutrient solution of Hoagland and Arnon (1938)

Product	Composition	Weight (g L^{-1})
Potassium nitrate	KNO_3	191.90
Calcium nitrate	$Ca(NO_3)_2{\cdot}4H_2O$	129.80
Ammonium nitrate	NH_4NO_3	210
Magnesium sulfate	$MgSO_4{\cdot}7H_2O$	61.5
Monopotassium dihydrogen phosphate	KH_2PO_4	54.40
Dipotassium hydrogen phosphate	$K_2HPO_4{\cdot}3H_2O$	34.23
Manganese chloride	$MnCl_2{\cdot}4H_2O$	1.80
Copper sulfate	$CuSO_4{\cdot}5H_2O$	0.176
Zinc sulfate	$ZnSO_4{\cdot}7H_2O$	0.219
Boric acid	H_3BO_3	2.861
Ammonium molybdate	$NH_4MO_7O_{24}{\cdot}7H_2O$	0.285
Ferric complex	EDTA ferric ($C_{10}H_{12}FeN_2NaO_8$)	0.050

Table 52.3 Composition of the saline solution

Weight of NaCl (g) per liter of water	Concentration NaCl (meq L^{-1})
5.84	100
11.68	200

retention capacity amounting to 80 mL per pot. Watering is done three times per week, two times with demineralized water and once in the nutrient solution Hoagland and Arnon type (1938) diluted to 1/1,000th (Table 52.2).

The pots were divided into five treatments with different bentonite concentrations (0, 3, 5, 7, and 10%). Each dose of bentonite received two concentrations of sodium chloride salts and a control (0, 100, 200 meq L^{-1}) (Table 52.3) with five replications for each salt treatment (Table 52.4). The control pots were irrigated with distilled water during the period of stress application. After 35 days of seed germination, application of stress was performed (Fig. 52.2).

52.2.2.3 Sample Collection

After harvesting of plants, leaves, stems, and roots were carefully separated. The underground portion rinsed with tap water and then dried using the blotting paper. To avoid contamination with culture substrate, each part of the plant was weighed and then wrapped in numbered aluminum paper and dried at 80°C for 48 h. The samples are weighed it their dry state. The water content was determined by the following formula:

$$\text{Water content }(\%) = \left(\frac{\text{Fresh weight} - \text{dry weight}}{\text{Fresh weight}}\right) \times 100$$

Table 52.4 Experimental design adopted in the greenhouse

Doses de bentonite (%)	NaCl meq L^{-1}	Number of pots
0	0	5
	100	5
	200	5
3	0	5
	100	5
	200	5
5	0	5
	100	5
	200	5
7	0	5
	100	5
	200	5
10	0	5
	100	5
	200	5
		Total = 75

52.2.2.4 Extraction of Minerals

The mineral contents of leaves and roots of stressed plants and controls were determined by using the standard methods (Lafon et al. 1996), through calcination and complete destruction of the organic material (Martin-Prevel et al. 1984). The residue is then analyzed, Na^+ and K^+ determined by flame photometer.

52.3 Results and Discussion

52.3.1 Mineral Balance of Sodium and Potassium in Plant (Leaves and Roots)

52.3.1.1 Sodium Content

Without Treatment with Bentonite

The addition of NaCl in the irrigation solutions significantly increased the Na^+ in plant roots (Fig. 52.3a). The level of sodium is relatively less important in leaves, and hence the roots record the highest levels. The control treatment records a very low rate of sodium (16.18 ppm) in the leaves. The accumulation of Na ion in the bean's organs increased proportionately with the increasing dose of salt concentration. The values increase to 35.84 ppm with 100 meq L^{-1} and reached to 83.76 ppm with 200 meq L^{-1}.

The roots and leaves show the same behavior in the presence of NaCl. The root samples from control treatment record levels of sodium (50.28 ppm), relatively

Fig. 52.2 Experimental set up in the greenhouse

higher levels of Na recorded, 72.84 ppm and 85.42 ppm, respectively, for salt concentrations of 100 and 200 meq L^{-1}. It is found that the sodium content in the roots remains higher than that of the leaves in substrates without bentonite.

