COURSE TITLE: INDUSTRIAL CROPS PRODUCTION

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CHAPTER 1. INTRODUCTION

1.1. Definitions

Crops: A collection of plants grown naturally or artificially for the benefit of man.
Industrial Crops: Crops, which supply industry with raw materials or crops, which should be processed before use.

1.2. Roles of Industrial Crops:

- Serve as source of cash income: usually fetch higher price than food grains, *e.g.* sesame, groundnut
- Provide employment opportunity, *e.g.* sugar estates of Methara, Wonji & Fincha; cotton farms
- Form the basis for agro-industries, *e.g.* sugar factories of Wonji-Shoa, Mathara & Fincha depend on sugarcane; edible oil processing factories depend on oil crops

1.3. Major Industrial Crops

The major industrial crops of economic importance in Ethiopia are:

a. Sugar producing crops: sugarcane
b. Fiber producing crops: cotton, sisal, kenaf, enset
c. Oil crops:
    - highland oil crops: noug, linseed, rapeseed, sunflower
    - lowland oil crops: sesame, groundnut, safflower, castor
d. Tobacco

1.4. History of Industrial Crops

The history of industrial crops can be traced back to primitive humans' earliest encounters with fire, artificially by friction. The value of wood as a natural resource for fire was known from the very beginning as humans watched fire. Increasing the efficiency of energy produced from wood by converting it into charcoal was one of the early industrial inventions. With time, humans learned that not only was the cellulosic biomass of the plant a reservoir of energy, but the seeds were also. Seeds of certain plant species were found to contain liquid that could be extracted easily and when burned, produced light. The ancient Egyptians burned castor oil to light lamps.

In some parts of the world, lamps using plant oil are still used on religious occasions. The 18th century revolution in agriculture and industry laid the foundation for the accelerated use of plant feedstocks for multiple industrial uses. Cotton was the leading industrial crop during this period and Britain led the league of industrialized nations. Cotton material during this period made up half Britain's exports. This industrial success of Britain was made possible by the importation of cheap cotton from its colony in the USA, where at that time approximately 80% of the world's cotton crop was produced.

Feedstocks for the synthetic industry were, for the most part, supplied by plants until approximately 100 years ago. Plants were the source of inks, paints, dyes, adhesives, glues and other industrial chemicals. Cotton, wool and some minor crops provided yarn for weaving clothes. The discovery of technology to convert coal into kerosene on an industrial scale in the mid-19th century led to a gradual replacement of plant oil by kerosene oil, because it was cheaper and more readily available. Kerosene also laid the foundation of the modern chemical industry. During the period preceding World War, I, it became possible to derive a host of chemicals from coal. The next wave of energy source came in the form of petroleum.

In the 1920s, the industrial economy based on living plants began shifting towards a fossil fuel-based economy. Petroleum became the dominant source for synthetic products after World War II, as chemists were able to convert large quantities of gaseous and liquid by-products during the production of gasoline for a new category of synthetics named petrochemicals. These chemicals replaced those produced from plant-based feedstock comprised of starch, vegetable oil and cellulose during the early industrial period. As a consequence, the quantity of plant matter consumed for industrial products declined drastically, except for papermaking. Today, petroleum-derived products have entered all facets of our life, from clothing to food dyes and vinegar.

Lately, the advantage in the concentration of petroleum deposits in a few countries has turned into a definitive hindrance to the reliable supply of this vital commodity. Like several of these countries are beset by political and economic problems in that petroleum pipelines are often sabotaged as a political statement, interfering with the governance of price under a free market system. Oil embargos have also been used as a political tool. Threats of unpredictable and artificially created shortages of petroleum. There is also growing apprehension that the world may run out of easily extractable petroleum soon. The next generation's sources of petroleum will be required much higher cost of procuring and processing into usable forms. In addition, these sources may pose an environmental threat on several fronts. Mining operations may alter the existing landscape and vegetation, Mining operations put pressure on water resources needed for agriculture, human and animal use and disturb existing ecological wildlife habitats.

Due to the above reasons, there are various projections that within the next 100 years, the world will run out of fossil fuel. So, there is rethinking on the heavy dependence on petroleum and a sincere search for alternatives has begun. The new emphasis is on finding resources that are inexhaustible because of their renewable nature. In this context, the plant kingdom has again come into focus as an industrial raw material, because it can be replenished.

CHAPTER 2. SUGAR PRODUCING CROPS

Sugar can be obtained from sugarcane, sugar beet, few palms and sweet sorghum "sorgho". However, sugarcane & sugar beet account almost 100% of sugar production in the world.

Comparison of sugarcane and sugar beet

Sugarcane	**Sugar beet**
Provides 60% of sugar product	Provides 40% of sugar product
Sugar is extracted from stalk	Sugar is extracted from root
Mainly tropical crop	Mainly temperate crop
Used as sugar source since 300 B.C.	Discovered in 18th century (of recent domestication)
Belongs to family Poaceae (grass)	Belongs to family Chenopodaceae

2.1. History, Origin and Production of Sugarcane

It is believed that the noble cane *Saccahrum officinarum* is originated in south pacific area probably in New Guinea and spread to India & China in 300 B.C. Some 2000 years ago, a crude form of sugar was first produced in India.

Production: Sugarcane is one of the world's economically most important cultivated plants. Worldwide, approximately 12 million ha of sugarcane were harvested for sugar production in 1994-1995, yielding 758 million tons of stalks from which were extracted 78 million t of sucrose.

Production and export of sugar

Country	Production (million tons/year)	Export (million tons/year)
Brazil	23	0.9
Cuba	9.3	6.5
Mexico	4.7	
USA	4.6	
China	4.0	
Australia		2.7
Thailand		1.7

2.2. Botany of Sugarcane

There are six species of the genus *Saccharum* native to Southeast Asia and India: *S. officinarum* L.; *S. spontaneum* L.; *S. robustum* Brandes and Jeswiet ex Grassl; *S. sinense* Roxb.; *S. barberi* Jesw.; and *S. edule* Hassk. Commercially produced cultivars are usually interspecific hybrids, primarily of *S. officinarum* and *S. spontaneum*, but also of all other *Saccharum* species except *S. edule*, since it is infertile.

All of the known *Saccharum* species are polyploids. Each has varying basic chromosome numbers and ploidy levels. Total chromosome numbers range from 2n = 36 to 2n = 170. Estimates of the basic number range from 6 to 10, with a ploidy level from 6x to 12x. Since varying degrees of introgression and chromosome sorting occur during interspecific hybridization and backcrossing, the genetics of sugarcane cultivars are extremely complex.

Classification

Family: Poaceae (gramineae)
Genus: *Saccharum*

The genus *Saccharum* includes 6-speicies of which 4- are domesticated and 2 are wild species.

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The cultivated species

- *S. officinarum*
- *S. edule*
- *S. barberi*
- *S. sinense*

The wild species

- *S. spontaneum*
- *S. robustum*

Cultivated species

1. *S. officinarum* (noble cane)

- called noble canes because of their thick stems
- high sucrose content with low fiber and soft rind
- 3-5 meters in height with few tillers
- mostly suited to tropical conditions
- susceptible to most of the major sugarcane diseases

- largely grown in world as well as in Ethiopia.

2. S. edule

- appears to be restricted to Malaysia & Indonesia
- considered to be a mutant of S. *officinarum*

3. *S. barberi*

- intermediate to low in fiber content
- suited to sub-tropical and temperate climate
- canes short, medium to slender in thickness
- high fiber content and poor yields
- tillers abundantly.
- believed to be hybrid of *S. spontaneum* and *S. officinarum*

4. *S. sinense*

- tall, hardy & vigorous with wide adaptation and early maturity
- believed to be originated from natural hybridization of *S. spontaneum* and *S. officinarum*

Wild species

1. *S. spontaneum*

- a perennial grass, free-tillering occurring in wild form in Africa & Asia
- used in hybridization as it provides vigor, hardiness and resistance to most of the major diseases.

2. *S. robustum*

- large (robust) bamboo-like plant often reaching 10m in height, which is used for house and fence posts
- it is restricted to New Guinea and neighboring islands
- hard stems, woody, pithy in center with little juice
- its use for breeding is limited because of its complete susceptibility to diseases

Nowadays almost all commercial varieties of sugarcane are hybrids derived from breeding between the species of commercial importance. A number of breeding stations exist to carry out the hybridization such as in Barbados, Hawaii, Australia, South Africa, and Brazil.

Thus, from crossing programs, the modern hybrid Sugarcane variety incorporates the vigor & hardiness of *S. spontaneum* & *S. sinense* coupled with the higher sugar content of *S. officinarum* & *S. barberi*

S. spontaneum X *S. officinarum*
(Vigor, hardiness, resistance) (sucrose yield)
↓
Hybrid - commercial varieties

2.3. Morphology of Sugarcane

The morphology of sugarcane plant is similar to that of maize (*Zea mays* L.) and sorghum [*Sorghum bicolor* (L.) Moench]. However, sugarcane is vegetatively propagated. Whole stems or stem pieces (seed pieces or setts) are planted and new shoots arise from buds that occur at each node on the sett. The first roots (sett roots) arise from root initials on the node of the sett, and these support the young shoots until they develop their own shoot roots. Most cultivars tiller strongly at the crown, although the number of tillers is also dependent on plant spacing within and between rows.

The apical meristem of the stalk produces the new cells that become the stalk body with its attached leaves.

1. Stem

- it is the economically important part
- it is called cane, stalk or culm which is divided into a series of joints-each consisting of a node & internode. At harvest time, there are 20-30 internodes on a single stem, each internode being 10-20cm long depending on climate and nutrition. Adverse conditions shorten the internodes**.**
- it is unbranched except for tillers at the base
- the buds are alternate on the stem and the leaf sheath envelops the stem.
- stems vary in length from 1.5-4m, typically 2-3m and are normally 2-4 cm in diameter.
- length, diameter, shape and color of the joints vary with the cultivars and used as a means of identifying the different cultivars but can be influenced by light and nitrogen status (sun has a darkening effect). The most found colors of a cane are yellowish green and purple.
- top portion of the stem is low in sucrose content and is usually removed before processing.
- stem consists of a hard epidermis or rind, fibro-vascular bundles and soft parenchyma full of sap containing the sugar.

Sugarcane stalks consist of a series of nodes, where leaf sheaths attach, and internodes, which form the bulk of the sucrose storage tissue. Both nodes and internodes are usually solid. Most of the internode tissue is parenchyma (unspecialized cells with primary and secondary walls), the primary sink for sucrose storage is in the stalk. Vascular bundles are scattered throughout the parenchyma cylinder, oriented vertically, with no vascular connections between bundles in the internode. Internodes lengthen due to elongation of cells. After elongation, parenchyma cells are 200 to 300μm long and 80 to 150μm in diameter. The volume of fully elongated storage tissue is approximately 20% cell walls and intercellular space (apoplast), 72% intreacellular space (symplast), and 8% vascular bundle. The apoplast is largely fluid filled. About 95% of the parenchyma cell volume is a large vacuole that accumulates sucrose. Sucrose also accumulates in the cytoplasm and cell-wall space (apoplast). In some internodes, rapid expansion of the cells causes the interior parenchyma to stretch apart, forming air-filled voids. These broken cells and the void are called pith. Pithiness decreases the amount of juice in a stalk, and is therefore undesirable. Pithiness is a genotype characteristic, but it tends to increase following inflorescence initiation and development, and also during periods of very rapid stalk growth.

The vascular bundles in the internodes are surrounded by a bundle sheath of cells with thick walls, which lignify and suberize with internode age. Vascular bundles are smaller and closer together at the periphery of the stalk than in the center. About 50% of the bundles are located within 3mm of the rind. There are 1200 to 1500 vascular bundles in a typical cross-section of stem. Sugarcane stalks usually show strong apical dominance, and the growth of the lateral buds is suppressed unless the terminal meristem is damaged or flowers.

There is great variation in sugar accumulation among genotypes within the *Saccharum* complex. Concentration of total soluble solids in juice range from 0.2% in a *S. robustum* clone to 24.5% in an *S. officinarum* clone. Commerical cultivars are capable of accumulating sucrose concentrations to 27% of juice in the storage tissues. Storage of sucrose requires the movement of sucrose from the sieve tubes of the phloem (phloem unloading) and sequestering that sucrose in compartments where it cannot be utilized or remobilized to other plant parts. There are two major types of phloem unloading, apoplastic and symplastic. In apoplastic unloading, sucrose is unloaded from the phloem into the cell-wall space. In symplastic unloading, sucrose is transported from the phloem directly into the symplast of adjacent cells.

2. Roots

Once established, the root system of sugarcane is mostly fibrous and concentrated in the top 30 to 60 cm of soil. The roots can extend outward from the crown for several meters. It develops mainly 2-types of roots:

- **Sett roots:** thin branched temporary roots developed from sets until 3 months after emergence and then succeeded by permanent roots. Provide nutrients and moisture for the plant during the early stages.
- **Shoot- roots:** permanent roots developed after a third month from emergence. Provide all the nutrients & moisture as well as physical support to the plant.

The 25% of the plant roots are in the top 25 cm and 90% are within 60cm of the soil surface. Thus, it is not deep and soil moisture, aeration and temperature all affect the root development

3. Leaves

- borne alternately in two rows on either side of the stem at nodes.
- it has leaf blade (expanded portion) and the sheath with a ligule (membranous appendage of the sheath separating the two parts). The ligule can be used as a distinguishing characteristic between cultivars.
- the blade is 2-10cm wide and 60-180cm long.
- a good crop of cane in full growth can have a leaf area of 10 times greater than the area of soil on which the crop is growing (LAI =10).
- as the leaves die, the sheaths may become loose and break away easily at the point of attachment a character known as “free-trashing” which is a desirable character compared with “non-free trashing” types because if dead leaves (trash) is retained it will impede harvesting and may shelter pests.

The apical meristem is surrounded by a cylinder of immature leaves (spindle) with the most immature leaves to the inside. As leaf blades and sheaths elongate, the leaves unfurl from the spindle, forming a whorl. Leaf blades reach full elongation approximately confidently with emergence of the collar between blade and sheath from the leaf whorl. But the leaf sheath continues to elongate after the collar is visible. Below the collar the leaf sheath encircles the stem, extending downward about 30cm to its point of attachment at the base of a node.

Leaf blades are alternate, long and lanceolate, with a prominent midrib and parallel venation. The leaves have a specialized anatomy. The vascular bundles are surrounded by a bundle sheath, which, in turn, is surrounded by several layers of mesophyll cells. The chloroplasts in the bundle sheath are different from those in the mesophyll, and the biochemical processes of carbon fixation and differentially distributed among tissue types. The anatomical and biochemical specialization of cells allows for efficient carbon fixation via the C_4 pathway of photosynthesis.

Like maize, sugarcane uses the C_4 **pathway** of photosynthesis. The four-carbon organic acid, oxaloacetic acid is the first product of CO_2 fixation in the mesophyll cells. Oxaloacetic acid is converted into malic acid by malate dehydrogenase. The malate is then transported to the bundle sheath where it is decarboxylated, and the released CO_2 is fixed into sucrose via the C_3 ribulosebisphosphate carboxylase reaction. Chloroplasts from the mesophyll are anatomically distinct from those of the bundle sheath. The enzymes involved in the different stages of C_4 metabolism are also distributed differently between the cell types. Phosphoenolpyruvate carboxylase, which initially fixes CO_2 into oxaloacetate, is primarily expressed in the mesophyll, while NADP-dependent malic enzyme, which decarboxylates malate, and ribulose bisphosphate carboxylase, which refixes the released CO_2, are primarily expressed in the bundle sheath. Most of the sucrose synthesis also occurs in the bundle sheath and it is loaded from the bundle sheath to the phloem.

Carbon assimilation rate is influenced by many factors, especially light intensity, age of the plant, and soil and leaf water content. This is especially true under field conditions. Estimates of maximum carbon assimilation in leaves at full sunlight range from about 18 μmol m^{-2} s^{-1} in Hawaii during winter to 52 μmol m^{-2} s^{-1} in Australia during summer. Carbon assimilation rate apparently reaches a maximum at a photon flux density of about 1100 μmol m^{-2} s^{-1} in field-grown sugarcane.

d. Inflorescence

- known as arrow or tassel and consists of a branched panicle with a vertical axis
- when cane has reached maturity it can under certain conditions, change from the vegetative to the reproductive phase.
- most *Saccharum* varieties will not flower on day lengths longer than about 12½ hrs nor if given light in the middle of the dark period. Thus, short days enhance flowering
- the extent of flowering varies greatly with latitude, species and cultivars (some rarely flower, others flower profusely). Flower formation is greatest between 7^0 and 12^0 latitude and is non-existent around 30^0 latitude.
- flowering is an undesirable character as it results in a loss of sugar, which is used up in the process. It also terminates further internode development and increases fiber content.
- canes about to flower can be recognized by the last 7-8 leaves showing successive lengthening of the sheath and shortening of the blades.
- the flower is protogynous (the stigma is receptive before the pollen is shed)
- natural pollination is by wind.
- the flowers rarely set seeds and even if set the seeds soon loose viability with in only a few hours, but modern freeze-drying technique permit storage and transport between countries for breeding purpose
- as the production of flowers reduces the sucrose content of the stem, efforts are often made to delay flowering by:
  - ✓ adjusting temperature: < 18^0c hinders flowering; 18-24^0c – optimum for flowering
  - ✓ adjusting light: it is a short-day plant (that flowers in short day): < 12 ½ hrs of light – optimum for flowering; > 12½ hrs of light hinders flowering –possible to supply artificial light. Thus, exposing the fields to light at night for half an hour will hinder flowering.

Thus, it is possible to adjust the planting date & using varieties so that the time of flowering does not coincide with the environmental conditions favoring flowering.

2.4. Ecological Requirement

Most commercial sugarcane is grown between 35˚N and S of the equator.

Climate

Sugarcane requires high temperatures, plenty of sunlight, large quantities of water with at least 1525mm of rain per year unless grown with irrigation. The optimum average temperature is 25-26˚C. Tropical cultivars grow slower at 21˚C and at 13˚C do not grow at all. Temperatures under 5˚C lead to chlorosis.

Soil

Sugarcane can be grown in a wide variety of soil types, but heavy soils are usually preferred. The best soil is loam to clay loam soil. The crop is a heavy feeder and soils should be of high natural fertility or given adequate fertilizer. The optimum soil pH for sugarcane is 6.5, but it can grow at the range of 4-8.5. At low pH, Al becomes increasingly soluble and Al-toxicity occurs to sugarcane. CEC of the soil should be > 15 meq/100g of soil and organic matter of 2-4%.

2.5. Agronomic Practices

Land preparation

It should not be compact or very fine. It involves ploughing (sub-soiling) to uproot old cane stools and to break the soil into larger clods-to a depth of 40-45cm; harrowing after an interval of 10 days or so to produce soil of good tilth and making furrows for planting.

Planting

Sugarcane is propagated vegetative using stem cutting of immature canes referred as seed cane, setts or seed pieces. A seed cane is from 25-30 cm long and contains at least 1 bud, but it is preferable to have from 2-3 buds. If we use a very long cutting with more than 3 buds, there will not be a uniform stand as there is apical dominance, *i.e.* the upper buds prevent the germination of the lower buds and the lower buds will remain dormant. While the cane is still growing, the terminal meristem provides apical dominance, which prevents the growth of the buds below. Thus, the cane should be topped a week before taking the cutting.

Cuttings should not be taken from the tip or from the very basal portion. This is because the tip is watery, and the base is fibrous and cannot support the growth of the seedlings and may result in decay.

Appropriate age of cutting: 8-12 months old for plant crop and 6-8 months old for ratoon crop (regrowth). About 1-1.5 tons of cane will plant one ha and 1 ha of propagation nursery can plant from 5-6 ha. It is preferable to have propagation nursery where strict phytosanitary measures can be enforced.

Seed Treatment: Seed treatment is essential as most important sugarcane diseases like ratoon stunting disease, smut, leaf scald, are systemic, *i.e.* they are present within the cane stalk. Planting infected seed cane can spread these diseases. Thus, treatment of the seed cane with:

a) Organo-mercuric compounds
b) Hot H_2O treatment at 50˚C for 2 hrs. prevents diseases like chlorotic streak and ratoon stunting disease

Seed treatment also improves the germination of the cane.

Planting pattern: Generally, three types are used:

1. **Single line planting**: only a single seed piece is put on a point at spacing of 1.5 m (between furrows) x 0.6 m (between seed canes)
   - used when the environmental conditions are favorable for germination and for varieties with high germination rate.
2. **Double line planting**: two seed pieces are put at a spacing of 1.5m between rows & 0.6 m between plants to ensure good germination rate.
   - used when the environmental conditions are not favorable for germination and for varieties with poor germination.
3. **Single line planting with the edges of the seed canes overlapping by 10 to 15 cm**.
   - This is the common planting pattern used in Ethiopia.

May be planted at an angle of 45º or laid horizontally on the base of a furrow and depth of planting is from 15-45 cm. The germination occurs from 10-12 days after planting (fairly quick).

The crop cycle of sugarcane is from planting to harvesting of the last ratoon crop. Thus, it includes plant crop + 3-4 stages of ratoon crop

Sugarcane is grown on the same land for many years. The estate should be planned so that a constant supply of mature cane is available throughout the milling period of 5-6 months duration. This can be done by adjusting the planting date or by using cultivars with different maturity.

Stand Establishment

Sugarcane is a perennial crop, re-growing from vegetative buds on the crown after the crop has been harvested. Regrowth of the sugarcane field is called ratooning. Distinctions are usually made between the initial or plant cane crop, and subsequent or ratoon crops. In most cultivars the plant cane and first ratoon crops tend to have the highest yields. Stalk population and size tend to decrease with each successive harvest, and the planting will finally be destroyed and replanted. Worldwide, there is variability in length of time between harvests from 1 to 2 or more years. Two-year harvest cycles occur in tropical areas where frost does not damage the terminal apex of the stalk. In subtropical areas cold winter temperatures or, in some cases, flowering compel a 1-year harvest cycle. In some of these areas the effective growing period for sugarcane may be less than 9 months, since sugarcane regrowth following harvest is strongly inhibited at soil temperatures below 18°c.

Since sugarcane is vegetatively propagated, initial stand establishment and therefore yields are dependent on germination of the vegetative buds on the stalks. Healthy buds on nodes of stalk sections as young as the elongation phase is capable of germinating, although bud growth in intact stalks is usually suppressed by apical dominance. Percent germination and time to germination after cutting tend to increase with bud age. Water content of the node may influence germination; the bud does not sprout until the water content increases to 70%. Warm and moist soil is desirable for rapid germination in sugarcane. Reduction of soil water potential below field capacity increasingly reduces germination percentage of buds, although sett roots can sprout even at 3.03 Mpa.

Bud position also influences early growth. Placing the sett so that the bud is on top slightly enhances shoot emergence but delays shoot-root development. Buds oriented to the side or beneath the sett are delayed in emergence but have enhanced shoot-root development.

The number of buds per sett does not appear to significantly affect stand establishment. It might be expected that when whole stalks are planted, the earliest sprouting buds would suppress the growth of the others. Alternatively, shorter setts are more subject to invasion by soil organisms through the cut surfaces of the stalk. In practice, there is little difference in stand establishment between whole stalk and cut setts as long as the buds are not damaged during cutting. Setts 45-60cm long with several buds are easier to handle than several-meter long, possibly curved stalks, but planting whole stalks is still practiced in many areas.

The optimum temperature for germination is 30°c. Temperatures below 16°c inhibit bud germination, and both high (50°c) and low (10°c) temperatures during germination suppress tillering, growth, and yield in the plant and ratoon crops. Therefore, planting is scheduled to avoid high or low soil temperatures during germination.

Like many grasses, sugarcane produces new tillers from the base of each stalk until light, temperature, or other environmental factors become limiting. Unlike many grasses, which appear to have distinct tillering and elongation stages, sugarcane stalks begin to grow and elongate as soon as they are formed, even while new tillers are being formed. Thus, a single plant will have tillers of many different heights and maturities. Cultivars that produced many tillers after the earliest tillers were elongating had reduced sugar concentrations in the early growth.

In field situations, tillering effectively ceases at the time of canopy closure, mostly due to reduced light at the soil surface. Canopy closure is the time of maximum stalk numbers, since the most immature stalks die after this time. It is not known if this is due to insufficient carbohydrate assimilation caused by shading, or if the plant triggers tiller death in some manner. Tillering ability of the plant is not permanently inhibited by canopy closure, however. If stalk lodging creates holes in the crop canopy, new tillers will emerge. Since immature stalks have many green leaves and poor quality juice, new tillers appearing near harvest reduce the juice quality of the entire crop.

It is generally accepted that wide intra-row plant spacing increases tiller numbers per plant over those in narrower spacings, and stalks in wide spacings are thicker and shorter than stalks in narrow spacings. However, narrow plant spacing usually increases the milleable stalk population per area and cane yield especially in areas with a short cropping season.

Plant crop versus ratoon crop

Advantages of plant crop:

- gives higher yield
- low disease problem

Advantages of ratoon crop:

- early maturity:- takes from 12-14 months whereas plant crop 12-24 months.
- no or low cost of establishment. It does not require land preparation for planting or seed treatment
- less requirement of irrigation H_2O and fertilizers

Disadvantages of ratoon crop:

- lower yield as compared to plant crop (2/3 –3/4 of the crop yield of plant crop).

- build up of diseases, insect pests and weeds.
- soil compaction because of lack of land preparation

Post-planting operations

Irrigation, cultivation, fertilizing and earthing-up are the most important cultural measures

1. Irrigation

- 70% of the fresh weight of sugarcane is H_20
- for good harvest 1200 – 1500 mm of total annual rainfall is required.
- H_2O requirement/intensity of irrigation depends on:
    - Crop type: plant crop – requires more H_20 (2750 mm/ha) and ratoon crop requires less H_20 (2250 – 2750 mm/ha)
    - Soil characteristics: sandy – low amount of H_20, but high frequency; loam soil-needs medium amount and medium frequency (20 days) and clay soil: high amount of less frequency
    - Method of irrigation: furrow: commonly used – surface (high loss); drip: applying slowly (drop by drop) below surface (small loss) and sprinkler: above the ground – directly on the plants (medium loss)

2. Cultivation

It is done 3- times: 1st (6-8 weeks after planting); 2nd (4-6 weeks after the 1st earthing-up to encourage tillering); 3rd after the crop produced sufficient tillers to suppress extra tillers.

3. Fertilize application

Sugarcane is a heavy feeder – removes large quantities of nutrients from soil. A 74 tons/ha of cane removed: 107 kg N, 60 kg P_20_5, and 300 kg K_20.

Nitrogen

- Adequate supply of nitrogen is essential for high sugar yields, but excess should be avoided
- It is most important during early growth of the plant crop and immediately after cutting in the ratoon crops.
- Excessive or delayed application results in delayed maturity, lodging of the canes, and reduction in juice quality with less amount of recoverable sucrose.
- N-deficiency causes yellowing of old leaves, followed by drying of the old leaves, retarded growth and canes with small diameter.
- Rate of application varies according to local circumstances such as rainfall and irrigation and applications are usually in the range of from 100-140 kg N/ha.
- N-is usually applied soon after germination with the second application at the maximum growth stage for plant crop or early during the ratoon crops: applied as urea (46% N), DAP (18% N, 48% P_2O_5) or Ammonium sulphate nitrate (21% N)

Phosphorus

- Promotes root growth
- Stimulates early and vigorous tillering
- Promotes early ripening and improve juice quality
- Phosphorus deficiency causes in reduction of the length and diameter of the cane, with short internodes and little tillering.

- P is usually applied at the time of planting and the quantity applied varies greatly depending on factors such as fixation and varies from 50 kg P_2O_5/ha to 250 kg P_2O_5/ha.

In some soils the soluble form of P fertilizer quickly forms insoluble compounds especially with iron and aluminum and becomes unavailable to plants called fixation. Where it occurs it can be overcome by:

- placement of the fertilizer in the furrow (rooting zones of the cane)
- using pellets rather than finely divided forms of fertilizer to have less contact with the soil.

It is applied in the form of triple super phosphate (TSP) (48% P_2O_5) or DAP (48% P_2O_5).

- Phosphates in the juice are removed in the filter-mud, which is often returned to the soil as organic fertilizer.

Potassium

- It is essential for the normal synthesis of carbohydrates and the production of sucrose
- Deficiency leads to a reduction in juice quality with low sucrose content.
- The potash in the juice appears in the molasses, which is not returned to the soil.
- Potassium chloride (muriate of potash) or suplhate of potash are the cheapest form of K fertilizer and therefore the most widely used in the sugarcane industry.
- Applied at rate of 60-375 kg K_2O/ha in the planting furrow

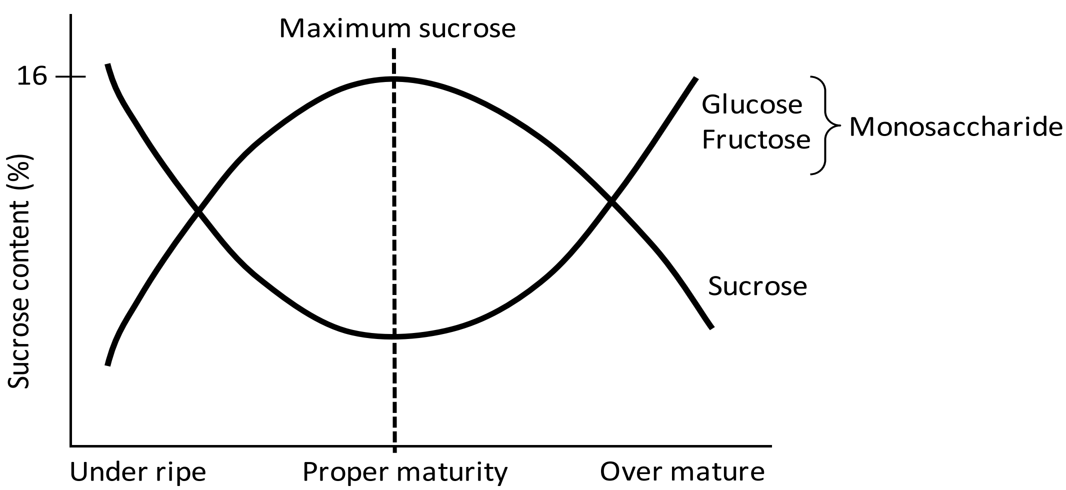
2.6. Maturity, Harvesting and Processing

Depending on variety and growing condition sugarcane is harvested form

- 12-24 months of plant crop
- 12-14 months for ratoon crops

In order to have efficient and fast delivery to the factory, it is important to harvest at optimum physiological maturity. Sugarcane should be harvested when it reaches the stage of maturity with the highest sucrose content.

Cane ripening



- In under ripe cane the juice is watery and the sucrose content is low
- Over mature cane – Inversion of sucrose to glucose and fructose by an enzyme called invertase occurs. Matured cane has 13-16% sucrose

How to determine the physiological maturity of sugarcane?

- Visual observation and field history – estimation based on experience
- Laboratory tests: Taking random samples and analyze for sucrose, fructose, glucose.
    - **Brix**: Percentage of total soluble solids in the juice and determined using hand refractometer or hydrometer. For proper maturity brix content should be≥ 20%.
    - **Pol**: Percentage of sucrose in the juice and for proper maturity it should be about 16%.
    - **Purity**: Percentage of sucrose in total soluble solids: pol/brix x 100. Purity should be about 80%

Sugarcane harvesting involves the following series of operations: Pre-harvest burning; cutting; topping; stacking; loading; and transporting to factory

Pre-harvest burning

Purpose:

- to facilitate the movement of the workers in the field
- to reduce injury on cane cutters by cane leaves
- to avoid trashes
- to clear fields from animals and insects sheltering in the plantation
- to expose obstacles that may cause damage to the machines when mechanical harvester is used

However, burning may initiate inversion. Therefore, burning, cutting and transporting to the factory should be undertaken immediately. Burning is usually done a night before cutting, when there is no strong wind.

Cutting: Sugarcane is cut either manually or mechanically. However, in most countries the cane is cut by hand at or just above ground level, as cutting higher will lead to a loss in yield.

Topping: As the top portion contains little sucrose it is normally removed because sucrose is not uniformly distributed on the canes.

Transport: The cane should be transported to the factory as soon as possible within 24-48 hrs from its harvest. If delayed, inversion of sucrose to monosaccharides (glucose and fructose) by an enzyme invertase will occur.

Processing: The ideal cane for processing is:

- Clean ripe cane
- Free from trash, tops and foreign matter
- Delivered within 48 hrs to factory after cutting

All cane is weighed as it enters the factory in the vehicles, which carry it

1. Milling

Disintegration: cane is cut with rotating knives and shredders and reaches the 1st mill in the form of a coarse fibrous blanket.

Extraction and expression: heavy revolving mill is applied to separate the juice and fiber (bagasse), which is usually conveyed to the boiler furnaces for fuel. H_20 is applied during crushing

2. Clarification (filtration)

The juice contains some suspended matter and soluble sugars. Inert materials and soluble materials are separated through filtrations and the filter mud is the by product.

3. Evaporation and crystallization

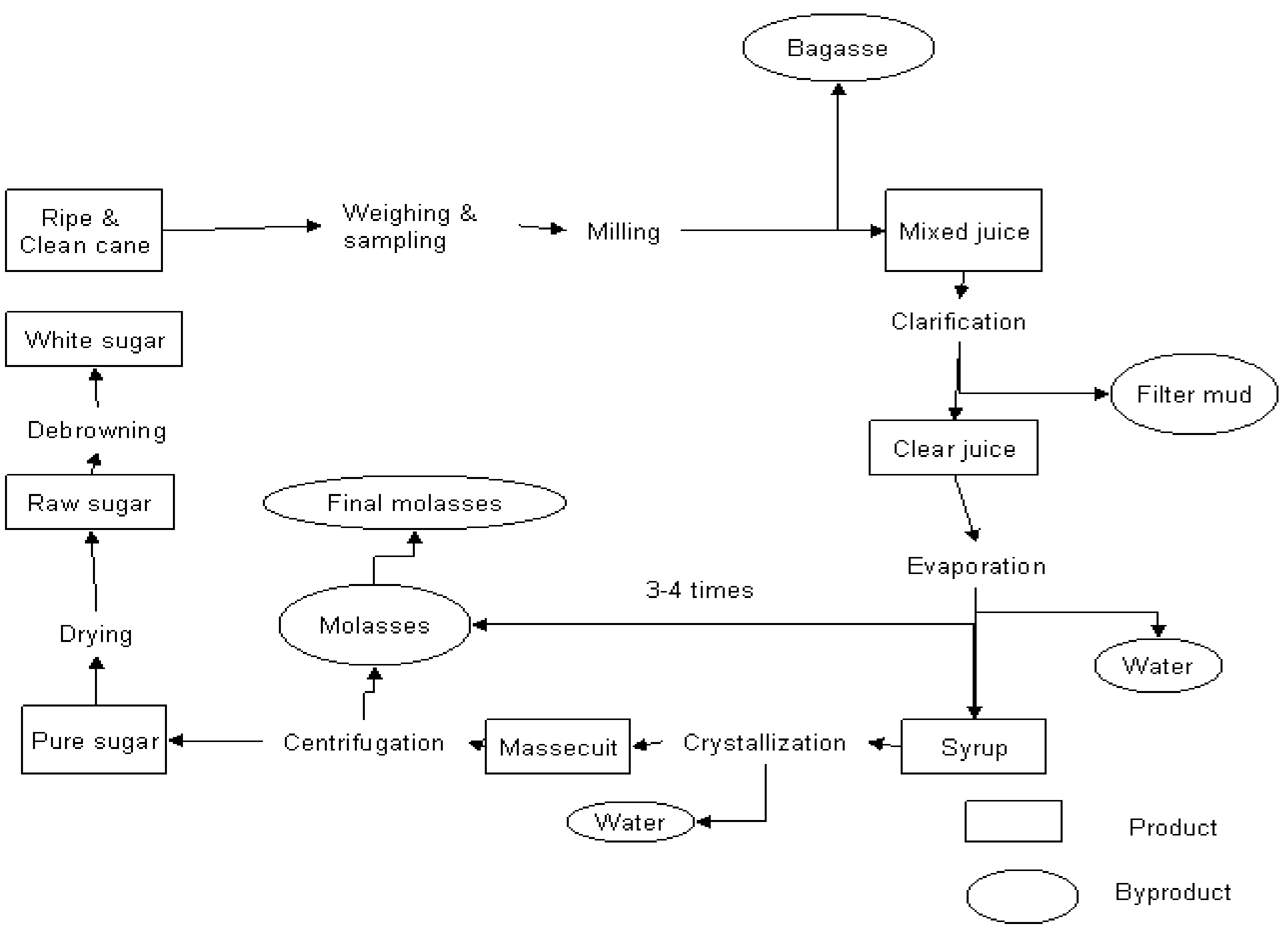
Boiled at low pressure to form thick syrup. The juice is heated, milk of lime is added to clarify it and it is filtered to remove the suspended matter and various materials coagulated or precipitated by the liming, phosphating and heat treatment. The juice is heated further to concentrate and it is evaporated on a series of vessels (containers). The resulting raw syrup is finally concentrated in vacuum pans to super saturation to produce massecuite (heavy viscous liquid containing sucrose crystals and molasses)

4. **Centrifugation**

Separation of different items of particles of varying density by using centrifugal force. The sucrose crystal is separated from the molasses and pure sucrose crystal is obtained. The molasses still contains some crystalizable sucrose and it is mixed with syrup and boiled and this process is repeated 3-4 times to extract as much sucrose as possible.

Decoloration

The resulting sugar, known as raw sugar is brownish in color and contains 96-98.5% sucrose. It is usually exported on this form, final refining taking place on the importing countries and declouring is done with carbon black.



Flow diagram of sugarcane processing

Recovery percent = $\dfrac{\textit{Raw sugar yield}}{\textit{Sucrose yield in cane}}$ x 100

Commercial cane sugar yield = cane yield per ha x recovery percent

The most efficient factories recover up to 87% of the sucrose that was originally present on the cane when it entered the factory.

Yield

The total stalks taken to the sugar mill constitute cane yield. Sucrose yield averages about 10% of the cane yield.

Average yield of milleable cane per ha: 90-120 tons/ha (plant crop); 45-90 tons/ha ratoon crop

The highest yields are obtained in Hawaii (22 tons of sucrose/ha)

Useful Products of Sugarcane

1. Sucrose

Sugarcane is the most important member of plant kingdom with a metabolism leading to the accumulation of sucrose. Thus, it provides the cheapest form of energy. Cane and beet sugar are indistinguishable and thus serve to supplement each other.

2. Molasses

It is dark brown viscous liquid discharged after no more sugar can be separated. It is one of the most important by products from the manufacture of cane sugar. It contains about 35% sucrose and 15% fructose & glucose. Thus, it is used to produce an alcoholic drink called rum by fermentation where 2-3 liters of molasses produces 1 liter of rum. Industrial ethyl alcohol is manufactured from molasses and it is also used for fattening of animals.

3. Bagasse

The fibrous residue left after extraction of the juice from the sugarcane. Usually it is the main source of fuel (steam) in sugar factories and used in manufacture of paper & cardboard

4. Filter mud

Residue, which settles out during clarification of the juice and is used as organic fertilizer

2.7. Major Diseases and Insects

Diseases

1. Bacterial diseases

Gumming disease (*Xanthomonas vasculorum)*

Symptom:

- yellowish translucent stripes that occur towards the tip of the leaves
- vascular bundles of the stem become reddish and exude a yellowish gum on cutting.

Control: resistant varieties

Leaf scald (*X. albilineans)*

Symptom:
- thin pale- yellow stripes occur along the leaf blade and may extend into the leaf sheath
- a large number of small side-shoots
- red vascular bundles of stalks

Control: resistant variety

2. Fungal diseases:
Redrot: *Colletotrichum falcatum*

Symptom:
- dark red lesions on the mid rib
- reddish discoloration in one or more internodes with whitish spots

Control: resistant varieties

Pineapple disease (*Thielaviopsis paradoxa*)
Symptoms
Attacks the setts which become black in the center and small of over ripe pineapples

Control: disinfecting the setts before planting

Pokkah boeng (*Fusarium moniliforme)*

Symptom
Causes malformation of the young leaves with chlorosis at their bases

Smut*: Ustilgo scitaminea*
Symptom
Black whip like organs emerge from the center of the leaf-roll

Control: Highly resistant varieties are available

3. Virus diseases
Mosaic
- Produces a yellowish green mottling of the leaves with stunting in severe cases
- Vector is *Aphis maidis*
- Control: resistant varieties are available

Ratoon Stunting Disease (RSD)
- infected canes show depressed growth, particularly on ratoon crop
- thin canes, orange red vascular bundles at the nodes
- pink discoloration of the growing point

Control
- Hot H_2O treatment of setts at $50^{\circ}c$ for 2 hrs
- Sterilization of knives used for cutting setts.

Chlorotic streak

- yellowish streaks on young leaves, sometimes with necrosis

Control: Use of disease free setts and hot water treatment for 30 minutes at 50^0c

Major Insects

Stem-borer: Larvae of moth belonging to several genera

- the most destructive insect pest of sugarcane
- the eggs are usually deposited on the young leaves and the larvae burrow into the stem, subsequently emerging as adults
- Sucrose is lost, stems are weakened and young tillers may be lost
- The tunnels provide access for disease causing organisms such as red rot fungus.

Control: biological with parasites

2.8. Improvement

Objectives

1) Resistance to disease: Resistance to disease is usually governed by a few major genes, such oligogenic resistance tends to be rather not permanent and new virulent strains of pathogens arise.

2) Yield & juice quality are quantitative and ploygenic

Yield depends on:

- the number of stalks per ha.
- the weight per stalk
- sucrose content.

Factory requires cane of uniform quality, good milling character & medium fiber content; easily clarified juice, which is, high in sucrose and maximum sugar recovery

3) Ratooning: The capacity for good ratooning is of major importance, as the more ratoons, which can be profitably harvested.

4) Habit of growth

a. Tillering: heavy tillering with vigorous growth is desired; it is assessed by the number of canes which develop from one eye
b. Good ground cover: cultivars with stools, which close in quickly help to check weed growth.
c. Cane stand: erect canes are essential for mechanical harvesting
d. Free trashing habit: this is especially desirable when burning is not done before harvesting
e. Cane thickness: canes of reasonable thickness are required for hand-reaping

5. Age of maturity: cultivars, which mature at different periods, are essential to supply the cane continuously during the milling season.
6. Response to soil treatment and manuring & irrigation,
7. Resistance to insect attack especially borers
8. Adaptation to a particular environment

- In areas with high wind – strong canes with vigorous root system are required
- Tolerance to drought or frost (out side tropics).
- etc.