52.3.1.1.2 Bentonite at the Rate of 3%

In substrates treated with bentonite at 3%, levels of sodium obtained in the plant organs were higher compared to the soil without bentonite (Fig. 52.3b). Indeed, these soils at 3% of bentonite record sodium content from 17.38 ppm in the leaves of non-stressed plants; this level increases to 52.2 and 61.68 ppm for salt concentrations of 100 and 200 meq L^{-1}. However, for roots, we noticed a significant increase in of Na up to 40.94 ppm in the total absence of salt. Once the plant received 100 meq L^{-1}, a net increase of sodium up to 78.14 ppm was recorded. The level of sodium increases only to 9% in the roots treated with NaCl at 200 meq L^{-1}.

52.3.1.1.3 Bentonite at the Rate of 5%

According to the results (Fig. 52.3c) and compared to the substrate at 3% of bentonite, a significant increase was noticed for the sodium levels in leaves and roots of the plant, that is, 59.28 and 83.48 ppm with dose of 100 meq L^{-1} NaCl and 76.24 and 94.29 ppm dose of 200 meq L^{-1} NaCl for leaves and roots of the bean, respectively. The roots show the highest levels of sodium for salt treatments (0, 100, 200 meq L^{-1}) (Fig. 52.3c). The concentration levels are less important for the leaves where the lowest level was recorded in the control (0 meq L^{-1}) treatment. In the control substrate, the sodium levels are low, ranging between 34.4 and 78.04 ppm.

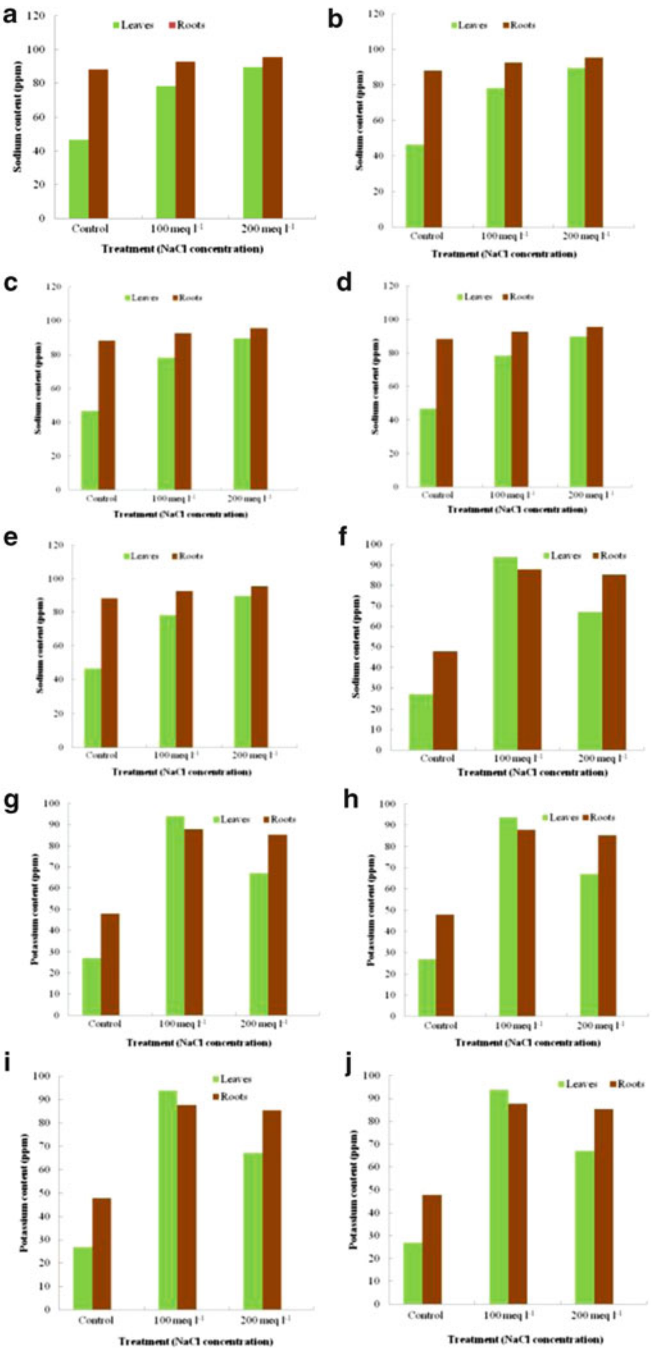

Fig. 52.3 Sodium (ppm) content in roots and leaves of bean in substrates (**a**) without bentonite but with salt stress for a week, (**b**) at 3% of bentonite and salt stress for a week, (**c**) at 5% of bentonite and salt stress for a week, (**d**) at 7% of bentonite and salt stress for a week, and (**e**) at 10% of bentonite and salt stress for a week. Potassium (ppm) content in roots and leaves of bean in substrates (**f**) without bentonite but salt stress for a week, (**g**) at 3% of bentonite and salt stress for a week, (**h**) at 5% of bentonite and salt stress for a week, (**i**) at 7% of bentonite and salt stress for a week, and (**j**) at 10% of bentonite and salt stress for a week

52.3.1.1.4 Bentonite at the Rate of 7%

The sodium levels in the bean leaves grown in substrate at 7% of bentonite are relatively low with an average of 37.14 ppm for non-stressed control plants. Then a major change appeared in the sodium level of the leaves for salt concentrations of 100 and 200 meq L^{-1}, and the mean values vary between 76.92 and 61.56 ppm. These increases in sodium levels are due mainly to the combined effect of the presence of bentonite in one hand and the salt concentrations practiced on the plant in the other.

According to the recorded results in soils with 7% of bentonite (Fig. 52.3d), we noted that the levels of sodium in roots are higher compared to those recorded in the leaves, and this is true for non-stressed plants and those subjected to salt concentrations. As soon as plants receive saline solutions of 100 and 200 meq L^{-1}, a considerable accumulation of Na^+ is recorded in the roots, where concentrations are ranged from 89.28 to 90.64 ppm. The action of bentonite promoted the accumulation Na^+ in roots, which explains well the content variability of sodium in bean roots exposed to two variables: salinity and bentonite.

52.3.1.1.5 Bentonite at the Rate of 10%

The treatment of the substrate soil at 10% of bentonite results in a considerable ionic load of sodium in the leaves and roots. Overall, the increase in sodium is very consistent in both parts of the plant to 200 meq L^{-1} salinity, still with maximum recorded values (89 and 92.6 ppm).

The sodium levels found in both bean bodies (Fig. 52.3e) are the highest compared to other treatments with bentonite, and this is valid for non-stressed plants and the two saline doses of 100 and 200 meq L^{-1}. Moreover, in roots, sodium increases more than in the leaves. In addition, the sodium levels analyzed in soils receiving salt (NaCl) are much higher than those obtained in the plant without salt stress (control).

52.3.1.2 Potassium Content

52.3.1.2.1 Without Treatment with Bentonite

The potassium in plants (Fig. 52.3f) in the substrate where no bentonite was applied varies between 26.14 and 89.14 ppm with a sizable difference in the potassium content between non-stressed plants and under saline stressed plants. In the plants with stress of 100 meq L^{-1}, the potassium was higher in the leaves than those with saline concentration of 200 meq L^{-1}. A significant drop in potassium in the leaves compared to the roots up to 87.58 ppm was recorded. The roots display the highest level of Na (89.14 ppm). Moreover, under the application of salt stress, the potassium is much higher than those where no salt was applied.

52.3.1.2.2 Bentonite at the Rate of 3%

The results (Fig. 52.3g) in substrates at 3% of bentonite and without bentonite show a significant increase in potassium levels in bean leaves and roots at 0 and 100 meq L^{-1}; however, these concentrations significantly decreased at 200 meq L^{-1} in leaves and roots ranging from 68.48 to 57.46 ppm, respectively. This decrease of potassium is due to the strong absorption that occurred in the plant at the salt concentration of 100 meq L^{-1}. Overall levels of potassium are more consistent in the leaves than in roots even when maximum values are recorded in the leaves (68.48 and 89.2 ppm).

52.3.1.2.3 Bentonite at the Rate of 5%

According to the results (Fig. 52.3h) and compared to the substrate at 3% of bentonite, a consequent reduction of the potassium content in the leaves was noted for all salt treatments, a level of 32.22 ppm for the stress-free saline plant and 68.24 ppm for the saline dose of 100 meq L^{-1}. The concentration level of 63.78 ppm is relatively less important for salt concentration of 200 meq L^{-1}.

We noted that the accumulation of potassium in the leaves is higher in stressed plants than in the non-stressed plant; this is valid for the two organs of the culture. At 3% of bentonite, potassium increases in the plant roots regardless of saline treatment. Its content remains low in non-stressed plants; however, the potassium content in the roots increases much more with 200 meq L^{-1} salts.

52.3.1.2.4 Bentonite at the Rate of 7%

The results of plants under no-stress condition show that the variation of potassium is very low between leaves and roots. The contents of potassium are higher in plants of salt concentration 100 and 200 meq L^{-1} where the values vary between 67.98 and 75.32 ppm; however, the substantial accumulation was recorded in roots than in leaves (Fig. 52.3i). Whereas with the dose of 200 meq L^{-1}, we observed a significant decrease of K up to 67.98 and 74.7 ppm, respectively, for leaves and roots.