Methods of breeding

1) Selection of setts: based on weight, sucrose content and specific gravity of the cutting. It is used to purify the existing clones, but not genetic improvement.

2) Hybridization and raising of seedling canes

- the discovery of viable seed quickly led to organized breeding of sugarcane.
- methods of pollination and germination are well established
- male sterile clones are usually used as female parents, making emasculation unnecessary.

2.9. Sugarcane Production and Planting Practices in Ethiopia

Sugarcane Production in Ethiopia

Sugarcane was introduced to Ethiopia in 19^{th} century. In 1951, agreement was signed between Ethiopian government and Dutch company to establish large-scale sugarcane plantation and processing factory. Then the following factories were established: Wonji in 1954; Shoa in 1962; Metahara in 1969 and Fincha in 1998.

Annual Production

In Ethiopia, annually about 250, 000 tons of sugar is produced from 24,000 hectares. All the sugar estates grow cane required for their sugar factories, although Wonji-Shoa crushes some cane from out grower farmers. Sugar and its by-product are used for domestic and export market. In recent years the country has exported between 40 to 60 thousand tones of sugar annually. Ethiopia is one of the first Least-Developed Countries (LDC) to export sugar to the European Union (EU) under the Everything But Arms (EBA) initiative. Accordingly, the country shipped about 14 thousand tones of raw sugar to EU in 2002 and nearly 15 thousand tones during 2003.

The annual consumption of sugar in Ethiopia is estimated at 5.4 kg/head/year. This is considered low even by African standards, which is estimated to be 20 kilograms per person per year. Ethiopia still needs to produce an additional 80,000 metric tons per year to satisfy the current total demand of sugar consumption in the country.

Consumption: 5.4 kg/head/year (Ethiopia); 60 kg/head/year (Ireland); 54 kg/head/year (Netherlands) and 52 kg/head/year (Australia)

General

Planting is generally considered in the sugar estates as one of the major field practices that deserve special attention, as it is the corner stone for good initial establishment of cane fields. For this reason, brief discussion is given hereunder for key field operations, namely: land preparation, pre-planting, planting and post-planting activities.

Pre-planting Operations

Soil Preparation Method

The method of soil preparation adopted for cane growing involves the following sequence of field operation: uprooting (for cane after cane fields), brush cutting (for cane after fallow fields), sub soiling, ploughing, planning and furrowing. In general, the rows have a spacing of 1.45(furrow width) with a bottom width ranging from 40-45 cm.

Pre-planting Irrigation

This field practice (light irrigation) is performed in both furrow and sprinkler irrigation systems and has the following advantages:

- help to check any irregularity in furrow depth and its suitability for irrigation water conveyance.
- create favorable condition for smut spores in the soil to germinate and die in the absence of host plant.
- ensure availability of adequate soil moisture for cane bud germination.

Planting Material Preparation Procedures

Profitable crop production partly depends on the quality of the seed planted. This principle applies to sugarcane as much as to any other crop. The potential cane yield that should be obtained will not be achieved if seed cane of poor quality is planted.

Seed cane quality is determined by freedom from diseases and pests, varietal purity and germination capacity. The need to control diseases is the main reason for adopting a planned system of seed cane production. Therefore, the selection of quality planting material is of high importance, and requires the most careful attention.

The planting material should preferably be well-grown immature plant of about 9 to 12 months old. Generally, a seed cane free from diseases, having healthy and vigorous buds is the base for a good commercial crop since seed cane itself can be the carrier of pathogens of many serious diseases such as smut, ratoon stunting disease (RSD), red rot, chlorotic streak and others.

Seed setts/canes are usually prepared by laborers working on the interval at the side of a field to be planted. Alternatively, this work may be done at some central point, from which the setts are distributed to the fields. The cane is chopped on a wooden block, using a cane knife. During chopping, cane should be taken that the top soft parts of the stalk and the old/hardened bottom parts should be discarded since their germination is negligible. Fertile and well-drained soils are selected for initial seed cane.

Unlike many other countries, two series of nurseries (tier-seed program) are known in Ethiopia.

i) Initial Seed Cane (I.S.C)

Initial seed cane is the first source of planting material, which requires selection of seed material, planting and sanitation. Usually it is raised from carefully selected seed source that is taken from another I.S.C. field having no disease, with its genetic identity and purity. Its establishment is much tedious and time consuming which at the same time needs careful seed cane manipulation and preparation. The seed material for planting initial seed cane field under goes hot water treatment (HWT) before planting.

ii) Seed Cane (S.C)- Certified Seed

The seed material is taken from initial seed cane without HWT but other precautionary measures are considered to raise this crop. The nursery contains the varieties best suited to the commercial cane fields.

Requirements for Quality Planting Material

- a seed material obtained from 9-12 months crop age is used
- seed material obtained from a well-fertilized and irrigated crop
- it should have more than 95% viable healthy buds.
- moisture content of the setts should be more than 70%.

- it should be free from incidence of diseases and insect pests.
- it should be from hot water treated cane stalks.

Seed Material Preparation Procedures

i) Initial Seed Cane (I.S.C)

- the seed material should be around 9-12 months crop age.
- the seed material is cut into setts with at least 2 healthy buds having a length of 20-30 cm without sheaths being removed in order to protect buds from mechanical as well as heat injury.
- 3% lysol solution is used to disinfect chopping cane knives.
- the chopped seed material should undergo hot water treatment (HWT).
- mercurial dressing/immersing in Agallol solution after HWT at a rate of 100-200g in 40-80 1t of water (consumption required is 0.70 kg/ha of mercurial dressing) or 180 g/ha of Benlate (Benomyl) powder is used in 200 1t of water.
- an average seed material consumption per ha ranges from 16-20 quintals (1.6-2 tons).

ii) Seed Cane (S.C.)

- the seed material should be around 9-12 months crop age.
- chopping is done after leaf sheath removal.
- cutting seed material starts from the top to down ward maintaining two buds per sett.
- length of cane setts chopped is 20-30cm.
- distance of chopped setts between node and end should be 5 cm.
- setts should be Agallol or Ben late (Benomyl) treated.
- 3% lysol solution to disinfect cane knives is required.
- an average seed cane material consumption per ha ranges from 0.8 to l ton (8 to 10 quintals).

Seed cane Treatment Practices

HWT is used to get a seed material free from diseases such as smut, ratoon stunting disease (RSD), leaf scald, chlorotic streak, etc. which can cause serious yield losses. In Ethiopia, HWT for seed cane/setts have temperature ranging from 50°C to 51°C and duration from minutes to hours. But in most cases, seed setts are treated at 50°C for 2 hours.

Planting

In Ethiopia, cane planting is executed manually (by hand). Pieces are cut from unripe whole cane from nursery at the optimum stage of growth but even older canes can be used for planting without loss in both germination and early vigor or growth. Planting is done by laying one sett of two buds about 20-30 cm lengths in the furrow. Young plant canes 9-12 months of age is normally selected for seed material in Ethiopian conditions.

Time of planting

In Ethiopia, cane is mainly planted in five months viz. mid-December to May. The early planting has favored the growth of cane and ultimately resulted high yields. Late planted crop is likely to suffer more due to water logging at younger stage.

Furrow planting

In general, furrow method of planting is used, the depth of planting is about 30cm and depth of soil covering varies from 2-8 cm. All cane varieties are planted in an overlap of 5 cm except long internodes (20-25 cm) varieties, *e.g.* M165/38, CO-421 and Mex. 54/245 that need to be planted at 10 cm overlap, keeping the bud sideward.

Density of planting

Density of planting is sometimes used to denote the number of setts or seed pieces planted per ha. This is determined by the distance between row centers and spacing of the setts in the row. Seed rate of sugarcane setts vary due to number of factors *viz.* variety, row distance, planting method, sett placement and number of buds per sett. In Ethiopia, normally around 40,000 to 45,000 two-budded setts are used per hectare depending on variety.

Propagation ratio

A recommended seed cane propagation ratio is used, as a point of reference at the three Sugar Estates is 1:9, *i.e.* to plant nine hectares, one hectare of seed cane is required. However, cane propagation ratio varies per variety and crop season.

Filling gaps/open spaces

Filling gaps by setts is done sometimes due to uncontrollable factors such as climatic condition coupled with particular inherent problem of fields that bring about unsuccessful germination. Open spaces exceeding 30 cm in length to be commonly observed two months after planting is usually filled with healthy setts or sprouts.

Some facts and practices about the Ethiopian Sugar Estates (Aregawi, 2003)

Description	**Sugar Estate**		
	Wonji-Shoa	**Metahara**	**Fi**
Geographical Location	Upper Awash river basin, 110km SE of Addis Ababa	Upper Awash river basin, 190km SE of Addis Ababa	In the Fincha r 350km NW of A
Altitude (m.a.s.l)	1540	950	1350-1650
Latitude	8˚31’N	8˚51’N	9˚3’-10˚N
Longitude	39˚12’E	39˚52’E	37˚15’-37˚30’E
Cultivated area (ha)	7,000	10,000	6,900
Climatic Features			
Annual rainfall (mm)	800(mainly July, August & September)	550(mainly July, August & September	1250(mainly Jun
Temperature (˚C): Mean min.	15.3	17.0	15.0
: Mean max.	26.9	32.6	31.0
Relative humidity (%) Mean min.	34.7	28.0	38.0
Mean max.	81.9	85.0	84.0
Pan evaporation (mm/day)	6.6	7.0	6.9
Sun shine hours (hrs/day)	8.16	8.28	7.8
Production Cane/ha (tons)	155	174	180
Factory yield (%)	11.8-12.0	10.8-11.0	12
Crushing capacity (tons of cane/day)	Wonji =1400; Shoa 1600; Total = 3,000	5,000	4,000
Sugar Production Started	Wonji in 1954, Shoa in 1962	1969	1998
Soil Physical and Chemical Characteristics			

PH	6.8-9.0		7.7-9.8	4.3-7.6	
EC (ms/cm)	0.05-0.4		1.38-9.12	0.01-1.22	
$CaC0_3$ (%)	0.5-9.3		3.38-5.76	0.60-0.70	
Texture	Sandy clay loam to clay		Silty clay to silty loam	Sandy clay loam	
CEC (meq/100 g soil)	29-46		30-62	11.2-75.20	
General gradient	Flat slope; the overall gradient is from North East to South West		Generally plain	Generally undula 2-3% down t average of 4-6 escarpment dowr	
Conventional seed-bed preparation (Tillage operation)	**(C.A.C.)*** - Uprooting - Sub-soiling - Ploughing - Harrowing - Planning (2x) - Furrowing	**(C.A.F.)** - Brushing cutting -Harrowing -Sub-soiling (occasionally) -Ploughing -Harrowing -Planning -Furrowing	- Uprooting - Sub-soiling - Ploughing - Harrowing - Planning (2x) - Furrowing	**(C.A.C)** -Uprooting -Sub-soiling -Ploughing -Harrowing -Planning (2x) -Furrowing	**Vi** -B -R -Pl -H -Fu
Sugarcane cultivars at commercial level [% share of (2002/03) Production Year)					
- B52298	30.7		26.7	20.1	
- Nco-334	32.1		24.1	32.7	
- B41227	2.7		10.6	13.5	
- Co-376	-		7.9	-	
- Mex 54/245	0.06		4.7	-	
- M 165/38	4.7		-	-	
- Co-449	-		7.9	-	
- N-14	7.7		-	-	
- D141/46	1.9		-	25.1	
- N57-150	-		0.4	-	
- Co-740	-		1.6	-	
- Co-421	6.2		3.1	-	
- Co-678	-		1.3	-	
- Co-680	-		2.4	-	
- NCo-310	1.2		-	-	
Time of Planting	Late December-March		December-May	December-Marcl	
Harvesting Months	November-June		November-June	November-May	
Age at harvesting (months)					
- plant cane	22-24		18-22	18-22	
- ratoon	14-20		13-18	14-17	

System of Irrigation	Blocked end furrow irrigation	Furrow irrigation using siphon tubes	Semi-solid dr irrigation
Inorganic fertilizer rate	Urea (46%N); 200-700 kg per ha	Ammonium Sulphate Nitrate 300-400kg/ha	-Urea (46%N); 1
	$FeSO_4$ (3-7 kg/ha)	$FeSO_4$ (3-7 kg/ha)	DAP (18% 250kg/ha
Weed control	Manual and Chemical	Manual and Chemical	Manual and Che
Harvesting Systems	Semi-mechanized (Manual cutting and mechanical loading and transport)	Semi-mechanized (Manual cutting and mechanical loading and transport)	Semi-mechanize and mechanic transport)
Major Weed Species	*Cyperus rotundus, C. esculentus*	*Cyprus rotundus,*	*Cyprus spp., Dig*
	Commelina sp., Cynodon dactylon	*Acalypha indica,*	*Commelina beng*
	Amaranthus spp., Datura stramonium,	*Launea cornuta,*	*Bidens pilosa, S Rottobellia exalt*
	Digitaria abyssinica	*Sorghum spp.*	*Lactuca cor dactylon, Eleusir*
Major Diseases and Insect Pests			
Insect Pests	(*Heteronychus licas*)	Black beetle	Termites (microterms sp
	Shoot borer (*Sessamia* spp.)	Shoot borer	Shoot borer
	Stalk borer (*Sessamia nonegroiodes*)	Stalk borer	Stalk borer
	Top borer (*Sessamia* spp.)	Top borer	Top borer
	Grasshoppers (many spp.)	Grasshoppers	Army worm (*Spodoptera*
	Mealy bugs (pink sugarcane mealy bug)	Pink mealy bug	Trash worm (many spp.)
	White flies	White flies	Grasshoppers
	Leaf rollers	Leaf rollers	Pink mealy bug
	Aphids (*Aphis sacchari*)	Aphids	White flies Leaf rollers
Diseases	smut (*Ustilago scitaminea*)	Smut (*Ustilago scitaminea*)	Similar to Wonji - Sh prevalence of foliar disea
	Root Stunting Disease [RSD (*Clavibacter xyli*)] sub spp. *xyli*	RSD (*Clavibacter xyli*) sub spp. *xyli*	

	- Other foliar diseases	Other foliar diseases	

*C.A.C. = Cane after cane; C.A.F. = Cane after fallow

CHAPTER 3. FIBER PRODUCING CROPS

Crops grown mainly for their fiber (they may have other uses also) and fibers produced from these crops (fibers from plant sources) are collectively termed as **vegetable fibers.**

Fiber is a class of materials that are continuous filaments or are in discrete elongated pieces, similar to lengths of thread. Fibers are of great importance in the biology of both plants and animals, for holding tissues together. Human uses for fibers are diverse. They can be spun into filaments, thread, string or rope. They can be used as a component of composite materials. They can also be matted into sheets to make products such as paper. Fibers are often used in the manufacture of other materials.

There are 3 sources of fibers:

1. **Vegetable fibers:** produced from plant sources: account 65% of world fiber product. Vegetable fibers are generally based on arrangements of cellulose, often with lignin: examples include cotton, hemp, jute, flax, ramie, and sisal: 96% of the World's plant fiber comes from tropical and sub-tropical countries. Cotton (78% of plant fibers); sisal (2%), jute and kenaf (14%) Temperate: flax (3%), hemp (1%)
2. **Man-made fibers**: account for 30 %. Man-made fibers may come from natural raw materials or from synthetic chemicals. Many types of fiber are manufactured from natural cellulose, including rayon, modal, and the more recently developed Lyocell. Some of the common synthetic fibers are:
   a. **Rayon:** silk like fiber manufactured by pressing and solidifying cellulose acetate.
   b. **Nylon:** Highly elastic and very strong fiber derived from coal, water & air.
   c. **Acrylic:** derived from hydrogen cyanide.
   d. **Polyester**: derived from polymerization of ester
3. **Animal fibers:** (wool & silk) account for 5%. Animal fibers consist largely of particular proteins. Instances are spider silk, sinew, catgut, wool and hair such as cashmere, mohair and angora.

Vegetable fibers are classified based on:

1. **Botany:** Based on fiber sources of plant part
   a. **Seed fibers:** fibers associated with the fruits and seeds of plants**.** These are single celled out growths from the testa (seed coat) or from the ovary wall, which protect developing seeds, *e.g.* cotton, kapok (Thailand, Cambodia)
   b. Stem/Phloem/Bast fibers: these are schlerenchyma fibers associated with phloem of the stems of plants. These fibers are a constituent of the bark, which is stripped from the stems. The fibers occur in bundles of up to 700 individual cells, *e.g.* flax, jute, kenaf, hemp, enset (Psuedostem).
   c. **Leaf fibers:** these are bundles of schlerenehyma fibers, which occur in the leaves, *e.g.* sisal, abaca.
2. **Classification based on utility:**
   a. **Textile fibers:** Soft fibers used mainly to make cloths, *e.g.* cotton

b. **Cordage fibers:** coarse and hard fibers used to make ropes, sacks, netts, etc., *e.g.* flax, jute, kenaf, sisal, enset.

3.1. Cotton

3.1.1. Area, Production, Trade and Uses

The seven largest producers of cotton in the world are: China, India, the United States, Pakistan, Brazil, Uzbekistan and Turkey. The five leading exporters are: the United States, Uzbekistan, India, Brazil, and Burkina Faso. The biggest non-producing importers are Bangladesh, Indonesia, Thailand, Russia and Taiwan. In the United States, the state of Texas leads in total production while the state of California has the highest yield per acre in the world.

In 1989, the total world production of seed cotton was 49 million tones grown on 32 million hectares. It is grown in the tropics, sub – tropics, and even extends to temperate regions. From Ukraine in the North to South Africa in south. Grown both under rain fed and irrigation.

Africa

In 1989, the area cultivated was 3.9 million ha with production of 3.9 million tones of seed cotton with an average yield of about 1 ton/ha of seed cotton.

The ten leading cotton produces in Africa are: Egypt, Sudan, Uganda, Tanzania, Nigeria, Namibia, South Africa, Malawi, Kenya and Ethiopia.

The international cotton trade

The United States, with sales of $4.9 billion, and Africa, with sales of $2.1 billion, are the largest exporters of raw cotton. Total international trade is $12 billion. Africa's share of the cotton trade has doubled since 1980. Neither area has a significant domestic textile industry, textile manufacturing having moved to developing nations in Eastern and South Asia such as India and China. In Africa cotton is grown by numerous small holders.

Uses

Cotton is used to make a number of textile products. These include terrycloth, used to make highly absorbent bath towels and robes; denim, used to make blue jeans; chambray, popularly used in the manufacture of blue work shirts (from which we get the term "blue-collar"); and corduroy, seersucker, and cotton twill. Socks, underwear, and most T-shirts are made from cotton. Bed sheets are often made from cotton. Cotton is also used to make yarn used in crochet and knitting. Fabric can also be made from recycled or recovered cotton that would otherwise be thrown away during the spinning, weaving or cutting process. While many fabrics are made completely of cotton, some materials blend cotton with other fibers, including rayon and synthetic fibers such as polyester.

In addition to the textile industry, cotton is used in fishnets, coffee filters, tents, gunpowder, cotton paper and in bookbinding. The first Chinese paper was made of cotton fiber.

The cottonseed, which remains after the cotton is ginned, is used to produce cottonseed oil, which after refining can be consumed by humans like any other vegetable oil. The cottonseed meal that is left is generally fed to livestock. In the past, cotton seeds were used as an abortifacient, that is, a folk remedy to provoke abortion.

Cotton linters are fine, silky fibers, which adhere to the seeds of the cotton plant after ginning. These curly fibers are typically less than 1/8in, 3mm long. The term may also apply to the longer textile fiber staple lint as well as the shorter fuzzy fibers from some upland species. Linters are traditionally used in the manufacture of paper and as a raw material in the manufacture of cellulose.

Cotton Industry in Ethiopia

- Some 50 years ago, cotton in Ethiopia was no more than a home-yard grown plant, but now its production reached a status of export.
- The area was estimated to be about 75,900 ha of which 56,000 ha is peasant sector, 8500 ha of private commercial farms and 11,400 ha state farm (30000 ha).
- Production is estimated at 60,600 tons of seed cotton with about 20,600 tons of lint.

Cotton production and export from Ethiopia

Year (E.C)	Cotton lint Production (‘000 t)	Lint Export (, 000t)
1979	18	1.678
1980	20	5.781
1981	20	5.007

The most important cotton growing areas in Ethiopia are:

1. The Awash Valley
   - Upper Awash: Abadir, Awara Melka, Nuraera, Tibla.
   - Middle Awash: Melka Sedi, Melkawerrer (National Cotton Research Center), Amibara
   - Lower Awash: Asaytta, Gewane, Tendaho
2. The upper Rift Valley: Arbaminch

The most suitable areas for cotton production are:

- Awash Valley
- Upper Rift Valley
- Baro-Akobo basin (Western Ethiopia)
- Abbay basin
- Lower Wabi- Shebele basin (eastern)

3.1.2. Useful Products of Seed Cotton

1. Lint (Seed foss): Is the white fluffy, spinnable mass of long fibers attached to the seed coat.
   - each lint (fiber) is formed through a rapid outward extension of a single specialized cell of the epidermal wall of the ovule or seed.
   - each fiber is a unicellular cellulose
   - 36-38% of the seed cotton is lint
   - is the most important textile material throughout the world
2. Linter (fuzz)
   - are shorter hairs or fiber on the seed coat with greater basal diameter and much thicker cellulose deposition (not removed from the seed during ginning).
   - the thick cellulose deposition on the secondary wall prevents the formation of convulations (spinning) (twisting and coiling) as compared to the lint.
   - used to fill pillows, mattresses, etc
   - threads are used to make bags, sacks, and nett.
   - 6% of the seed cotton is linter
3. Cotton seed oil

- It is a valuable product obtained by crushing and heating the seeds after removal of fibers.
- 10% of the seed cotton and 16% of the seed is oil (fuzzy)
- the seed contains a poisonous phenolic compound called "Gossypol" but it becomes harmless upon crushing or heating.

Uses of cotton oil:
- cooking and salad
- raw material in manufacture of soap, margarine, detergents, paints and varnishes, etc.

4. Cotton Seed Oil Cake
   - the residue left after extraction of oil from the seed.
   - accounts for 29% of the seed cotton and 46% of the seed (fuzzy)
   - used as a protein concentrate for livestock (contains 21% protein)
5. Hull:
   - the seed coat of the seed cotton removed before extraction of oil from seed
   - used for animal feed, mulch or organic manuring.
   - accounts for 15% of the seed cotton and 23% of the seed

Composition of the seed cotton (summary)

Product	% of the seed Cotton	% of the fuzzy seed
Lint (seed foss)	36-38	-
Linter (fuzz)	6	9
Oil	10	16
Oil cake	29	46
Hull	15	23
Other components	2-4	6

3.1.3. Origin, Taxonomy and Morphology

Center of origin

The various spp of cotton have originated in different centers: probably in the desert areas of the world (America, Africa, Australia, Asia)

Domestication
- all wild cotton are perennials with high heat requirement and no cold resistance (frost – sensitive)
- have seeds covered with short fiber that do not easily separate
- first step taken by primitive man towards domestication was the selection of cotton having long fiber, which could have been obtained by natural mutation.
- 1st domesticated cotton appeared in Africa where they reached S. America to have cross-bred spontaneously with the wild species in the new world.

Taxonomy

Family: Bombaceae (Malvaceae): Genus. *Gossypium*. So far 31 species of cotton have been recognized, out of which four species are cultivated. The cultivated species are grouped into 2 based on origins, ploidy level and plant form.

1. Old World Cotton Species (Africa, Asia, Australia)
- Species: *Gossypium arboreum* L. & *G. herbaceum*

- Origin: Old World
- Ploidy level: Diploids (2n = 26)
- Plant form: Small plant size, leaves, flowers and fruits with less vigorous stem.
- Lint quality: Produce short fibers, and the length ranges from 10-20 mm in *G. arboreum* and from 6-20 mm in *G. herbaceum*.

These are not important for commercial production except in home yard gardens. The old World cotton species are occasionally grown in Africa, and to a considerable extent on S & E Asia. For instance, in India *G. arboreum* takes 28% and *G. herbaceum* 19% of the area under cotton production.

2. New World Cotton Species:

- Species: *Gossypium barbadense* (Sea Island Cotton) & *G. hirsutum* (Upland cotton)
- Origin: *G. hirsutum* (southern Mexico), *G. barbadense* (northern Peru)
- Ploidy level: Allotetraploids (2n = 4x = 52). One set of chromosomes is homologous with old world cotton (A genome) probably with *G. herbaceum* and one set of chromosomes is homologous with a new world species (B-genome).
- Plant form: Large plant size, leaves, flowers and fruits with large vigorous stem.
- Lint quality: Produce long fibers
- *G. barbadense*: 40-50 mm length (1/3 of the worlds total cotton production and used for very fine textiles). In Africa it is cultivated in north Africa under irrigation.
- *G. hirsutum*: 13-35 mm (2/3 of the world total cotton production because it is productive). It is used for less fine fibers. In Africa, it is grown in sub-Saharan Africa (including Ethiopia)

Morphology of *G. hirsutum*

Root system:

- has a well – developed tap-root with 4 – rows of lateral and feeder roots
- the taproot becomes thinner and thinner down the soil depth.
- the depth of the root system ranges from 1.2 – 4m depending on species, variety and growing condition.

Stem:

- cotton plant can grow even to a height of 12-20 cm and produce bolls or to a height of 2-3m depending on species, variety & growing condition: However, the best crop especially for mechanical harvesting has a height of 1.2 – 1.5m.
- it has a single main stem which shows two types of branching (dimorphism)

a) Monopodium (vegetative branches)

- arise from the lower buds especially from the first four buds of the main stem.
- more or less have an up right growth habit and form acute angles
- they do not bear flowers or fruits at their nodes (the point on stem or branch at which a leaf or flower is borne) but the secondary branches from the monopodium can give flowers and fruits.

b) Sympodium (fruiting branches)

- arise from the main stem usually between the 4th and 8th buds
- they grow more or less horizontally and produce flowers and fruits at their nodes.

Leaf

- has got a long petiole (stalk of leaf) with stipules (a pair of small leaf like structure)
- palmately lobbed with 3-5 lobes
- most of the present day east African varieties have got hairs on the lower surface of the leaves. Thus, provides mechanical protection against cotton jassids and thus used on breeding programs.

Squares and flowers

- square is an unopened floral bud. The 1st square on the cotton plant appears, from 35-40 days after seedling emergence and develops or opens into a flower after 15-20 days
- flowers, which are 6-12 on each fruiting branches, are borne single or separately on short stalks.

Pollination

- bi-sexual flower (perfect) and it is often cross-pollinated crop. It is 80-90% self-pollinated, but depending on the insect population out crossing can go from 5-25% since the pollen can remain viable for 12 hrs, it can lead to a cross-pollination.
- the corolla (petals) fall off 2-3 days after pollination and expose tiny fruits/bolls.
- flowering in cotton occurs:
    - from the base to the top (acropetal)
    - from the main axis to the lateral axis (epipheral)

Thus, the first flowers are formed near the main stem on the lowest fruiting branches.

Fruits/bolls: Spherical or ovoid capsules splitting at maturity exposing the white fluffy seed cotton. Under optimum conditions the cotton plant would set all the bolls it can bear, but up to 50% are shed in some varieties before maturity through bud shedding and boll shedding. Factors enhancing (promoting) boll shedding are: drought, H_2O-logging, low light intensity, nutrient deficiency and pest-damage

A boll takes from 60-90 days from flowering to split and give fluffy fiber.

The seed cotton consists of:

- long fibers (lint) and short fuzzy fiber (linter) except the Sea Island cotton (*G. barbadense*) which has no linter
- dark brown or black seed coat (hull)
- an embryo with 2-large cotyledons which make up almost entire kernel used for oil extraction

Fibers are each unicellular cellulose formed through rapid out ward extension of specialized cells of the epidermis of the ovules and cellulose deposition on the secondary wall.

Fiber development:

(1) Elongation (extension): starts on the day of anthesis (pollination) and proceeds for 20-25 days. During elongation a very thin primary wall is developed (lengthening)

(2) Thickening (cellulose deposition)

- begins when length of growth is about to cease (20 days after anthesis) and proceeds until 40-45 days after anthesis (flowering)
- the thickening of fiber through cellulose deposition is known as secondary wall development and it gives the fiber its body.

Life Cycle of Cotton

Naturally cotton plant is a weak perennial shrub because if provided with ample amount of moisture, it continues to grow indefinitely with regular cycles of flowering and fruiting (indeterminate growth), *e.g.* home yard garden cotton.

In practice, however, under large-scale production it is grown as an annual crop in order:

- to allow more crops to grow
- perennial cotton husbandry may not be possible in certain rainfall regions.
- build-up of diseases and insect pests may occur on perennial cotton.

Summary of life cycle of cotton crop (*G. hirsutum*, Upland cotton)

Growth stage	Days required From planting (Sowing)	Cumulative days	Typical date in Ethiopia (Melkawerer)
1. Sowing to emergence	5-10	5-10	May 5- May 10
2. Emergence to 1st flower bud (square)	35-40	40-50	June 10 – July 20
3. 1st flower bud to – 1st flower	15-20	55-70	June 25 – July 10
4. 1st flower to 1st boll split	60-90	115-160	August 25 – Oct.10
5. 1st boll split to end of harvest	40-60	155-220	Oct. 10 – Dec.10

Thus, cotton requires from 155-220 frost – free days for successful production. That is why cotton production is limited to warmer areas of Ethiopia. The critical period for moisture is at the time of flowering & fruiting.

3.1.4. Ecological requirement

Adaptation: Commercial cotton production in the world extends from 47°N (Ukraine) to 30°S (S. Africa) in the old World and from 37°N to 32°S in the New World.

Altitude: Cotton is a crop of plain and its production extends from sea level to 1500 m. a. s. l. (some species can grow up to 1800 m).
In Ethiopia:

a). Irrigated cotton regions are: 300-1200 m – Awash valley
b). Rainfed cotton belt: 1300 contour (800-1600 m)

If the altitude is > 1300m, frost is the major problem, but somehow it can be overcome by: adjusting the sowing date (early sowing), using early maturing and frost tolerant/resistant varieties.

Rainfall: Cotton tolerates drought as compared to other annual crops. However, for rainfed crops a minimum of 450-500 mm of annual rainfall with good distribution is required. If the amount is < 450 or erratic distribution, irrigation is required.

Temperature: Ranges from 16-40°C, optimum 26-32°C and soil temperature > 20°C for germination. Low temperature increases the number of vegetative branches and extends the cropping period (maturity period). High temperature increases the number of fruiting branches and reduces the cropping period.

Sunlight: It is a sun-loving plant and does not tolerate shading especially at the seedling stage. Shading retards flowering, fruiting, and increases boll shedding (dropping).

Photoperiodism: All wild cotton species are short-day plants and do not flower if the day length exceeds 12 hrs, but cultivated cotton are photoperiod insensitive (day neutral). Thus, have wider adaptation.

Soils: has wide adaptation from the lightest sand to heaviest soils. However, the best cotton soils are sandy loams, loams, clay loams and alluvial soils.

In Ethiopia, cotton is grown mainly in alluvial soils (Awash valley), black soil (rift valley) and black, brown & red soils of volcanic origin. It is not very sensitive to either acidic or alkaline soils. pH range is 5.5 – 7, with the best performance in neutral soils.

Temperature: ranges from 16-40°C.
- Optimum: 26 –32°C
- Soil temperature: >20°C for germination.

Low temperature increases the number of vegetative branches and extends the cropping period (maturity period). High temperature increases the number of fruiting branches and reduces the cropping period.

3.1.5. Agronomic Practices

In some areas of the world, cotton is grown as continuously (the same crop year after year) but in such areas there is severe problem of insects, diseases and weeds. Therefore, continuous cropping of cotton is not advisable and crop rotation should be used.

Crop rotation: Is the growing of different crops on the same land on a systematic or planned succession in different seasons.

Purposes of crop rotation:
- improves soil physical conditions (structure)
- maintenance of soil fertility especially if legumes are included
- controlling of diseases, insect pests and weeds as some diseases, insects and weeds are crop specific.
- equitable and economical distributions of land, labor and other available farm resources.

Suitable cotton crop rotation scheme:
- should not involve those crops with depressing effects on cotton, *e.g.* sorghum before cotton.
- inclusion of legumes is desirable, *e.g.* groundnut, beans, etc.
- cotton should come every 3rd year: cotton-cereals (wheat, maize, sorghum) → legumes → cotton
- will benefit more with inclusion of fallow or green manuring (legumes)

Cotton is usually monocropped (grown in pure stands) but on some cotton growing areas of Ethiopia intercropping with groundnut, maize, etc, is practiced.

Land Preparation: Objectives of land preparation (primary tillage).
- to incorporate crop residue
- to break compact soil layers
- to create a good tilth or the seed bed
- to control weeds

Operations of seed bed preparation
1. Crop residue management

Involves chopping of crop residues and incorporating them in the soil by ploughing to a depth of 25-30cm. For chopping rotary slashers are used. Note that this operation is applicable only with resistant varieties of cotton to bacterial blight (angular leaf spot) or when the plants are free from this disease. If the field is infested with bacterial blight, uprooting the stools and burning them together with the trashes is advisable.

2. Sub-soiling: Involves breaking of a compact subsoil layer without inverting it

Sub-soiling should better be done during the dry seasons and if there is no compact layer up to 45cm, sub-soiling is not needed.

3. Ploughing involves stirring (mixing) the top soil to a depth of 20-30cm using either disk or mould board ploughs.

Purposes:
- cutting, loosening, granulating and inverting the top soil
- turning under organic matter and germinating weeds.

4. Disking/Harrowing
- necessary to break-up large clodes and to effect some degree of leveling of the field.

Precautions during tillage:
- disking should not be over done because fairly coarse seedbed is necessary for cotton.
- over tillage on soils containing clay may lead to crust formation when wet and dust formation when dry.
- compaction of the soil may occur if heavy implements are used.

5. Ridging: formation of ridges or beds (raised structure).
Importance of ridging:
- to specify the rows and inter-row spacing.
- cotton in many irrigated areas is planted on raised beds or ridges.
- to apply irrigation water through furrows.
- to permit for drainage systems.

Propagation:
Cotton can be propagated by cuttings, budding (to commence growth from buds) and grafting. But commercially cotton is propagated by seeds.
Delinted seeds (seeds free from linter or fuzz) are normally used

Advantages of planting delinted seeds:
- result in uniform distribution of seeds (precision planting) and thereby reduce cost of thinning.
- encourages rapid emergence of the seedling
- provides some control against angular leaf spot.

Merits of fuzzy seeds (seeds with linter)
- will not rot as readily as delinted seeds (resistant to wet and cold conditions of the soil).
- Seed dressing chemicals tend to adhere better on fuzzy seeds than delinted seeds.

Methods of delinting
1. Mechanically
- chipping off or pulling off the linter by hand
- Shaking with sand
2. Chemically (Acid delinting): immersing on 90% commercial H_2SO_4

Additional advantage of acid delinting is that the acid sterilizes the seed surface and can serve as seed dressing.

Seed treatment-
Cottonseeds for commercial planting receive preplant fungicidal or other insecticdal dressing of physical treatment (hot H_20).
Purposes of seed treatment
- to control some important diseases and insect pests, *e.g.* seed decay, damping-off, soil and seed borne diseases like bacterial blight.
- to improve emergence of seedlings with strong and vigorous growth and thereby minimize replanting costs.

Planting method
1. Manual/hand planting
   a) Broadcasting – traditional and practiced by small farmers
   - high seed consumption
   - non-uniform distribution of the seed
   - problem of post plant cultivation
   b) Hole planting-placing the seeds (4-6) on holes and cover with the soil
   - Practiced in Egypt and Sudan.

2. Mechanical planting
   - Using mechanical planters, which put the seeds on hills or on drills and cover them with soil. In hill planting cluster of seeds are put on specific distance while in drill planting only single seed is drilled through the row.
   - In most areas of cotton production, mechanical planting is used including Ethiopia.

Spacing, plant population and seed rate
- Inter row spacing: 80-100 (150) cm
- Intra-row spacing: 10-25cm
- Distance between hills: 40 – 50cm
- Plant population: 50,000 – 100,000 plants/ha
- Seed rate:
    - Fuzzy seeds: 35kg/ha
    - Mechanically delinted seeds: 30kg/ha
    - Acid delinted seeds: 20-25 kg/ha

Recommendation in Ethiopia
- Inter row spacing: 80cm (often), 85 or 90 cm sometimes
- Intra row spacing: 25 cm
- Plant population = 50,000 plants/ha (often).

Seed rate:
a. Mechanically delinted
    -Drill sowing: 30 –45 kg/ha.
    -Hill-sowing: 20 kg/ha
b. Acid delinted seeds: 10-16 kg/ha for drill sowing

Depth of sowing: 3-4 cm in humid climate and 5-8cm in drier regions.
Planting time: May 1-May 15 in Middle Awash
Germination: epigeal (seed coat emerges above ground).

Post-planting operations

1) Thinning
2) Cultivation (periodical loosening of the top soil)
3) Weed control

Thinning: Cotton is planted densely and thinning is required to reduce population to optimum.
It is done:

- 3-4 weeks after seedling emergence or
- when plants reach a height of 15-20 cm or when plants develop 4 true leaves.

Spacing: 1 plant at 25 cm (drill sowing), 2-3 plants per hill every 40-50 cm (if hill planted).
Thinning could be bone:

- Manually (hand or hoe)
- Mechanically (cross-ploughing, mechanical chopping).

2. Cultivation (Periodical loosening of the top soil)

Purpose:

- Improves soil aeration and drainage.
- Improves H_2O percolation and retention to the soil
- Controls weeds (mechanical weed control).

Cultivation can be done by hand hoeing, tractor drawn hoes, spike tooth harrows and field cultivators. Avoid deep cultivation so as not to disturb the root system.

3. Weed control

Early weeding is a key for successful cotton production and weed control could be done using:

I. Cultural practices
   a) Manual weed control
   - Hand weeding (only means for broadcast cotton)
   - Hoe cultivation (only means for broadcast cotton)
   b) Mechanical cultivation
      - Rotary hoe cultivation
      - Inter-row cultivation

About 4-weedings are normally required if done by cultural practices:

- 1st hand weeding about 2 weeks after emergence
- 2nd major weeding at about thinning time
- Inter-row cultivation before the plants become overlarge to prevent passage of implements, 50-75% of the total weed population is found at this time.
- Final weeding may be necessary to control late emerging weeds.

Flame cultivation: involves killing weeds by directed flame from gas burners (when the crops considered are small about 20 cm in height)-used in N. America for noxious weeds, as it is expensive practice.

II. Chemical weed control (herbicides).

a) Pre-planting – broad spectrum (non-selective)
   e.g. Dalapon, Glyphosate (roundup).
   -applied 2-weeks before planting.
b) Pre-emergence-creates weed free condition for 6-8 weeks after planting.
   -broad spectrum herbicides – Dalapon, Glyphosate.
c) Post –emergence-Selective herbicides

-Important to control weeds within the rows

e.g. Diuron, Triazines (2, 4-D is not recommended because cotton is broad leaved)

Nowadays, Integrated Weed Management is advocated.

Irrigation

Irrigation is necessary when the rainfall is below 450-500mm per annum or if the distribution is erratic.

In hot arid and semi-acid areas cotton productions is entirely dependent on irrigation. For satisfactory growth and yield, adequate supply of moisture is necessary for 120-130 days after planting (from planting up to shortly after the first bill split).

General recommendation of irrigation:

- Irrigation must be given when 15% of the available soil moisture has been depleted and when 1st sign of H_2O stress on plants seen.
- In general 3-10 irrigations are required during the growing season depending on growth conditions and varieties.
- Final irrigation should be given 15-21 days after the 1st boll split or 15-21 days before 1st picking
- Cotton is most sensitive to water stress during flowering and boll development period.
- Avoid very frequent H_2O – application because:
    - may cause water-logging
    - facilitates excessive vegetative growth
    - delays ripening and prolongs harvesting period.

Recommendation in Middle Awash

1st Irrigation	10 days before planting		150 mm
2nd Irrigation	21 days after planting		75 mm
3rd Irrigation	35 days after planting		75 mm
4th Irrigation	49 days after planting		75 mm
5th Irrigation	63	“	125 mm
6th Irrigation	84	“	125 mm
7th Irrigation	105	“	125 mm
8th Irrigation	126	“	125 mm
Total			875 mm

Nutrition

Cotton is not heavy feeder but requires moderate quantities of N, P and K

Experience in eastern Africa has shown that:

- N is deficient in soils
- P is likely to be deficient in majority of the soils
- K is not deficient in majority of soils because east African soils are made up of parent material containing high amount of K such as granite

State farms of Melka sedi do not use any fertilizer because the irrigation water, which is obtained from Awash River, contains adequate nutrients eroded from the highlands of Ethiopia

Nitrogen

- Promotes good growth and increases yield.
- N-deficiency causes chlorosis, reduce the number of fruiting branches and increase bud and boll shedding.

In Ethiopia, N-is applied 1/3 at planting and 2/3 at the period of peak growth stage of the crop

Phosphorus

- Essential for root development
- Promotes earliness
- P deficiency causes dark green leaves, delayed flowering & fruiting
- P is applied at the time of planting (50 kg of P/ha)

Potassium

- Helps normal development of roots, stems, leaves and bolls.
- Improves fiber quality
- Increases boll mass and percent mature fibers.
- Responses to potassium are not common in the tropics

3.1.6. Harvesting and Processing

Harvesting

Harvesting of cotton is known as picking. It involves removal of "seed cotton" from the matured split open bolls.

Methods of picking:

1. Manual picking (hand picking).

- Common method in East Africa including Ethiopia
- Tedious, time consuming and costly operation because:
  a) Carried out when 50-60% of the bolls mature (starts 2-4 weeks after first boll split and 2, 3 or 4 (sometimes) pickings are necessary at 1-3 weeks interval)
  b) Efficiency is low
     -Output is from 30-80kg/man/day as compared to mechanical pickers.

2. Mechanical pickers

- Used in developed countries where there is labor scarcity
- Harvesting is done only once

There are generally two types of mechanical harvesters:

a) Strippers (stripper pickers): This machine stripes all the bolls (mature and immature) together with the burs (seed cases) and leaves, leaving only the main stem and twigs of branches (non selective).
b) Spindle pickers: Machines equipped with rotating spindles capable of picking the seed cotton from mature open bolls without damage to the unopened bolls and the plant.