52.3.1.2.5 Bentonite at the Rate of 10%

According to the results obtained in the substrate at 10% of bentonite (Fig. 52.3j), we noted that the potassium levels in the leaves of non-stressed plants are the lowest compared to those of previous substrates. But this level remains high for the roots.

Moreover, in plants at 100 meq L^{-1} NaCl, potassium increases much more than in the plants of 200 meq L^{-1} of salt concentration. In addition, the analyzed levels of potassium in the leaves at 100 meq L^{-1} NaCl are much higher (93.86 ppm) than those obtained in roots (87.76 ppm). The accumulation of potassium is much higher with 100 meq L^{-1} NaCl application compared to the salt concentration of 200 meq L^{-1}.

Table 52.5 Significance statistical test of Fisher ($p=5\%$) of sodium and potassium contents in leaves and roots of plant stressed to salinity for a week and cultivated sandy substrates amended with bentonite

		Na^+ (ppm)		K^+ (ppm)	
Dose of bentonite (%)	NaCl (meq L^{-1})	Leaves	Roots	Leaves	Roots
0	0	16.18 ± 5.01	50.28 ± 2.18	26.14 ± 3.83	35.52 ± 5.95
	100	35.84 ± 5.43 s	72.84 ± 1.58 s	55.2 ± 3.6 s	48.28 ± 4.65 s
	200	83.76 ± 3.52 ss	85.42 ± 3.89 ss	87.58 ± 5.48 ss	89.14 ± 6.48 ss
3	0	17.38 ± 4.49	40.94 ± 4.49	46.86 ± 7.39	44.66 ± 7.74
	100	52.26 ± 6.69 s	78.14 ± 5.09 s	89.2 ± 8.99 s	63.78 ± 9.27 s
	200	61.68 ± 7.19 ss	86.1 ± 9.15 s	68.48 ± 8.61 ss	57.46 ± 9.20 ss
5	0	34.4 ± 8.46	78.04 ± 3.63	32.22 ± 5.21	55.8 ± 4.63
	100	59.28 ± 8.05 s	83.48 ± 8.03 ns	68.24 ± 6.46	62.36 ± 6.80 ns
	200	76.24 ± 8.76 ss	94.2 ± 2.48 ss	63.78 ± 8.98 s	90.68 ± 6.69 ss
7	0	37.14 ± 8.03	80.46 ± 8.48	33.54 ± 4.54	31.06 ± 3.96
	100	76.92 ± 6.87 s	89.28 ± 7.84 ns	74.52 ± 4.20 s	75.32 ± 9.25 s
	200	61.56 ± 9.29 ss	90.64 ± 5.14 ns	67.98 ± 9.51 s	74.7 ± 9.98 s
10	0	46.58 ± 8.32	88.26 ± 6.82	26.9 ± 9.76	47.88 ± 7.35
	100	78.18 ± 9.60 s	92.72 ± 9.31 ns	93.86 ± 4.70 s	87.76 ± 8.48 s
	200	89 ± 7.34 s	92.6 ± 8.85 ns	67.06 ± 8.79 ss	85.35 ± 8.06 s

$m \pm \sigma m$ statistical average, σ standard deviation, *ns* not significant, *s* significant, *ss* highly significant

52.4 Conclusions

It is concluded that the sodium content in the roots remains higher than that of the leaves in substrates without treatment with bentonite. Overall, the increase of sodium level is very consistent in the leaves and roots of non-stressed plants in substrates rich in bentonite. The accumulation of sodium is very significant in both organs of plants grown in the absence of bentonite to salt doses 100 and 200 meq L^{-1}. The leaves accumulate more sodium under the combined effect of different doses of bentonite and salt concentrations. Leaves and roots of plants grown in substrates of 3% bentonite and stressed to 200 meq L^{-1} NaCl accumulate lower levels of sodium than in substrates without bentonite. The addition of increasing concentrations of salt loads the bean leaves with Na^+. The sodium accumulation occurs in plants grown in saline conditions, and the leaves are more vulnerable than the roots because it accumulates in the leaf edge and causes an ionic imbalance, deficiency symptoms, and disturbance of metabolites. The potassium content increases dramatically in plants subjected to a combination of salt-bentonite. Once the plants received salt solutions of 100 and 200 meq L^{-1}, potassium levels become high in the leaves and roots of plants grown in substrates at 5 and 7% of bentonite. With the combination of bentonite-salinity, plants record higher rates of potassium.