Disadvantages of mechanical harvesting:

- Creates unemployment (labor replacement)
- Results on higher field loss of lint.
    - Stripper picker: 2-5% yield loss
    - Spindle picker: 5-15% yield loss
- Reduces lint quality – picks with trashes

- Requires definite timing (optimum) and varieties adapted to different kinds of harvesters (uniform boll splitting) are recommended.
- Requires especial field layout and design
- Requires pre-harvest preparatory treatment

Preharvest treatments:
- For strippers: the moisture content of the leaf should be reduced (desiccation)
- For spindle pickers: abscission of the leaf must be induced (defoliation)

Desiccation:
A pre-harvest artificial induction of rapid drying of the foliage of cotton 1-3 days before harvesting by applying chemicals known as desiccants
Applied either by ground machine or aircraft.

Defoliation: is a pre-harvest artificial induction of foliage drop of cotton 7-10 days before harvesting by applying chemicals known as desiccants
-Applied either by ground machine or aircraft, *e.g.* of defoliants
-Calcium cyanamide at the rate of 22-45 kg/ha; Ethephone/Ethrel at rate of 15-25 kg/ha

Purposes of defoliation:
- Increases harvest efficiency by reducing trashes
- Reduces boll rotting

Processing (Ginning)
Ginning: Is the process of separation of the lint/fiber from the seed cotton by mechanical means to get spinnable fibers and undamaged seeds.

Gin: Is a machine that separates the lint from the seed cotton

Originally, ginning was accomplished entirely by hand, a tedious task that produced less than 1 kg of fiber per worker per day.

There are two types of gins:
(1) **Roller gin:** Consists of 1 or 2 rollers, 20cm in diameter, covered with leather.
- Output of roller gin is much lower (23-36 kg of lint/hr)
- Its action is more gentle and suitable for very fine long fibers, *e.g. G. barbadense* but it may damage the seed.

(2). **Saw gin:** Consists of revolving row of small circular saws 20-30 cm in diameter
- Output is much higher than roller gins (290 kg lint/hour).
- But, their action is too rough for the longest fibers and if badly set; they can even damage the lint of medium fiber contents.

Nowadays, fully mechanized cotton gins are used in Industrial Processing:
- that condition and clean the seed cotton
- separate fibers from the seed
- clean the ginned lint
- package the lint for shipment to the textile factory

Ginning percentage: The weight of the lint divided by the weight of seed cotton expressed in percentage.

$$\frac{Weight\ of\ l\text{int}}{Weight\ of\ seed\ \text{cot}ton} \text{ x } 100$$

Ginning percentage in east Africa varies from 32-37% and the best varieties give about 40% ginning.

Yields

The yield of seed cotton can reach 4 t/ha under optimum conditions, but in practice it is seldom over 2.5 t/ha, and the global average is only about 1.6 t of seed cotton/ha. In tropical Africa, farmers obtain yields of about 300-500 kg/ha of seed cotton and with improved management yields up to 1500 kg/ha of seed cotton may be obtained.

Under irrigated farms of Ethiopia, the yields range from 2.5-3.5t of seed cotton/ha although the potential yield levels are 4-5 t/ha

After ginning, the lint is compressed on to bales (180 kg) and covered with sisal/jute cloth, and finally bound with iron bands and transported to textile factory.

Lint Quality Parameters

Lint quality can be assessed using different criteria:

1. Staple Length: Staple is the term used in textile industry for fiber length.

a) Long staple cotton: the length of individual fiber ≥ 29 mm
- used to make shirts, sheets, and other fine fabrics

b) Medium to long staple cotton: length of individual fiber is 25-28mm

c) Medium staple cotton: individual fiber length of 22-25mm.

d) Short staple cotton: an individual fiber length of <22 mm
- used to make less expensive fabrics like blanket

In Ethiopia the fiber length is medium

Staple length is determined by a photoelectric device, which scans the fiber samples and gives the fiber length frequency distribution

2. Fineness: refers to cell diameter and thickness of the fiber

For a given staple length, fine fibers give stronger and more uniform threads than do coarse fibers.

3. Fiber bundle strength: this is a measure of strength of fibers before they are spun in to threads

- Determined by measuring the force required to break a known size of bundles of fibers
- Stelometer: is a modern device used for measuring the bundle strength of fiber.

4. Maturity: refers to the degree of secondary wall formation (cellulose deposition) on the inner walls of the fibers.

- immature lint contains 25% or more of thin walled hairs.
- it affects the strength of individual fiber and appearance of the lint.

5. Freedom from trashes.

3.1.7. Important Diseases, Insect Pests and Weeds

Diseases: Cotton is attacked by variety of diseases causing damage at all stages of growth.

1. Bacterial blight (Angular leaf spot, black arm)-Caused by *Xanthomonas malvacearum.*

- the most important cotton diseases in Ethiopia as well as in the World.
- it attacks cotton at all stages of its growth.

Symptoms

- Produces water-soaked lesions on cotyledons, leaves, bolls and leads to death of leaves and branches
- Shedding of young bolls and premature opening of bolls.
- It forms angular lesions along the veins on the undersurface of the leaves, *i.e.* why the name angular leaf spot.

Source of inoculum: bacteria infected seeds and plant debris.

Control measures:

- seed dressing with mercuric or copper bactericides
- seed quarantine
- acid delinting (sulphuric acid)
- sanitation: destruction/burning of crop residues
- use of resistant varieties.

2. Fusarium wilt caused by fungus *Fusarium oxysporum*

- Favored by higher temperature and common under rainfed cultivation.
- It penetrates through the root-lesions and the mycellia closes the xylem vessel, which then interferes with normal movement of water.

Symptom:

- It causes stunting and yellowing of leaves.
- Leaf shedding and sprouting of side shoots
- Brown dry patches which often occur between veins of the leaves

Source of inoculum

- Seeds: the fungus lives on the inner side of the seed coat. Thus, seed dressing is not effective to control the disease.
- Infected debris (left overs)
- Infested soil and farm implements

Control

- Use of resistant varieties
- Crop rotation is not effective because the fungus can stay in the soil for long time.

3. Verticillium wilt (*Verticillium alboatrum*)

- The fungus closes the sap-conducting tissue (phloem)
- Soil borne and favored by cold wet weather and irrigation

Symptom: It causes stunting and shedding of leaves

Control: Crop rotation may help.

4. Damping-off
- Caused by *Rhizoctonia solani* and *Phytophthora* sp
- Damages the seedlings before emergence of the first 2 & 3 weeks after emergence

Source of inoculum
- Infected seeds (seed borne)
- Infected soils (soil borne)

Control:
- Seed treatment
- Avoid excessive moisture
- Sowing at optimum soil temperature (>20°C)

5. Leaf curl (viral disease): A serious disease especially in Sudan and all parts of the plant are distorted.
- Caused by 2 strains of virus
- Small vein thickening (SVT).
- Main vein thickening (MVT).

Vector: white fly (*Bemisia tabaci*)

Control:

- Use of resistant varieties
- Control of white fly (vector) by insecticides
- Sanitation: good cleaning of the preceding crop (crop coming before)

Insect pests:

Are too serious to the extent of abandoning of cotton production in many parts of Africa, South of Sahara. Thus, cotton production is not economically feasible without an adequate insect control programme.

About 150 species of insects are recorded feeding on cotton.

(1) **Seedling insect pests.**

1.1. Crickets & grasshoppers –

- wide spread in the tropics and sub-tropics
- damages seedlings and young plants.

1.2. Termites: damages seedlings and young plants

1.3. Cut-worms: Cut the stem of seedlings just above the ground level.

2. Sucking insect pests

2.1. Aphids (*Aphis gossypii*)

- Aphid infestation often appears during the dry-period after rains.

Control: Insecticides: Dimethoate & Malathion

2.2. Cotton white fly (*Bemisia tabci*).

- Feeds by sucking the nutrient sap
- Vector of viral disease (leaf curl)
- White fly infestation is severe during the dry spell after rain.

2.1. **Cotton jassids** (*Empoasca* spp, *E. lybica*, *E. facials*)

- Major pest in middle & lower Awash cotton farms of Ethiopia

Control: Development of variety with hairy leaves. Leaf hairiness discourages these insects and serves as mechanical protection.

2.2. **Stainers:** cotton stainer: *Dysedercus spp*

Stainers are sucking bugs, which pierce the boll walls with their mouth parts and introduce Nematospora fungus with their salivary juice as they suck. The fungus stains the lint and reduces the grade of the seed cotton.

Control:

- Biological (predator) –Guinea fowl feed on stainers
- Avoid ratooning of cotton
- Growing non-host plant in crop rotation
- Insecticides: carbonyl spray

3. Boll worms

3.1.African Boll Worm (ABW) –*Helicoverpa armigera*

- An important pest on almost all cotton growing areas of the world.
- It has wide host range (alternate host) including maize, sorghum, millet, sunflower, tomato, pepper, chick pea, etc (crop rotation is not effective in such type of insects)
- The adults are small night flying moths
- The larvae may be green, brown or yellow with pale stripes on each side.
- The larvae feed on buds, flowers and bolls and occasionally feed on leaves (voracious pest).

Control:

- Biological control (predator and parasites), *e.g.* Polyhedral virus is used as a parasite
- Monitoring and control of night flying moths by light traps.
- Insecticides: Endosulfan, DDT (abandoned).

Apply when 1 or 2 worms appear on 1 plant (Economic threshold). If the application is delayed fully grown instars are resistant to these insecticides.

3.2. Pink boll worm: *Pectinophora gossypiella*

- smaller than African Boll worm
- the larvae have a double pink bar on each segment of their bodies
- the larvae bores in to bolls through minute and sometimes undetectable holes and spends the entire of its life cycle feeding the contents of the boll.

Control:

- Insecticide: carbonyl spray

3.3. Spiny bollworm: (*Earias spp*).

- is not a major pest
- rarely causes as much damage as ABW.
- has got fewer alternate hosts.

Control: Insecticide spray (carbonyl & endosulfan) as soon as the eggs are found

3.4. Sudan Bollworm (*Diparopsis watersii*)

- Bores into buds and bolls
- Insecticides –carbonyl and endosulfan

4. Leaf eaters:

4.1.Cotton leaf worm – *Spodoptera littoralis*, *S. exempta*

4.2.Cotton flea beetles –*Podagrica* spp

Weeds: Mostly weeds are not crop specific, but the perennial nut grass (*Cyperus sp.*) is an important weed in irrigated cotton growing areas of Ethiopia.

3.1.8. Improvement

Major improvement objectives:

1. High production of lint (fiber) – achieved by:

- Increased seed cotton yield –yield is a function of the number, size and weight of bolls.

- Increased ginning percentage: 32-37 to 40%

2. Improved lint quality (staple length, fiber strength, fineness, and maturity).
3. Early maturity
4. Resistance to diseases & insect pests
5. Adaptation to particular environment (frost, salt)
6. Response to soil treatments (fertilizer, manuring)
7. Adaptation to mechanical harvesting

Suitable cotton characters for spindle picking are:

- Upright growth habit
- Early fruiting & uniform boll splitting
- Fairly determinate growth habit
- Bolls evenly spaced over the plants.
- Leaves that shed when most of bolls are ripe

Desirable cotton characters for stripper harvesters are:

- Dwarf or semi-dwarf with short to medium branches
- Early and uniform boll splitting

Methods of improvement:

(1) Germplasm collection, introduction and recurrent selection

- Germplasm collection involves expedition to the center of origins of the crop where there is a great diversity.
- Selection must be based on broad genetic base (many genotypes).

2). Hybridization:

- Interspecfic: crossing between two species: *G. hirsutum* x G. *barbadense*
- Intraspecific: crossing within the same species, *e.g.* varieties of *G. hirsutum*

3). Genetic Engineering: the process of copying a gene from one living thing (bacteria, plant or animal) and adding it to another living thing by using biotechnology. Genetic engineers argue that genes should be classified by their function rather than their origin. For example the gene responsible for drought resistance can be transferred from camels to crops. Such genetically engineered crops are called transgenic crops or Genetically Modified Crops.

Nearly 60% of the US cotton in 2000 was grown with transgenic cotton varieties mainly for Lepidoptera (boll worm) resistance and herbicide resistance cotton so that they can use glyphosate (non-selective herbicide) in cotton.

Genetically modified (GM) cotton was developed to reduce the heavy reliance on pesticides. GM cotton is widely used throughout the world with claims of requiring up to 80% less pesticide than ordinary cotton. The International Service for the Acquisition of Agri-Biotech Applications (ISAAA) estimated that worldwide GM cotton was planted on an area of 67,000 km² in 2002. This was 20% of the worldwide total area planted in cotton. The U.S. cotton crop was 73% GM in 2003.

The initial introduction of GM cotton proved to be a commercial disaster in Australia as the yields were far lower than predicted, and the cotton plants were cross-pollinated with other varieties of cotton. However, the introduction of a second variety of GM cotton led to 15% of Australian cotton being GM in 2003. About 80% of the crop was genetically modified in 2004, when the original variety was banned.

Organic cotton

Organic cotton is cotton that is grown without insecticide or pesticide. Cotton is the most pesticide-dependent crop in the world, accounting for 25% of the world's pesticides. According to the World Health Organization (WHO), 20,000 deaths occur each year from pesticide poisoning in developing countries, many of these from cotton farming. Organic agriculture uses methods that are ecological, economical, and socially sustainable and discourages the use of agrochemicals and artificial fertilizers. In stead, organic agriculture uses crop rotation (the cropping of different crops than cotton). The use of insecticides is prohibited; organic agriculture uses natural enemies to suppress harmful insects. The production of organic cotton is more expensive than the production of conventional cotton. Organic cotton is produced in organic agricultural systems that produce food and fiber according to clearly established standards. Organic agriculture prohibits the use of toxic and persistent chemical pesticides and fertilizers, as well as genetically modified organisms. It seeks to build biologically diverse agricultural systems, replenish and maintain soil fertility, and promote a healthy environment.

3.1.9. Glossary of Cotton Yield Physiology Terms

Because cotton vegetative and reproductive growth differ substantially from grain crops, cotton agronomists and physiologists have established terms or expressions that have helped describe various aspects of cotton's growth and development. A brief list of these terms and their definitions are provided below:

Anthesis: the time when the flower opens.

Bloom: The term bloom is usually used to indicate the developing fruit (ovary) of cotton. The boll contains the capsule and carpels (which produce the seed and lint).

Boll retention: the number of mature bolls formed divided by the number of blooms. In some cases the denominator refers to the seasonal total number of blooms in other cases it may refer to a specific group of tagged blooms.

Bur: Mature capsule tissue of the boll that has dried and "opened."

Bract: a leaf-like structure. Typically in cotton, three bracts subtend the flower and are attached near the receptacle. Prior to anthesis, bracts envelop the flower and are approximately 8cm^2 each. After anthesis, bracts remain attached to the boll throughout boll development. There are usually three bracts per fruiting form.

Carpel: one cavity of a compound pistil or a cavity of the pistil (boll) that develops around the ovules.

Capsule: the outer boll wall structure.

Fruiting position (Fp): relative location of fruit or sympodial leaf on the sympodia. First position leaves and fruit are proximal to the main stem whereas second and third position fruit and located distal to position one. FP1 refers to a first position fruiting site, FP2 to a second position fruiting site, etc.

Lint: single cell trichomes (fibers) that initiate on the seed coat epidermis. At maturity, most fibers are between 22 and 28mm long and are composed primarily of cellulose. Short trichomes are referred to as fuzz fibers and remain attached to the seed after ginning.

Lint percentage: lint weight divided by seed cotton (lint/seed) weight x 100. Values for commercial cultivars and production systems often range from 30 to 42%.

Micronaire: an indirect measure of fiber thickness (linear density, roughly microgram per inch) that is strongly related to the fiber's perimeter (circumference) and maturity. Typical values range from 3.0 to 5.5.

Monopodial branch: indeterminate shoot growth similar to a main stem often emanating from lower main stem nodes.

Boll: uppermost harvestable FP1 boll with broken sutures and visible lint. This number is often used as an indicator for timing of defoliation.

Pima cotton: *Gossypium barbadense* L., extra-long staple or Egyptian cotton

Seed cotton: unginned combination of seed plus lint.
Square: a developing flower and its subtending bracts (square refers only to prebloom or preflowering stage). The first square of the season is often visible around 40 days after planting. Anthesis occurs approximately 20 to 25 days after the square becomes visible. In cotton literature, a square is sometimes referred to as a floral bud.
Square retention: the number of floral buds at selected fruiting sites that produce flowers divided by the number of fruiting sites. To simplify collection of monitoring data, square retention data is sometimes restricted to the first fruiting position.
Sympodial fruiting: a branch originating directly from a main stem leaf axil (usually branch (sympodia) from main stem node number four or greater) that produces fruit and leaves.
Yield: lint biomass per unit area. Others may use yield to refer to seed cotton biomass per unit area.

3.2. Sisal

Among the vegetable fibers, sisal fiber is the most used hard fiber.

Useful Product:
Sisal has a wide variety of purposes including:

1. Traditional: High-grade sisal fibers are made into yarns (either on their own or in blends with wool or acrylic) and used in carpets. Medium-grade fibers are made into cordage, ropes and baler twine for agricultural and industrial use and particularly useful in a marine environment as they are resistant to deterioration by salt water.
2. Used for pulp and paper production: Sisal biomass contains a high proportion of cellulose in which its pulp is a substitute for wood fibers and adds bulk to paper and cardboard. It also being absorbent and has a high fold endurance characteristic, making it a high quality input for paper products. It can be used in cigarette paper filters and also tea bags.
3. Used in textile factories: A major use of the fiber is in buffing cloth, because sisal is strong enough to polish steel and soft enough not to scratch it. It is used to substitute or enhance fiber glass and used to reinforce plastic in automobiles, boats, furniture, water tanks and pipes. It is used to add strength in cement mixtures for the development of low-cost housing and to replace asbestos in roofing and brake-pads. It is an insulation material and can be made into fiber-board as a wood substitute.
4. Used as plastic and rubber composites: Sisal has good potential as reinforcement in polymer (thermoplastics, thermosets and rubbers) composites due to its low density and good welding specific properties. The sisal composites can be used in automotive components and other furniture. Sisal also continues to make the best material for dart boards.
5. Sisal waste products/byproducts: Used for making biogas, pharmaceutical ingredients and building material. The waste produced by decortication such as sisal juice, particles of crushed parenchymatous tissue, and fragments of leaves and fibers can be used as a fertilizer or animal feed. The juice of the plant is used to make pharmaceuticals like hecogenin, inulin and others.
6. Other uses: Bird breeders use the hollow trunks of the plant for nesting. It is used as a geotextile in land reclamation, stabilization of slopes and road construction. It is also used to manufacture good cat scratching posts, spaproducts, lumbar support belts, rugs, slippers, cloths, and disc buffers. It is valuable forage for honey bees because of its long flowering period. The attractive sisal poles are widely used in game parks for bomas and hides.

3.2.1. Production, Origin and Taxonomy

Production:

In terms of production, sisal occupies the 6th place among fiber plants, representing 2% of the world's production of plant fibers. Sisal comprises about 70% of the total world production of the principal hard fibers and it provides > 65% of the world trade of hard fibers.
Area of production: 0.48 million ha (World), 0.11 million ha (Africa)
Production: 0.43 million tones of fiber (World), 0.11 million tones of fiber (Africa) in 1989.
Major producers: Brazil: (>½ is the world production); Tanzania: about 30% of the country's total export revenue comes from sisal (36 million kg of fiber per year); Kenya; Uganda, Angola and Mozambique
Major importers: U.K, U.S.A, Canada, Portugal, Japan

Sisal production reported in 2003 notes that Tanzania produced approximately 22,000 tons per annum, 22,000 tons in Kenya and 8,000 tons in Madagascar. China contributed 40,000 tons with smaller amounts coming from South Africa, Mozambique, Haiti, Venezuela and Cuba. In Mexico henequen production has fallen from 160,000 tons in the 1960's to about 15,000 tons today. The first commercial plantings in Brazil were not made until the late 1930's and the first sisal fiber exports from there were made in 1948. It was not until the 1960's that Brazilian production really accelerated and the first of many spinning mills were established. Today Brazil is the major world producer of sisal at 125,000 tons. Sisal occupies 6th place among fiber plants, representing 2% of the world's production of plant fibers (plant fibers provide 65% of the world's fibers).

In Ethiopia there was about 1500 ha of sisal at Awassa with one processing plant, but the area of production has decreased nowadays because of competition from synthetic fibers. It is also grown for soil conservation purpose and fence. The rich soils in the Ethiopia create a wonderful growing environment. Sisal grows in the Ethiopia, but yet no local people are harvesting sisal or turning it into fibers. The Ethiopian sisal factories are anxious to see if MAI (Morrell Agro Industries) can find a way for them to gain access to local sisal plants and fibers. There is a market for sisal fiber in Addis. This would be a great opportunity to create a more industrious people with hope for the future. Sisal factories in Addis Ababa process the fibers that come from the plant. They import all of the fibers from other African countries, such as Uganda.

Taxonomy: Family: Agavaceae
Genus: *Agave*
Species: *sisalana* (2n = 138)

In the past, several species of *Agave* were used for fiber production, but presently *A. sisalana* is commercially grown species. Its hybrids, the most common of which is known as Hybrid no. 11648 and *A. fourcroydes* (known as henequen) are the most important variety for fiber production on a commercial basis.
Origin and Distribution: *Agave sisalana* is a naturally occurring pentaploid hybrid found wild in Central America and Mexico (takes the name sisal from small Mexican port of sisal). Sisal was introduced to east Africa late 19th century or early 20th century. For example to Tanzania in 1893 and to Kenya in 1903.