References

Alberto C, Laiz-Carrion R, Del Rio MP, Maseguer M, Mancera J, Angeles MJ, Esteban M (2005) Salinity influence the hormonal immune parameters of gilthead sea bream (*Sparus aurata* L.). Fish Shellfish Immunol 18:255–261

Araujo SAM, Silveira JAG, Almeida TD, Rocha IMA, Morais DI, Viegas RA (2006) Salinity tolerance of halophyte *Atriplex nummularia* L. grown under increasing NaCl levels. Engenharia agricola e ambiental 10(4):848–854

Belkhodja M, Bidai Y (2004) Réponse des graines d'Atriplex halimus L. à la salinité au stade de la germination. Sécheresse 15(40):331–335

Ben Naceur M, Rahmoune C, Sdiri H, Meddahi ML, Selmi M (2001) Effet du stress salin sur la germination, la croissance et la production en grains de quelques variétés maghrébines de blé. Sécheresse 12(3):167–174

Benkhalifa M, Daoud Y (1998) Influence de la bentonite sur les propriétés physiques d'un sol sableux. Annales de L'INA- EL Harrach 19(1 and 2):18–29

Dejou J (1987) La surface spécifique des argiles, sa mesure, relation avec la CEC et son importance agronomique. Dans C.R.Coll.AFES "CEC et fertilisation des sols agricoles", Caen, France, Nov 1987, pp 72–83

Djili K, Daoud Y (2000) Influence des hauteurs des précipitations sur la répartition du calcaire et du pourcentage de sodium échangeable dans les sols du Nord de l'Algérie. Sécheresse 11(1):37–43

Halilat MT, Tessier D (2006) Amélioration de la rétention en eau de matériau sableux par l'ajout de bentonite. Cah Agric 4:347–353

Hamdy A (1999) Saline irrigation assessment and management for a sustainable use saline irrigation. In: Saline irrigation: Halophyte production and utilization, Hamdy, A. Lieth, H. CIHEAM-IAMB publication, Bari Italie. pp 157–227.

Hoagland D, Arnon DI (1938) The Water culture method for growing plants soil. Univ Calif Agric Exp Stn Circ 347:1–36

Jacoby B (1994) Mechanisms involved in salt tolerance by plants. In: Pessarakli M (ed) Handbook of plant and crop stress. Marcel Dekker, New York, pp 97–123

Kartashov AV, Radykina NL, Ivanov YUV, Pashkocski PP, Shevyakova NI, Kuuznetsov VV (2008) Role of antioxidant systems in wild plant adaptation to salt stress. Russ J Plant Physiol 55(4):516–522

Khan MH, Panda SK (2008) Alterations in root lipid peroxidation and antioxidative responses in two rice cultivars under NaCl-salinity stress. Acta Physiol Plant 30:81–89

Lafon JP, Tharaud PC, Levy G (1996) Biologie des plantes cultivées: Tome I organisation physiologie de la nutrition. Edition. Lavoisie, Paris, France, pp 153–160

Levigneron A, Lopez F, Vansnyt G, Berthomieu P, Fouriroy P, Casse-Delbart F (1995) Les plantes face au stress salin. Cah Agric 4(4):263–273

Martinez JP, Kinet JM, Bajii M, Lutts S (2005) NaCl alleviates polyethylene glycol-induced water stress in the halophyte species *Atriplex halimus* L. J Exp Bot 419:2421–2431

Martin-Prevel P, Gagnard J, Gautier P, Drouineau G (1984) Analyse végétale dans le contrôle de l'alimentation des plantes tempérées et tropicales. Technique et Documentation-Lavoisier, Paris, pp 161–179

Mouhhouche B, Boulassal M (1999) Contribution à une meilleure maîtrise des pertes en eau d'irrigation et de la salinisation des sols en zones arides. Rec Agron 4:15–23

Munns R (2002) Comparative physiology of salt and water stress. Plant Cell Environ 25:239–250

Munns R, James RA, Lauchli A (2006) Approaches to increasing the salt tolerance of wheat and other cereals. J Exp Bot 57(5):1025–1043

Parida AK, Das AB (2005) Salt tolerance and salinity effects on plants: review. Ecotoxicol Environ Saf 60:324–349