3.2.2. Morphology

Sisal is a xerophytic perennial monocot with:
- -fibrous root system
- -a short stem or 'bole'
- -sessile leaves (leaves directly attached to the bole with no petiole)

-Sisal is a hardy plant that can grow well fast all year round and attains a height of only 15.2 cm in 9 months after planting and 0.6 m at the end of 2 years.

-a long stout flowering shoot "pole" which is produced after 8-12 years and the plant dies after production of flowers and bulbils (monocarpic).

Root System:

- Spreading fibrous root system, which arises adventitiously from the base of the leaf scars at the bottom of the bole.
- It extends horizontally for a length of 1.5 – 3 m (up to 5 m) in the top 30 – 40 cm of the soil.

There are 2 kinds of roots:

1) **Bearer roots:** 2-4 mm in diameter and arise at the base of the bole from leaf scar and used mainly for anchorage. Can extend horizontally to 3 m at depth of 30 – 40 cm
2) **Feeder roots:** thin roots 1-2 mm in diameter arises from the bearer roots with no attachment to the main bole. Important for absorption of H_2O and nutrients.

Rhizomes: is underground stem 1.5 cm in diameter running horizontally up to 2m in the upper 5-15 cm of soil depth. It produces young plants know as suckers

- A plant can produce 5 – 10 rhizomes and 20 suckers throughout its life
- Sucker production starts about a year after planting.
- Suckers are removed during cultivation (desukering) and can be used for propagation (but not commercially)

Stem/bole: Short, thick and fleshy with an apical meristem (growing point)

-A bole can reach 1.2 m length with 20 cm in diameter.

-It is covered with highly lignified bark and leaves arise from these barks.

-The bole serves both as storage organ and main axis

Leaf: Commercially important plant part.

-Mature leaves are:

-Sessile (no petiole), rigid and linear lanceolate

-1.2 m long (up to 2m)

-Broadest in the middle (10 – 15 cm wide)

-Concave at the upper surface and convex at the lower surface.

-It has a well-developed waxy cuticle

-There is extremely sharp dark brown spine at the end of each leaf

A sisal plant can produce 200 – 250 leaves during its life cycle

The main components of the plant are the leaf, the trunk and the rhizome. The leaf yields the sisal fiber and a pulpy waste. The fiber is by far the most important product of the sisal plant. Sisal leaf contains about 12% of pulp waste. The trunk and rhizome yield various wood and chemical products at the end of their productive life.

Fibers:

A sisal leaf can contain from 1000 – 1200 creamy white fibers, which run the whole length of the blade. Fibers are of 2 kinds:

1. **Mechanical fibers**: Comprise 75% of the total fiber of the leaf with the main concentration in 3-4 rows in peripheral (external) zone of the leaf under the epidermis. They keep the leaf rigid and make the bulk of commercial fiber.
2. **Ribbon fibers**: are found in the median line coalescing (uniting together) and become lignified to form the terminal spine. They are associated with conducting tissues (phloem and xylem). Those covering the xylem are small, weak, thin walled and are mostly lost during decortications, while those covering the phloem are large and tend to split longitudinally during decortications.

Average composition of fiber in dry weight basis:

Cellulose	78%
Lignin	8%
Other CH_2O	10%
Ash	1%
Wax	2%

Normal commercial fiber consists of 10-12% moisture.

Inflorescence

At the end of the life cycle of plant the stem meristem is transformed into reproductive shoot known as pole. Formation of narrow, tapering and sword like leaves, which become shorter successively, indicate this. It flowers once in its life cycle and after flowering it dies. Thus, it is a monocarpic plant. It takes from 8-12 years to complete its life cycle. After the pole reaches its ultimate height of 5-6 m, flowering branches are produced. Sisal forms a panicle type of flower. The panicle branches 5 to 6 times producing up to 40 flowers in each branch. Flowering in sisal is acropetal along the pole, *i.e.* it progresses from the base to upper parts. Flowers are protandrous, *i.e.* the stamens dehisce (shed pollen) before the style is fully elongated and the stigma is receptive. Thus, it is a cross-pollinated plant.

Seeds

The fruit or seed capsule is green and fleshy when immature but dries out and turns to black on ripening. The fruits ripen on about 6-months after pollination of flowers. Sisal rarely sets seeds in East Africa. Although the flowers are normal and the pollens are sound, seed capsules are not formed due to developments of an “abscission layer” between the base of ovary and the pedicel or a flower stalk – being extremely thin the flowers together with their ovaries fall to the ground. Only some seed is produced in Kenyan highlands.

Bulbils

Normally produced on the panicles after flower abscission. Consist of a meristem, 6-8 reduced leaves, and rudimentary adventitious roots from the base of the lower leaves. Grow to 6-10 cm height in about 6-months and then are shed. From 2000 to 3000 bulbils are produced per pole. Bulbils are the major materials used for commercial propagation.

3.2.3. Ecological Requirements and Husbandry

Rainfall: The plants are not frost tolerant and produce the best in areas with an annual rainfall of 500 mm and higher. An annual rainfall average of between 600 to 1500 mm is required. Sisal can also grow in areas with less or erratic rainfall. In high-rainfall areas, production may become problematic due to weed infestation and occurrence of diseases. Waterlogging causes stunted growth.
Temperature: Sisal grows best in subtropical climates. The plant grows well in hot climate with temperatures between 10 to 32°C. Optimum temperature 27-32 ºC; minimum temperature > 16 ºC
Altitude: Sea level – 2000 m.a.s.l.
Soil: It is not soil specific, but it grows best in well-drained loamy soil. It can be cultivated in most soil types except clay and has low tolerance to very moist and saline soil conditions. Soil pH of between 4.0 and 6.0 is important.

Propagation: Sisal is propagated vegetatively with bulbils or suckers.

1. Sexual/seed: Rarely produced and even if produced, it is used manly for experimental and breeding purpose. Germination is epigeal, *i.e.* the white radicle emerges first followed by the cotyledons, which usually carry the black testa at its top.

2. Vegetative/Asexual propagation: Commercially sisal can be propagated by suckers and bulbils. Both are clones (plants developed vegetatively from a single plant and are of the same genotype as the parent plant).

But, suckers are seldom used for commercial preparation because of:

-they are produced in limited quantities (20 sukers per plant)
-the stands/plants from suckers are not as satisfactory and uniform as the parent plant.
-produce less number of leaves during the later growth period.

Bulbils are preferred to suckers for commercial production because:

-they are produced in much greater amount (up to 3000 bulbils/pole).
-plants from bulbils are more robust (vigorous).
-they give more uniform stand and higher early and total yield as compared to suckers

Disadvantage: The bulbils require pre-growing in nurseries before transplanting, while suckers are available for planting directly from the field. Directly planted bulbils show uneven growth, high death rate and weak plants. The grower prefers sucker because it enables them to maintain pure lines.

Nursery raising of bulbils:

a) Bulbil collection: Bulbils can be collected in 3 ways:
- from ground after they are shed
- by shaking the poles and collecting from ground
- by cutting the poles and shaking it in sacks

They are planted in well-prepared nurseries. The nurseries are made on loose, friable and well-prepared seedbed. The nurseries should be fertilized with sisal waste. The bulbils are planted in beds at 10 x 10 cm apart at a depth of 1.3 cm at the beginning of the rainy season where they grow for six months. After that they go to secondary beds where they are placed 30 x 30 cm apart. After 12 to 18 months the plants are ready to be planted out into the field. When they reach a height of 25 to 40 cm and produce 15 fully expanded leaves, they are lifted from the nursery for transplanting. Before transplanting, all the transplants are graded according to size in order to obtain a uniform stand of plants. At transplanting the fibrous roots around the base of the plantlets are usually cut off and the lower leaves may be pulled off.
Transplanting of sisal into the field can be done any time of the year as it is a succulent with good drought resistance. The number of plants/ha varies from 4000-6000 and most estates in east Africa use a plant density of 5000 plants/ha. Depth of planting in a field is from 5 to 8 cm. Transplanting is done by hand and planting holes are made by hoe and soil insecticide is applied into the soil.

There are 2 types of planting pattern:

1. Single row planting pattern: 2.5 m between rows and 0.8 m between plants = 2m^2/plant, *i.e.* 5000 plants/ha
2. Double row planting: 1 m between single rows = a
   4 m between double rows = b
   0.8 m between plants = c

Area/plant= $\frac{(a+b)}{2} \times c = \frac{(1m + 4m) \times 0.8}{2} = 2\ m^2$/plant

- No of plants/ha = $\frac{10{,}000m^2}{2m^2}$ = 5000 plants.

The recommended planting patterns are a series of double rows. As far as yields are concerned, there is no difference between single and double row planting. But double row planting:

- allows easy mechanical cultivation and harvesting
- allows the growing of cover crops like maize, legumes, cotton in between the sets of rows.

Suckers may be established directly. Before planting in the field, the soil is cleared mechanically or by hand and it may be ploughed shallowly.

Post – planting operation:

1. **Weed control:** during the first 2-3 years after transplanting weed is very crucial (70% of yield loss can occur). Thus, weed control either by hand hoeing, mechanically or with use of herbicides is essential. Sisal is associated with perennial weeds like *Digitaria* spp, *Cyperus* spp; *Panicum* spp. After 1st cutting, minimized cultivation and herbicides are applied less frequently. After 2 to 3 years, weeds may be allowed to grow during the rains and cut down at the beginning of the dry season to conserve moisture and provide mulch. It is recommended that cover crops should be grown between the rows during the first 3 years after establishment in order to keep the land free from weeds. Once sisal is mature a medium weed cover is not harmful.
2. **Manuring/Fertilization:** Sisal is an environmentally friendly fiber and almost no fertilizers are used in its cultivation. Where sisal is established on new land fertilization is generally unnecessary, but where it is established on an old land, fertilizer is usually needed. Application of N-was found to give response on old sisal fields; P-has little or no effect on sisal. Potash application is required in areas where there is banding disease (K-deficiency syndrome). Banding disease symptoms are small pale green, brownish yellow spots, 1-2 mm in diameter, which develop on the underside of the leaf. Heavy dose of muriate of potash (KCl) at rate of 200 – 500 kg/ha should be applied when there is banding disease. Ca – liming or application of ground limestone is recommended on strongly acid soils. Purple leaf tip is associated with exhausted acid soils, which are deficient in Ca. Sisal waste manuring has proved more beneficial than inorganic fertilizers especially along with liming because sisal waste increases soil acidity, but its bulkiness hinders its application.
3. **Irrigation:** Growing sisal does not require irrigation, as the sisal plant is drought resistant and cultivated as a rain fed crop. However, the processing of sisal leaves is very water intensive and on average 100 m3 of water is used to produce one ton of fiber.
4. **Desuckering:** removal of suckers to reduce competition and increase yield

3.2.4. Harvesting and Processing

Harvesting: The development of the plant is determined by factors such as soil potential, rainfall, temperature and general managerial practices. Under normal conditions the plant may be harvested for the first time in 3 to 4 years after establishment. At this stage, the plant already has 120 to 125 leaves that are 60 cm or more in length and is about 1.5 meter high. It is ripe as soon as the colour of the thorn at the tip changes from dark brown to a light brown colour. Harvesting (cutting) is done manually with simple knives. First cutting is usually made 2-3 years after planting in east Africa, when the height of majority of leaves is 1.5m. By this time, the plant has produced about 100 leaves of which 35 – 40 are of economic value. In the cooler conditions, harvesting does not start until the crops are of 4 – years old.

Intensity of cutting: Only leaves around the bole are cut leaving those on the meristem. In each cutting, it is necessary to leave sufficient leaf on the plant to enable the plant to continue growth without damage. However, at final harvesting all the leaves are harvested when the plants are at poling. An early start of cutting is conducive to better yields, provided the plants are not cut too severely. If cutting is over delayed, the plants pole earlier and there will be a loss of leaves through withering. Cutting too soon reduces the length of the subsequent leaves grown on the plants. Where the field is uneven, selective cutting should be done to avoid cutting immature plants. The length of the leaves is of paramount importance as the fiber content increases as the leaves grow longer.

Frequency of cutting: Sisal leaves are harvested at regular intervals during the life cycle of the crop, thereafter only 25 leaves per year can be harvested. Cutting once per year is commonly used in many countries and in some countries it can be done two times. Six to eight cuttings are done per life cycle since sisal can live from 8-12 years. Soon after cutting the leaves, the terminal spines are cut-off and the leaves are bundled for transport to the factory. The leaves must be decorticated within 24 hours after cutting.

Processing

The actual processing of sisal involves:

(1) **Decortications:** It is the separation of the fibers from the leaves by scrapping and scratching process, which removes the soft and thin – walled parenchymateous tissue without damaging the fibers. Leaves should be decorticated not later than 48 hours after cutting.

Separation of fibers can be done using:

a) Raspadors: machines 1st invented by a Mexican monk in 1839 and used prior to advent of modern high speed decorticators
b) A modern decorticator consists of:
- decorticating drum
- chains or ropes for leaf gripping (holding) and belts

The leaves are fed by hand or a conveyor belt. Water is sprayed on the drums continuously and this washes the fiber and carries away the waste leaf pulp, which consists of about 95% of the leaf. A modern decorticator can treat 25000 leaves, weighing 10-20 tones/hour – for which about 1000 ha of sisal area are required to keep the decorticator on constant function. H_2O-requirement is from 36,000 – 45,000 lt/hr. Thus, is needs a lot of H_2O.

(2) **Drying**: After decortication and washing, the fiber is dried, either in the sun or in drying machines and this gives the fiber a more uniform quality. The fiber immediately after decortications consists of about 60% moisture and this should be reduced to <15% moisture as soon as possible to preserve the natural creamy white color of the fiber.

Drying can be done by sun or by machine:

- Sun-drying: the fibers are put on 3-wires stretched on poles and take 8-12 hrs to dry in fine weather. Excessive drying in the sun may lead to deterioration in colour.
- Artificial fiber drying machines are available, but not common.

(3) **Brushing**: on drying the fibers become stiff and congealed (firm). Therefore, they are beaten lightly to free individual fibers, to remove dirt and other foreign matter and to facilitate grading & packing. The brushing process is necessary to straighten the tangled, wavy fibers and to polish them.

(4) **Grading and packing**: Fibers are graded based on length, freedom from tow (broken fibers) color and other decortication characteristics. The buyers insist on correct grading and general neatness of the bale. The presence of oil, bits of coal and other impurities in the bale is strongly disapproved.

Grade 1: > 0.9 m in length, creamy white to creamy in color.
Grade 2: 0.75 – 0.9 m
Grade 3: 0.61 – 0.75 m

Packing: The fibers are packed according to their grade. Moisture content of the packed fiber should be 10-12%, if too wet – they become stiff and reduce quality while the moisture is lower they are easily broken. If it is too wet, it becomes stiffly matted and there is a danger of spontaneous combustion in the bales. Graded fibers are packed into bales using a manually or electrically operated pressing machine. One full bale is equivalent to 125 kilograms of fiber. One ton is made up of 8 bales.

Yields: Yields are usually expressed in kg of fibers per ha per harvesting cycle or per annum. On best plantations in East Africa, yields of 2000-2500 kg of dried fiber/ha per annum are obtained. On poorer plantations yields may be as low as 1120 kg/ha per annum. A 100 kg of fresh sisal leaves contain on the average 4 kg of dried fiber and tow, which yields on average 3.5% of extractable fiber on all cuts.

The area of sisal required to produce an annual output of 1500 tons of dried fiber per year is regarded as optimum for 1-modern decorticator. Assume mean yields of 2 tons of dried fiber/ha per year, and then 1500/2 = 750 ha of sisal plantation is required. To calculate the required area that should be planted every year for steady annual output of 1500 tons fiber/year.

Assume 2 tons of dried fiber/ha per year

$\frac{1500 \text{ tons}}{2}$ = 750 ha of ready to be cut sisal area is required.

Divide this area by the number of years that the sisal is cut (assume 6 years) = 750/6 = 125 ha of sisal should be planted each year.

If the sisal is first cut when two years of old and six annual cuttings are obtained before poling, a total crop of nearly 12 tons of fiber per hectare is produced during the productive cycle life of the sisal. In this case it will be necessary to replant 125 hectares of sisal per annum. Approximately 40000 tons of fresh sisal leaves are required to produce 1500 tons of fiber. Balanced rotational planting program assuming a mean fiber yield of 2 tons/ha/annum.

Age of sisal in years	Stage of sisal	Assumed dry fiber yield (tons/ha)	Area required (ha)	Total fiber yield (tons/annum)	Total tons of leaves /annum
1	Young	-	125	-	-
2	Young	-	125	-	-
3	1st cutting	0.8	125	100	4500
4	2nd cutting	1.5	125	187.5	6750
5	3rd cutting	2.0	125	250	7000
6	4th cutting	3.0	125	375	8500
7	5th cutting	2.7	125	337.5	7000
8	6th cutting	2.0	125	250	6250
Total		12.0	1000	1500	40000

Thus, allowing for further 125 hectares under fallow for replanting and further 75 hectares for nurseries, roads, etc., the total area of the plantation to produce 1500 tons of fiber per annum is approximately 1200 hectares.

3.2.5. Important Diseases and Insect pests

Diseases:

1. **Bole rot** – The most serious disease of sisal caused by fungus *Aspergillus niger*. A saprophyte and weakly parasite fungus and enters through the leaf bases immediately after cutting off the leaves.

Symptom: It causes a wet rot which becomes yellowish-brown and soft, bad smelling with a pinkish margin, and it may lead to plant collapse and die off. The fungus also causes a basal dry rot when it enters the base of the bole through damage. Wet weather during cutting favors attack as do soils deficient in Ca.

Control: Application of calcium-rich fertilizers and in waterlogged or highly acidic soils, agricultural lime must be added. The incidence can be reduced through removal of infested material and harvesting under dry conditions.

2. **Leaf-spot disease**

Symptoms: Tiny spots which develop into corky grey brown circular scab-like spots on leaves of both upper and lower surfaces feeding off the tender white tissue of the spike. The severity of leaf-spotting varies with seasons and it is always worse on slow-growing plants.
Control: Cultural measures: maintaining clean fields, soil fertility management, and use of clean planting material. Recommended chemicals can be use

3. **Zebra disease**- 1st appeared in 1961 in Tanzania and caused by *Phytopthora* spp, *P. parasitica* and *P. infestans*

4. **Banding diseases:**

Cause horizontal bands (flat and thin strips), 10-15cm wide of purple brown necrotic tissue across the leaves. It is the result of K-deficiency the commonest mineral deficiency in sisal and can cause substantial loss unless controlled by applying K – fertilizers.

5. **Purple leaf top** – the leaf tip become reddish purple and the margins of the blade (expanded portion of the leaf) curl upward. It is associated with exhausted acidic soils out a shortage of Ca, but other factors seem to be involved.

6. **Sun-scortch**: May occur at high temperature. The green palisade cells burst (sink), causing irregular shaped sunken areas. Which turns white and eventually darkened. Such leaves are difficult to decorticate.

Insect pest

Sisal is an environmentally friendly fiber and almost no pesticides are used in its cultivation, because it is resilient to disease. Sisal is relatively free from pests and diseases, though the only serious insect pest of sisal is sisal weevil.

- Agave weevil or Mexican sisal weevil (***Scyphophorus acupunctatus***), **Synonym:** ***Scyphophorus interstitialis:*** is the major insect pest of sisal in East Africa. The adult weevil, 9.5 – 15 mm long, and dull black in color feeds on the youngest leaves. Weevil damage to sisal plants is either done by the adult or the larva. The larvae damage the subterranean parts of young plants and may cause substantial losses. The larvae also damage leaves giving a shot hole effect.

Control

- Cultural control: Planting early in the rain, use of non-infected planting materials, removal of dead boles and avoiding contaminated fields (sanitation measures). Use of guard rows supported by placing split boles whose cut surfaces are dusted with insecticides to reduce infestation.
- Chemical control: The application of registered insecticides.
- Biological control: by sisal weevil's natural enemies, e.g. predators such as *Placodes ebeninus* Lewis (the beetle that feeds on the living larvae in rotten sisal boles).

3.2.6. Improvement

Breeding of sisal presents many difficulties because of:

1) It takes 10 or more years to flowering. Moreover, those with the longest vegetative life cycle are the ones of interest to breeders.
2) Difficult to synchronize flowering of the desirable parents.

The yield of fiber is dependent on:

-the number of leaves during the life cycle

-number of plants/ha
-the size of the leaf
-the percentage of extractable fiber on the leaf (fiber percentage).

Desirable Characters of Sisal:

i. Prolific leaf production (500 – 1000 leaves per plant during the life-cycle)
ii. Good dimensions and weight of the leaf (length: 1.3 – 1.5 m and a weight of 0.8-1 kg/ leaf)
iii. Smooth leaf margins which should be completely free of spines for ease of handling and to minimize leaf-scratching,
iv. High fiber % on over all cuts (4%).
v. Rapid growth and early development with 1st cutting at 2-years
vi. Hardiness and adaptability to local environment.
vii. Resistant to diseases and pests: bole rots and Mexican weevil

Method of breeding

Mostly interspecific hybridization. Many *Agavae* spp have larger number of leaves than *Agavae sisalana,* but the leaves are small and not suitable for fiber production.
A. sisalana is very heterogeneous, and rarely sets seeds particularly at lower altitudes.
A. amaniensis – is a useful parent. The fiber strands are twice as numerous and finer than those of *A. sisalana* and are of good commercial value. The leaves are long and heavy and devoid of marginal spines, but tend to be corrugated.