Petr J (1985) Non metallic sorbents in agriculture. ONUDI Edn, Tchecoslovaquie, p 39

Qian Y, Wilhelm SJ, Marcum KB (2001) Comparative responses of two Kentucky bluegrass cultivars to salinity stress. Corp Sci 41:1895–1900

Qadir M, Oster JD (2004) Crop and irrigation management strategies for saline-sodic soils and waters aimed at environmentally sustainable agriculture. Sci Total Environ 323:1–19

Rochdi A, Lemsellek A, Boussarhal A, Rachidai A (2005) Evaluation sous serre de la tolerance à la salinité de quelques porte greffe d'agrumes sitrus aurantium et deux hybrids de poncirus trifoliata (Poncirus × Citrus sinensis et Poncirus × Mandarinier sunki). Biotechnol Agron Soc Environ 9(1):65–73

Smith M, Compton JS (2004) Origin and evolution of major salts in the darling pans, Western Cape, South Africa. Appl Geochem 19:645–664

Teakle NL, Flowers TJ, Real D, Colmer TD (2007) Lotus tenuis tolerates the interactive effects of salinity and waterlogging by excluding Na^+ and Cl^- from the xylem. J Exp Bot 58(8):2169–2180

Tester M, Davenport R (2003) Na^+ tolerance and Na^+ transport in higher plants. Ann Bot 91:503–527

Wang S, Zheing W, Ren J, Zhang C (2002) Selectivity of various types of salt-resistant plant for K^+ over Na^+. J Arid Environ 52(4):457–472

Xianan L, Vance BWM (2003) Differential expression of genes regulated in response to drought or salinity stress in Sunflower. Crop Sci 43:678–687

Zid E, Grignon C (1991) Les tests de sélection précoce pour la résistance des plantes aus stress, cas des stress salin et hydrique: L'amélioration des plantes pour l'adaptation aux milieux arides. Ed. AUPELF-UREF, Paris, pp 91–108

Acronyms and Abbreviations

ADW	Agricultural drainage water
BOD	Biological oxygen demand
CA	Conservation agriculture
CAL	Central analytical laboratory
CCA	Canal command area
COD	Chemical oxygen demand
CTCRI	Central Tuber Crops Research Institute
CWSI	Crop water stress index
DEM	Digital elevation model
dS m^{-1}	Deci Siemens per meter
EAD	Environment Agency Abu Dhabi
EC	Electrical conductivity
ECa	Apparent electrical conductivity
EDXRA	Energy dispersive X-ray analysis
EMI	Electromagnetic induction
EPMA	Electron probe micro-analysis
ESP	Exchangeable sodium percentage
FAO	Food and Agriculture Organization
FCC	False color composite
FYM	Farm yard manure
GCCC	Gulf Cooperation Council Countries
GDP	Gross domestic product
GIS	Geographical information system
GR	Gypsum requirement
ICARDA	International Center for Agricultural Research in the Dry Areas
ICBA	International Center for Biosaline Agriculture
IDW	Inverse distance weighted
ILWIS	Integrated Land and Water Information System
IPNS	Integrated plant nutrient supply
IRS	Indian remote sensing
ISFM	Integrated soil fertility management
IUCN	International Union of Conservation Nature
IWMI	International Water Management Institute
KISR	Kuwait Institute for Scientific Research
LADA	Land Degradation Assessment in Drylands
LR	Leaching requirement
LTA	Low temperature ashing

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MCM	Million cubic meters
MDG	Millennium development goals
$mS\ m^{-1}$	Milli Siemens per meter
NDVI	Normalized difference vegetation index
NIAB	Nuclear Institute for Agriculture and Biology
NRCS	Natural Resources Conservation Service
NRSA	National Remote Sensing Agency
PAM	Polyacrylamide
PET	Potential evapotranspiration
QCS	Quick Check system
RBD	Randomized block design
RCBD	Randomized complete block design
RGR	Relative growth rate
RS	Remote sensing
RSC	Residual sodium carbonates
SAR	Sodium adsorption ratio
SEM	Scanning electron microscopy
SRDI	Soil Resources Development Institute
SSA	Sub-Sahara Africa
TDR	Time domain reflectometry
TDS	Total dissolved solids
TWW	Treated wastewater
UAE	United Arab Emirates
UNESCO	United Nations Education Scientific and Cultural Organization
USDA	United States Department of Agriculture
WDXRA	Wavelength dispersive X-ray analysis
XRD	X-ray diffraction

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