Techniques (procedures) of crossing

i. The pole can be lowered be cutting the roots of the plant on one side.
ii. A flowering branch can be used as a female parent is selected in the bud stage and branches below and above it are cut off.
iii. The flowers to be used as female parent are emasculated when the anthers extrude from the bud a day before pollen is shed and 2-3 days before the stigma becomes receptive.
iv. Flowers to be used as a male parent are cut-off in the bud stage and kept in water until the pollen dehisces.
v. Pollen is collected from the male parent and applied to the receptive sticky stigma with a camel hairbrush early in the morning.

Artificial pollination results in a greater set of seeds than open pollination, but rarely more than 150 viable seeds are obtained per capsule.

3.3. Kenaf Production

Kenaf (*Hibiscus cannabinus*) is a species of *Hibiscus*, probably native to southern Asia, though its exact natural origin is unknown. Kenaf was first domesticated and used in northern Africa. India has produced and used kenaf for the last 200 years, while Russia started producing kenaf in 1902 and introduced the crop to China in 1935. The name also applies to the fiber obtained from this plant. Kenaf is one of the allied fibers of jute and shows similar characteristics. It is also called Deccan hemp and Java jute is a warm season annual fiber crop closely related to cotton (*Gossypium hirsutum* L.) and okra (*Abelmoschus esculentus* L.). Kenaf is an annual herbaceous plant usually grown for bark fiber. It is a cordage fiber crop and gives hard, long and coarse fiber. The fiber comes from the basal portion of the stem with the best quality fiber obtained at the time of 10% flowering.

3.3.1. Useful Products of Kenaf

a) The fiber is used to make twines, ropes, sacks, bags, fishing nets, etc. It used in manufacturing of products like; automobile dashboards, carpet padding, corrugated medium, as a "substitute for fiberglass and other synthetic fibers", textiles, and as fibers for injected, molded and extruded plastics.
b) Pulp can be used to make paper. Kenaf is an excellent cellulose fiber source for a large range of paper products (newsprint, bond paper, and corrugated linerboard).
c) Seed contains up to 20% semi-drying oil and is used for cooking, manufacturing soaps, lubricants, paints, varnishes and illumination.
d) Seed oil cake/oil meal: the residue left after extraction of oil is an excellent animal feed rich in protein.
e) Kenaf bast fibers are presently in commercial use in other environmental as soil mulches to prevent soil erosion. Kenaf core products used for toxic waste cleanup and the remediation of chemically contaminated soils.

Kenaf has a long history of cultivation for its fiber in India, Bangladesh, Thailand, parts of Africa, and to a small extent in southeast Europe. The stems produce two types of fiber, a coarser fiber in the outer layer (bast), and a finer fiber in the core. Grown for over 4000 years in Africa where its leaves are consumed in human and animal diets, the bast fiber is used for cordage, and the woody core of the stalks burned for fuel. This crop was not introduced into southern Europe until the early 1900s. Today, principal farming areas are throughout China, India, and in many other countries including the following: Mackay, Australia in trial stages; Seed farms- Texas, USA and Tamaulipas, Mexico; North Carolina, USA, Senegal to name a few.

The main uses of kenaf fiber have been the manufacture of rope, twine, coarse cloth (similar to that made from jute), and paper. In the United States, its production began during World War II to supply cordage material for the war effort. In California, Texas and Louisiana, 3,200 acres (13 km^2) of kenaf were grown in 1992, most of which was used for animal bedding and feed.

Kenaf seeds yield a vegetable oil that is edible and high in omega antioxidants. The kenaf oil is also used for cosmetics, industrial lubricants and as bio-fuel.

Kenaf has great potential for paper production and offers environmental advantages over paper from trees. In 1960, the USDA surveyed more than 500 plants and selected kenaf as the most promising source of "tree-free" newsprint. Various reports suggest that the energy requirements for producing pulp from kenaf are about 20 percent less than those for wood pulp, mostly due to the lower lignin content of kenaf. Many of the facilities that now process Southern pine for paper use can be converted to accommodate kenaf. Because the kenaf fibers are naturally whiter than tree pulp, less bleaching is required to create a brighter sheet of paper. Hydrogen peroxide, an environmentally safe bleaching agent that does not create dioxin has been used with much success in the bleaching of kenaf.

3.3.2. Origin, Taxonomy and Morphology

Origin and distribution

Kenaf occurs wild in tropical and sub-tropical Africa and has been grown in West Africa, Egypt and India since ancient times. Currently, kenaf is widely spread over the world and is grown through out the tropics. The leading kenaf producers are: Thailand, India, China and Brazil.

Taxonomy

Family: Bombaceae (Malvaceae); Genus: *Hibiscus*

Botanical name: *Hibiscus cannabinus* L. (2n =36)

Morphology

It is an annual or biennial herbaceous plant (rarely a short-lived perennial) growing to 1.5-3.5 m tall with a woody base. The stems are 1-2 cm diameter, often but not always branched. The leaves are 10-15 cm long, variable in shape, with leaves near the base of the stems being deeply lobed with 3-7 lobes, while leaves near the top of the stem are shallowly lobed or unlobed lanceolate. The flowers are 8-15 cm diameter, white, yellow, or purple; when white or yellow, the center is still dark purple. The fruit is a capsule 2 cm diameter, containing several seeds.

- Kenaf is a herbaceous, erect, annual dicot plant.
- Root system: has well developed tap root system
- Stem long unbranched, 2.5 to 4 m tall. The stalk's average composition is 40% bark and 60% woody core by weight. The bark of the kenaf stalk contains a long fiber called bast fiber, while the woody core contains short fiber called core fibers.

Leaves: are borne alternately on the long petioles. The leaves are palmately divided into 5-7 lobes.

Flowers: borne singly on axis of upper leaves and red or yellow in color. Some cultivars are entirely self-pollinated but up to 4% cross-pollination has been observed.

Fruits: a spherical, dark – brown capsule with an apical point. The capsule has five segments and contains 18-20 seeds. Under ordinary condition of storage, the seeds retain their viability for about 8 months.

3.3.3. Adaptation and Husbandry

Adaptation

Photoperiod: Kenaf cultivars differ in their sensitivity and response to day-length. Latitude (N and S of the equator) that determines the day-length for any particular time of the year. Selecting the optimum cultivar for the production location and the intended use of the crop is important. Kenaf cultivars categorized into three based on maturity: early, early to medium, and late-maturing.

Early maturing: These cultivars are grown at latitudes >37°N, like Russia and Korea that mature in 70–100 days. These cultivars have high seed yields, shorter plants with lower fiber yields. These cultivars are doesn't grown at lower latitudes, because they will flower even earlier, and therefore produce even shorter and lower yielding plants.

Early to medium maturing: Early to medium cultivars, are normally referred to as photosensitive (short-day). These photosensitive cultivars initiate flowering when the day length decreases to approximately 12.5 hours. It is advantageous to delay flowering in these cultivars, because the initiation of flowering causes a reduction in vegetative growth. These cultivars planted at the mid-September.

Late maturing: these cultivars are called photo-insensitive (day-neutral) are suited for the latitudes around the equator, 0° to 10° N or S. These cultivars may be responsive (semi-sensitive) to day length for flowering initiation. They initiate flowering as early as 100 days after planting and can be planted in May or early June. Earlier floral initiation and seed production decreases the rate of vegetative growth resulting in lower stalk and fiber yields compared to the photosensitive cultivars. Photo-insensitive cultivars may be ideally suited for use as forage or livestock feed crops. As a livestock feed, kenaf is usually harvested at an earlier growth stage than as a fiber crop.

Kenaf culture extends between 45°N –30°S. The optimum climatic conditions for its growth are temperature of 16-28°C and rainfall of 500 – 625 mm. Rainfall during their growing season of 4-5 months. Rainfall should be evenly distributed, *i.e.* at least 100 mm of rain per month during the growing season. Kenaf can also be grown successfully with irrigation. Kenaf is not very demanding in its soil requirements and is grown on a wide range of soils, but it thrives best on a well drained, rich, sandy loam with a pH of 6-6.8. Kenaf also has shown excellent tolerance to drought conditions.

Husbandry

Land preparation- as kenaf is a small seeded crop; a fine seedbed is needed for its rapid germination and emergence. The land should be thoroughly ploughed and all stubble from the previous crop should be removed or buried in the soil. All big clods should be broken down. Kenaf is considered a hardy plant that requires a minimum of fertilizers, pesticides and water in comparison to conventional row crops.

Sowing/planting

The best time to sow kenaf is early in the rainy season so that the crop may get the maximum time for its vegetative growth during the long day period. The seed can be either broadcasted or drilled in a row of 20-40 cm apart at a depth of about 1.25 cm and later on the plants are thinned out to a distance of 8-10 cm with in the row and 30 cm between rows. For seed production wider spacing is adopted. The seed rate varies from 15-25 kg/ha for fiber production, but 8-10 kg/ha seeds are required for seed production. Plant populations of 185,000 to 370,000 plants/ha are desirable for maximum yields and the production of single stalk plants with very little or no branching. The optimum plant populations will require about 8 kg/ha of seed (corrected to 100% germination). When plant populations is below the range, the stalk yields also decreases. At low plant populations the crop produces plants with multiple branches, rather than the more desirable single stalk plants.

Weeding: is necessary until the plants are about 20-30 cm in height, but soon after the plants form close canopy, they give little chance for weeds to grow.

3.3.4. Harvesting and Processing

Harvesting

Kenaf reaches maturity from 3-5 months. Harvesting should be done soon after flowering starts (10% flowering), the best time for harvest being when a few flowers (8-10/plant) are in bloom. At this stage, the fiber is at its best quality and easily separable. Delayed harvesting makes the fibers coarse and have poor luster. The leafy tops are cut-off and then bundles are brought to a water source for processing. Kenaf has consistently been hand-harvested for use as a cordage crop (rope, twine, and sack cloth).

Processing: One of the first processing decisions is whether the whole stalk, either as an unmodified stalk or as a chopped stalk, will be separated into its bast and core fiber components or left unseparated for use as a combined fiber source. For example, kenaf used in some paper products or processes can be pulped using a mixed fiber supply (unseparated bast and core), while certain processing applications involve separating the bast and core components. Several existing commercial kenaf facilities mechanically separate the two fiber components by different methods with distinct processing efficiencies.

Processing consists of soaking (retting), stripping, washing and drying of the fibers. **Retting** is the process by which bast (bark) fiber is extracted from the stem through dissolving of the soluble substances in water. Kenaf was retted by natural processes that use primarily aerobic (air loving) bacteria. The whole stalk kenaf (bark and core), or only the bark portions, are tied in bundles and placed in ponds, canals, or slow-moving streams to allow the bacteria to digest the plant material around the bark's fiber strands (bast fibers).

Procedure

- Water is prepared in ponds, pool, ditch and bundles of kenaf (30-40 plants) are kept in rows of different arrangements and the bundles are pressed so that to allow the water to over-flow. The depth of water is about 60-90 cm in order to soak the bundles.
- Time to retting varies from 10-30 days
- Microorganisms dissolve soluble substances such as pectin's, nitrogenous substances and hemi-cellulose. When retting is complete, the dissolved substance in the stem are beaten lightly to separate fibers and after beating, it is washed with clean water to remove the remnants and then dried on sun for 2-3 days or with fiber drying machine. After drying, the fiber is sorted into different grades and transported to factories.

Although the natural water-retting (bacterial) process is still used throughout many portions of the world, kenaf can be harvested for fiber when it is dead, due to a killing frost or herbicides, or when it is actively growing. Actively growing kenaf can be cut and then allowed to dry in the field. The dry standing kenaf can be cut and then chopped, baled, or transported as full-length stalks.

Ribboners and decorticators: Ribboning is the process of removing the bark from the core material. The same process is also referred to as decorticating, the removal of the core from the bark. The original objective of the ribboners/decorticators is to harvest the bark for its valuable bast fiber and discard the core material. Newer ribboners/decorticators have been developed for the kenaf industry. The advantages of these newer ribboner/decorticator harvesters over other types of kenaf harvesters:

- the ability to produce a cleaner separation between the bark and core.
- quicker drying of the separated components, and
- greater flexibility in determining the cutting length of the fiber strands.

Yield of kenaf: 1000-3000 kg dry fiber/ha and the average fiber out put is about 4% of the weight of the green stems.

Important diseases and pests

Diseases: Root knot nematode; Leaf spot, Dry Rot; Antracnose. Pests: stem borers

Kenaf production status in Ethiopia

It is a crop of recent introduction to Ethiopia and its cultivation is not yet adopted by the peasant sector. Only small-scale hectare was being cultivated in the state farms in western Ethiopia. Farmers in the north western part of the country especially in Metekel area where different wild forms of the crop is still abundant, have been using kenaf fiber for traditional materials like rope and different packaging materials.

- Some agronomic recommendations from Melka-Werer Research center

- Sowing date: Mid April to early May
- Spacing: 30 x 10 cm
- Fertilizer: No response to NPK
- Maturity: Early varieties take 80-100 days to mature while medium varieties take from 120-130 days to mature

CHAPTER 4. OIL CROPS

Crops, which are, cultivated primary for the oils they produce in their seeds or fruits. Such oils are called vegetable oils to differentiate them from animal and fossil oils. Fats and oils are similar chemically, but they differ physically. At room temperature, oils are liquids, whereas fats are solids and become fluid only when heated. However, temperature-based distinction between oils and fats is imprecise, since the temperatures of rooms vary, and typically any one substance has a melting range instead of a single melting point. Oils are mainly found in the mesocarp (fruit walls), endosperm, cotyledons and vacuoles. For instance, the fruit of oil palm contains oil in the mesocarp (palm oil) as well as in the endosperm (kernel oil). These oils have different chemical composition, uses and market values. Oil is lighter than water and does not dissolve in water. The energy value of oil is high. Therefore, a lot of energy goes into producing it and this is one of the reasons for lower yield of oil crops as compared to cereals and pulses. Vegetable fats and oils are substances derived from plants that are composed of triglycerides.

4.1. Classification and Uses of Oil Crops

Classification of Oil Crops

Oils are classified based on:

1. Drying property

1.1. Drying oils: Are oils, which readily absorb oxygen on the exposure to air and drying to form a thin elastic film (coating or covering). This property is due to their relatively high proportion of unsaturated fatty acids, *e.g.* oils from linseed/flax, noug, safflower

- Uses: drying oils are good for paints and varnishes, besides being used as food.

1.2. Semi-drying oils: Are oils, which react fairly rapidly on exposure to air and form only a soft film after a long exposure, *e.g.* oils from cotton, sesame, sunflower

- Mainly used on soap manufacturing besides being used as food

1.3. Non-drying oils: are oils, which do not react on exposure to air to form any sort of film, *e.g.* oils from castor, groundnut

- Castor oil is used as a lubricant

2. Based on their volatility

2.1. Fixed/non - volatile oils: are oils, which are, stable and do not volatilize at ordinary temperature (do not change to gas or vapors).

- Most vegetable oils belong to this group.
- Are food reserves and are commercially important

2.2. Volatile oils: are oils, which change into vapor under ordinary temperature.

- Do not serve as reserve for storage energy in food
- Important as perfumes but not as edible oils

4.2. Uses and Production of Oil Crops

General Uses of Oil crops

1. Sources of cooking and salad oil (uncooked oil) = 90% of the vegetable oils are used for this purpose.
2. Sources of raw materials for different industries including the manufacture of paints, varnishes, soaps, detergents, candles, insecticides, etc.
3. Source of oils used as lubricates, *e.g.* castor oil is used for jet engines and brake fluids
4. Some oil seeds have medicinal value, *e.g.* linseed is used to cure certain skin diseases and as laxative during constipation.

5. Oil processing by- products (seed or oil cake, meals) are good sources of proteineous animal feed.
6. Sources of foreign exchange, *e.g.* sesame, groundnut
7. Seeds are also good sources of protein, *e.g.* groundnut, soybean

Specific Uses of vegetable oil

Culinary uses

Many vegetable oils are consumed directly or used directly as ingredients in food - a role that they share with some animal fats, including butter and ghee.

Secondly, oils can be heated, and used to cook other foods. Oils that are suitable for this purpose must have a high flash point. Such oils include the major cooking oils - canola, sunflower, safflower, Groundnut, etc. Some oils, including rice bran oil, are particularly valued in Asian cultures for high temperature cooking, because of their unusually high flash point.

Hydrogenated oils: Vegetable fats and oils can be transformed through partial or complete hydrogenation into fats and oils of higher melting point. The hydrogenation process involves "sparging" the oil at high temperature and pressure with hydrogen in the presence of a catalyst, typically a powdered nickel compound. As each double bond in the triglyceride is broken, two hydrogen atoms form single bonds. The elimination of double bonds by adding hydrogen atoms is called saturation; as the degree of saturation increases, the oil progresses towards being fully hydrogenated. Oil may be hydrogenated to increase resistance to rancidity (oxidation) or to change its physical characteristics. As the degree of saturation increases, the oil's viscosity and melting point increase.
The use of hydrogenated oils in foods has never been completely satisfactory. Because the center arm of the triglyceride is shielded somewhat by the end triglycerides, most of the hydrogenation occurs on the end triglycerides. This makes the resulting fat more brittle. A margarine made from naturally more saturated tropical oils will be more plastic (more "spreadable") than margarine made from hydrogenated soy oil. In addition, partial hydrogenation results in the formation of trans fats, which have increasingly been viewed as unhealthy since the 1970s.

Industrial uses

Vegetable oils are used as an ingredient or component in many manufactured products. Many vegetable oils are used to make soaps, skin products, perfumes and other personal care and cosmetic products. Some oils are particularly suitable as drying agents and are used in making paints and other wood treatment products. Dammar oil (a mixture of linseed oil and dammar resin), for example, is used almost exclusively in treating the hulls of wooden boats.

Vegetable oils are increasingly being used in the electrical industry as insulators as vegetable oils are non-toxic to the environment, biodegradable if spilled and have high flash and fire points. However, vegetable oils have issues with chemical stability (there has to be a tradeoff with biodegradability), so they are generally used in systems where they are not exposed to oxygen and are more expensive than crude oil distillate. Vegetable oil is being used to produce biodegradable hydraulic fluid and lubricant. One limiting factor in industrial uses of vegetable oils is that all such oils eventually chemically decompose turning rancid.

Vegetable-based oils, like castor oil, have been used as medicine and as lubricants for a long time prior to the discovery of crude oil and its petroleum-based derivatives (mineral oils, etc.). Castor oil has over 1000 patented industrial applications and castor oil is non-toxic and quickly biodegrades; whereas, petroleum-based oils are potential health hazards, and take a very long time to biodegrade, thus can damage the environment when concentrated.

Fuel

Vegetable oils are also used to make biodiesel, which can be used like conventional diesel. Some vegetable oil blends are used in unmodified vehicles, but straight vegetable oil needs specially prepared vehicles, which have a method of heating the oil to reduce its viscosity. The vegetable oil economy is growing and the availability of biodiesel around the World is increasing.

Production

The following vegetable oils account for almost all-worldwide production, by volume. All are used as both cooking, salad oils and industrial purposes. According to the USDA, the total world consumption of major vegetable oils in 2000 was:

Oil source	World consumption (million tons)	Notes
Soybean	26.0	Accounts for about half of Worldwide edible oil production Produced as a byproduct of processing soy meal.
Palm	23.3	The most widely produced tropical oil. Also used to make biofuel
Rapeseed	13.1	One of the most widely used cooking oils. The majority of European rapeseed oil production is used to produce biodiesel, or used directly as fuel in diesel cars, which may require modification to heat the oil to reduce its higher viscosity.
Sunflower	8.6	A common cooking oil, also used to make biodiesel.
Groundnut	4.2	Mild-flavored cooking oil. A clear oil used for dressing salads and, due to its high smoke point, especially used for frying.
Cottonseed	3.6	A major food oil often used in industrial food processing. Used in manufacturing potato chips & other snack foods. Very low in trans fats.
Palm Kernel	2.7	Extracted from the seed of the African palm tree The most widely produced tropical oil. Also used to make biofuel.
Olive	2.5	Used in cooking, cosmetics, soaps and as a fuel for traditional oil lamps
Coconut		A cooking oil, high in saturated fat, particularly used in baking and cosmetics.
Corn		A common cooking oil with little odor or taste
Canola oil		Canola oil (a variety of rapeseed oil), one of the most widely used cooking oils, from a (trademarked) cultivar of rapeseed.
Safflower		Produced for export for over 50 years, first for use in paint industry, now mostly as a cooking oil.
Sesame		Cold pressed as light cooking oil, hot pressed for a darker and stronger flavor.

4.3. Important Oil Crops of the World

Field oil seed crops

Soybean (*Glycine max*)
Sunflower (*Helianthus annus*)

Groundnut (*Arachis hypogeae*)
Rapeseed *(Brassica spp).*
Sesame (*Sesamum indicum*)
Linseed (*Linum usitatissimum*)
Castor (*Ricinus communis*)
Safflower (*Carthamus tinctorius*)
Niger seed (*Guizotia abyssinica*)

Trees oil crops

Oil palm (*Elaeis guineensis*)
Coconut (*Cocos nucifera*) Olive (*Olea europaea*)
Cocoa

Vegetable oil is also obtained as a by product, from the seeds of cotton and maize.

Other significant triglyceride oils include:

- Corn oil, one of the most common and inexpensive cooking oils.
- Hazelnut and other nut oils
- Rice bran oil, from rice grains

Table: World Production of Major Vegetable Oils

Oil crops	Million tons	Oil content of the seed (%)	Oil Yield* (liter oil/ha)
Soybean	15.0	19	446
Palm	4.5	---	5950
Sunflower	4.0	46	952
Rapeseed	4.0	32-45	1190
Coconut	3.2	-----	2689
Cotton seed	3.2	16	325
Groundnut	3.2	44-50	1059
Olive	2.0	-----	1212
Linseed	1.0	37.43	478
Sesame	1.0	40-45	696
Castor	0.45	50	1413
Safflower	0.3	24-36	779
Niger seed	Trace	33-50	----

4.4. Oil Extraction (Processing)

Sometimes oil seeds are consumed without any prior oil extraction, *e.g.* safflower and groundnut are roasted and eaten. However, commercially oil is expressed from oil seeds by one or combination of 2-different methods

1. Mechanical/pressure extraction: Involves expression of oil by means of mechanical/hydraulic pressing of heated or unheated seed. That is oil is extracted by applying pressure and the resulting oil is refined to remove impurities. Common commercial method
It is made the "traditional" way using several different types of mechanical extraction. This method is typically used to produce the more traditional oils (e.g., olive), and it is preferred by most "health-food" customers in the USA and in Europe. Expeller-pressed extraction is one type, and there are two other types that are both oil presses: the screw press and the ram press. Oil seed presses are commonly used in developing countries, among people for whom other extraction methods would be prohibitively expensive. The amount of oil extracted using these methods varies widely.

2. **Solvent extraction**: Involves the extraction of oils from oil seeds by volatile chemical fat/oil solvents from which the oil is then separated by distillation at a temperature of 60-110^{0}C. The "modern" way of processing vegetable oil is by chemical extraction, using solvent extracts, which produces higher yields and is quicker and less expensive. The most common solvent is petroleum-derived hexane. This technique is used for most of the "newer" industrial oils such as soybean and corn oils.

- Relatively of recent development and is more efficient for pressing oil cakes and seeds of low oil content. Commonly used chemical solvents are hexane, heptane's, carbon disulphide, trichloroethyle.

In commercial method of processing, either of the above or combination of both methods are used

Oils may also be extracted from plants by dissolving parts of plants in water or another solvent and distilling the oil; or by infusing parts of plants in a base oil a process known as maceration. Oils extracted by these methods are known as essential oils. Essential oils often have different properties and uses than vegetable oils.

Local method, rendering or melting out

For local use throughout the tropics, oil seeds are crushed on a mortar and then boiled on water until the oil rises to the top and floats on the surface. From this the oil is skimmed off.
Crude oil, straight from the crushing operation, is not considered edible in the case of most oilseeds. The same is true for the remaining meal. For instance, animals fed raw soy meal will waste away, even though soy meal is high in protein. Researchers at Central Soya discovered that a trypsin inhibitor in soybeans could be deactivated by toasting the meal, and both licensed their invention, and sold soy meal augmented with vitamins and minerals as MasterMix, a product for farmers to mix with their own grain to produce a high quality feed.

The processing of soy oil is typical of that used with most vegetable oils. Crude soy oil is first mixed with caustic soda. Saponification turns free fatty acids into soap. The soap is removed with a centrifuge. Neutralized dry soap stock (NDSS) is typically used in animal feed, more to get rid of it than because it is particularly nourishing. The remaining oil is deodorized by heating under a near-perfect vacuum and sparged with water. The condensate is further processed to become vitamin E food supplement, while the oil can be sold to manufacturers and consumers at this point.

Some of the oil is further processed. By carefully filtering the oil at near-freezing temperatures, "winter oil" is produced. This oil is sold to manufacturers of salad dressings, so that the dressings do not turn cloudy when refrigerated.

The oil may be partially hydrogenated to produce various ingredient oils. Lightly hydrogenated oils have very similar physical characteristics to regular soy oil but are more resistant to becoming rancid.

Margarine oils need to be mostly solid at 32°C (90°F) so that the margarine does not melt in warm rooms, yet it needs to be completely liquid at 37°C (98°F), so that it doesn't leave a "lardy" taste in the mouth.

Another major use of soy oil is for fry oils. These oils require substantial hydrogenation to keep the polyunsaturates of soy oil from becoming rancid.

Hardening vegetable oil is done by raising a blend of vegetable oil and a catalyst in near vacuum to very high temperatures and introducing hydrogen. This causes the carbon atoms of the oil to break double bonds with other carbons, each carbon forming a new single bond with a hydrogen atom. Adding these hydrogen atoms to the oil makes it more solid, raises the smoke point, and makes the oil more stable.

Hydrogenated vegetable oils differ in two major ways from other oils, which are equally saturated. During hydrogenation, it is easier for hydrogen to meet the fatty acids on the end of the triglyceride, and less easy for them to come into contact with the center fatty acid. This makes the resulting fat more brittle than tropical oil; soy margarines are less "spreadable". The other difference is that trans fatty acids (often called trans-fat) are formed in the hydrogenation reactor and may amount to as much as 40 percent by weight of a partially hydrogenated oil. Trans acids are increasingly thought to be unhealthy.

Sparging

In the processing of edible oils, the oil is heated under vacuum to near the smoke point, and water is introduced at the bottom of the oil. The water immediately is converted to steam, which bubbles through the oil, carrying with it any chemicals, which are water-soluble. The steam sparging removes impurities that can impart unwanted flavors and odors to the oil.

4.5. Processing of Oil Seeds in Ethiopia

There were about 160-oil mills and one solvent extractant in the county in 1980s, out of these 148 were privately owned and 12 oil mills including solvent extractant were state owned. Cooking oil and oil cakes (used for livestock feed or fertilizer) are the major products of most of edible oil factories. Only one plant in the country had the processing capacity of salad oil, which involves both the mechanical pressing and solvent extractants.

Raw materials: The major oil-seed raw materials are: cotton seed, gomenzer (rapeseed), noug (niger seed), linseed, groundnut, sunflower, sesame, castor.

Steps in processing of oil crops

1. Seed preparation: includes cleaning, delinting, decortications and size reduction of seeds

- Delinting and decortication operations are specific to cottonseed, whereas seed cleaning and size reduction is common to all oil seeds.
- Seed cleaning is done by seed cleaners to remove foreign matter and dirt.

- Delinting - removal of adhering linter (fiber) from cotton seed is done by machines known as delinters.
- Decortication: following delinting decortication is done to remove the hulls that surround the kernel.
- Size reduction is done in oil seeds to obtain products capable of measuring specific size and surface requirements of presses for more efficient oil extraction. Size reduction is done using hammer grinders (low efficient) or milling rolls (high efficiency)

2. Cooking: Is done mainly to increase the oil extraction efficiency

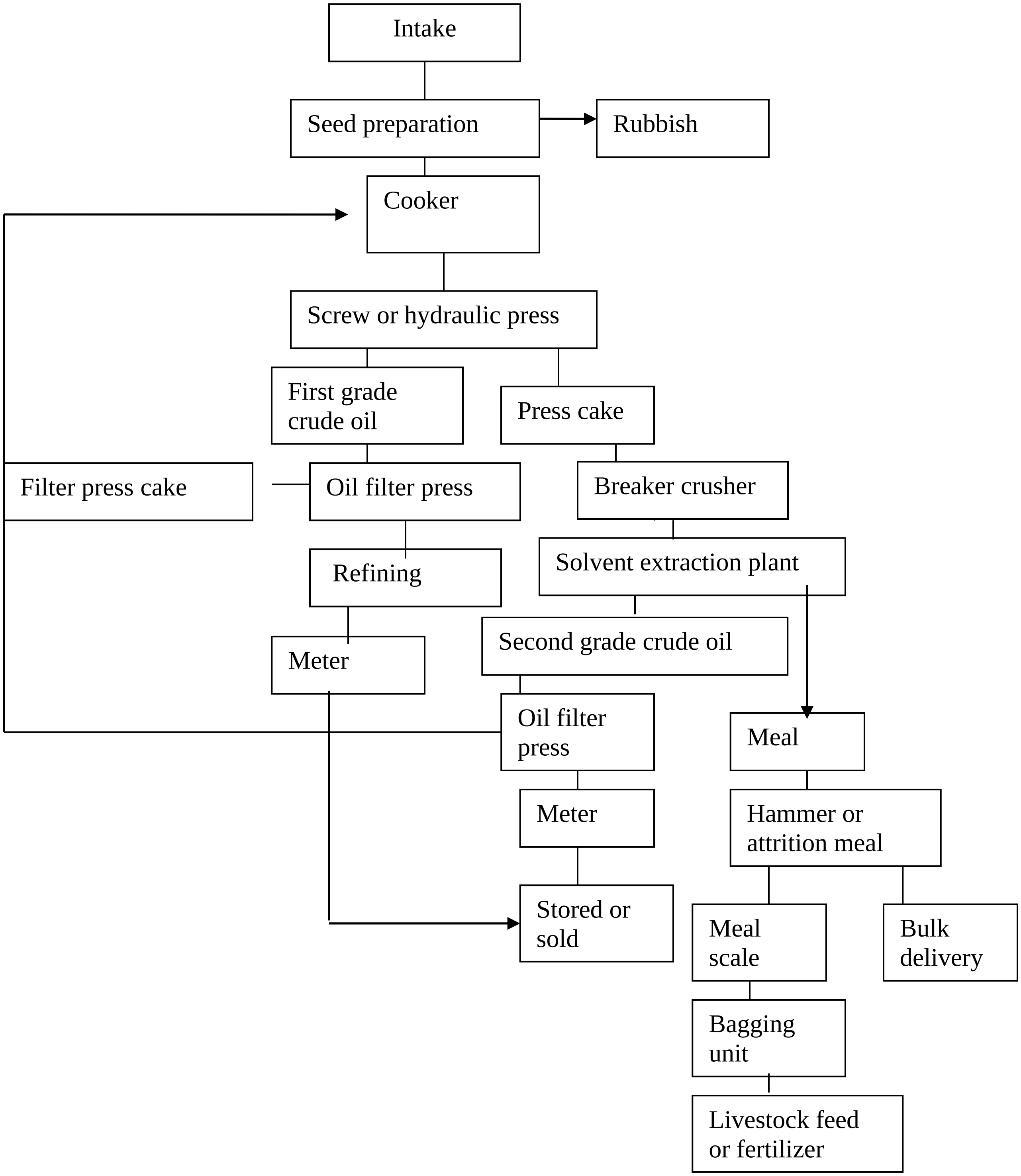
- If frees the oil for efficient extraction
- Generally, seeds with high protein content must be cooked to coagulate (change to thick or solid state) the protein in order to permit efficient oil extraction
- Cooking is done using cookers at 88-93 ^{0}C for 20 minutes.
- Other effects of cooking are:
    - Insolublizaiton of phosphatides and some other undesirable impurities so as to remove them efficiently.
    - Destruction of molds and bacteria.
    - Detoxification of gossypol (poisonous phenolic compound) in case of cotton seed

3. Oil – extraction: Oil mill screw presses are used to extract oil from oil seeds

- Depending on the type of the press, the seed material may be pressed once or twice.

4. Crude oil purification

- Involves a series of operations and this step has the greatest impact on yield and quality of the oil to be produced. There are 3-classes of impurities:
    - Solid suspended impurities (foots)
    - Colloidal impurities (gums)
    - Soluble undesirable components from the oil
- Separation of suspended solids (foots)
    - Screening tanks, centrifugal separators and filter presses are used to remove suspended solids
- Separation of colloidal impurities (gums)
    - Gums represent phosphatides, carbohydrates and protein fragments. These impurities are removed by hydrating and precipitating the gums, the process is known a degumming.
- Separation of oil soluble impurities
    - Soluble impurities include free fatty acids, pigments, flavors and odoriferous substances.
    - Free fatty acids, which are formed by lipoly break down of the oil itself, are removed by adding caustic soda (NaOH) solution in amount proportional to the free fatty acid content of the oil. A by - product is known as soap stock
    - Natural pigments (chlorophyll, cartenoids) are removed from the oil by adsorption cleaning using bleaching earths or adsorbents.
    - Components that cause undesirable odor and flavor to vegetable oil are removed by the process known as deodorization, which involves a highly specialized type of steam distillation. After deodorization the oil is cooled, optionally filtered and stored or sold.



. Flow chart of oil extraction with pre-pressing and solvent extraction

CHAPTER 5: STIMULANT CROPS

5.1. Tobacco

Tobacco is an important cash crop throughout the world. It has stimulating and slightly narcotic effects of smoking. Sniffing or chewing the dried, cured and fermented leaves of tobacco have led to almost universal use of tobacco.

5.1.1. Origin, Distribution and Types of Tobacco

Origin and distribution

It is native to tropical America, where it was used long before it was discovered by Europeans and is used as a psychoactive drug, narcotic, pain killer and pesticide. It was under cultivation in pre-Colombian times in West Indies, Central America, Mexico, Colombia, Venezuela and Brazil. The Portuguese and Spaniards spread the tobacco plant to other countries. Chinese claim to have used tobacco long before the discovery of America by Columbus in 1492. Commercial production of tobacco started in **Haiti** by Spaniards in **1580** and in **Trinidad** in 1595. Tobacco reached East Africa in **1560** by Portuguese-1st in **Malawi.** There are 4 species recognized in 1753 by Linnaeus. However, through research over 70 different species are recognized, almost all originating from South America with one endemic to Australia, another to Africa.

- There are several tobacco types which are grown, depending on their intended use.

-**Burley tobacco**: is produced in many other countries, with major production being produced in Brazil, Malawi and Argentina. The origin of Burley tobacco was Ohio, USA. Burley tobacco is a light air-cured tobacco used primarily for cigarette production.
-**Criollo tobacco** is primarily produced in the making of cigars. It was one of the original Cuban tobaccos that emerged around the time of Columbus.
-**Oriental tobacco**: is a sun-cured, highly aromatic, small-leafed tobacco. It is grown in Turkey, Greece, Bulgaria, Lebanon, and the Republic of Macedonia. It is frequently referred to as "Turkish tobacco." It is mainly used for blends of pipe and cigarette production.
-**Thuoc Lao**: is a nicotine-rich type of tobacco grown exclusively in Vietnam and is often smoked by Vietnamese rice farmers. It is most commonly smoked after a meal on a full stomach to aid in digestion.
-**Wild tobacco**: is native to the Southwestern United States, Mexico, and other parts of South America. It is scientifically known as *Nicotiana rustica* and is commonly used for tobacco dust or pesticides. *Nicotiana rustica* is the most potent strain of tobacco known.

In addition to the above tobacco types, other types are also under cultivation in parts of the world such as Virginia (brightleaf tobacco), Cavendish, Corojo (Cuba), Dokha (Iran/UAE), Ecuadorian Sumatra (the world's premium cigar wrapper leaf), Habano, Maduro (Spain), and etc.

China was reported to be the biggest producer and exporter of tobacco. It is said that China produced and exported 54% of tobacco, followed by Brazil with 13%, India with 7%, USA with 5% and lastly Zimbabwe and European Union each contributing 3%. Japan is the largest importer of tobacco products.

5.1.2. Tobacco Production History in Ethiopia

Ethiopia for long years ago is that there are several peoples in different part of the country that uses native tobacco in different forms, such as snuffing, chewing and pipe smoking (*Gaya*). Around the beginning of 20th century tobacco factory was emerged for the first time in Dire Dawa in 1931 (1923 E.C.). The factory was transferred to Addis Ababa which was owned by an Armenian investor.

Therefore, before 70 years, tobacco is grown for commercial purposes by state-owned farms and by farmers around these farms. The National Tobacco and Matches Corporation (NTMC), which is renamed as 'National Tobacco Enterprise (NTE)', has been given the mandate to organize tobacco production and processing in the country. It has been producing tobacco around Shewa Robit, Bilate, Wolaita and Awassa to supply its leaf processing plants and furnish the cigarette making factory in Addis Ababa.

The most common types even in our country, Ethiopia, are Virginia, Burley and Oriental. According to Country information brief, FAO report of June 1995, in Ethiopia, Virginia accounts for a little more than 74% of the total production, followed by Oriental 22%, and Burley 4%. The nicotine content of *Nicotiana tabacum* varieties grown commercially generally ranges from 0.3 - 3%, though 5% and even 7% have been recorded in some heavy bodied tobaccos.

5.1.3. Tobacco Utilization and Economic Importance

Tobacco is a controlled substance due to its habit-forming characteristics. It can be chewed, smoked or even snorted. The leaves are the essential parts, they are cured and processed to be used in the manufacturing of cigarette, pipe tobacco and the chewing tobacco. It has been smoked for centuries, starting with Native Americans and spreading into Europe and beyond.

Tobacco is consumed because of its stimulating and slightly narcotic effects and for aroma. The stimulating and narcotic properties are due to the presence of 1-3% of the ***ALKALOID NICOTINE*** in the processed leaf. Nicotine, having the formula $\mathbf{C_{10}H_{14}N_2}$.

Nicotine, in the pure stage is:

- colorless, rather mobile oily liquid, which soon darkens upon standing.
- Slightly heavier than water, with which it mixes in all proportions at ordinary temperatures
- soluble in most ordinary organic solvents.
- at cool temperature it has little odor but when slightly warmed its vapor become quite irritating.
- easily volatilized with steam and it boils at 247°C.
- strongly alkaline.

Nicotine occurs in all parts of the growing plant found in the leaves followed by the stalk and roots. However, nicotine is synthesized in the root and moved upward through the stalk to the leaves where it accumulates. Mature tobacco seeds contain no nicotine, but it promptly appears following germination and thereafter is present in all parts of the plant, including the seed in its early stages of ripening. Amount of nicotine in the leaf varies depending on species, cultivars and environments in which they are grown, the way they are cured, etc.

The smell and flavor of tobacco are due to the liberation of various essential oils and other aromatic substances during processing. Besides nicotine, tobacco contains numerous other compounds (solid, liquids and gases) that determine its flavor as well as being a hazard to health. Among these are resin phenols, pyridine compounds, etc.

Flavoring such as apple juice, menthol, spice or sugars may be added to the leaf when it is processed. The alkaloid nicotine is extracted from tobacco waste and was formerly much used as an insecticide. As a result of nicotine's lethality to insects it has been used as a pesticide in agriculture. It has also been used as a traditional medicine in treating insect bites and cuts. Furthermore, tobacco can also be turned into nicotine tartrate which can be used in medicine. Tobacco grown as cash crop that could be sold for money.

Forms of tobacco in trade and use

1. ***Chewed*** - common in our country where farmers use, they share the juice with their oxen.
2. ***Sniffed*** - inhalation of dust or powdered tobacco sometimes mixed with other herbs and perfumes: air and fire cured leaf is used
3. ***Smoked*** - widely used and include:
    - *Pipe* - A tube with a small bowl at one end in which tobacco is smoked: usually made from air-cured leaf.
    - *Cigar*: a tube-shaped roll of uncut tobacco leaves, usually tapered at one end used for smoking: usually made from blended fire and air-cured leaf.
    - *Cigarettes*: small cylinder of powdered tobacco rolled in thin paper usually made from air, flue, sun and fire cured leaf.
4. **Hookah (Hooka)** - called water pipe an oriental pipe with a long flexible tube by means of which the smoke is drawn through water so as to be cooled - used in India, Pakistan, Middle East Countries and also in our country.

Economic Importance

- It is the most widely grown commercial non-food plant. Tobacco is an economically important crop for many nations—more than 2 million tons of tobacco leaf, at a value of more than $6 billion, are exported each year worldwide.
- It has great contribution to the American and UK economy
- Today it is the 4th important crop in USA next to cotton, wheat and corn. Other countries, which depend a greater extent on tobacco are Greece, Turkey, Zimbabwe, etc.
- Its role in Ethiopian economy is also remarkably high. The industry is highly ruminative business.

In spite of consistent public condemnation and financial penalties tobacco consumption has been increased steadily. Smokers resist the condemnation due to:

- Some people consider smoking as a panacea (put away troubles, cure any illness) for a massive list of ailments.
- Medically it is considered to release tension.
- Partly due to its social implication-as a means of making social contact between and within the higher and lower class.

Today the health hazards of tobacco have become more evident than ever before. It is well known cause of cancer. However, its complete ban has not been possible anywhere in the world because of lobbying by multi-million-dollar cigarette companies and government interest for the revenue it brings.

5.1.4. Botany and Morphology of Tobacco Plant

Tobacco is a member of the largest family of plants mainly tropical in origin, known as **the solanaceae** or **potato family** and also called **Nightshade** family. It belongs to the genus *Nicotina*. The genus *Nicotina* contains about 50 species of which only two are cultivated. These are:

***Nicotiana tabaccum*:**

- widely grown commercially through out the world.
- taller than *Nicotina rustica*.

Nicotiana rustica:

- used to a limited extent for production of leaf tobacco.

- it has higher nicotine content and produced mainly for nicotinic acid for use in insecticide manufacturing.
- it is not so tall as ordinary tobacco and its stalk is smaller and less woody.
- *N. rustica* tobacco is more strictly an annual plant than is *N. tabaccum*.
- the leaves are very broad, thick, and heavy with rounded tips.

Description of the tobacco plant

Is a woody shrub-like, short-lived perennial but normally cultivated as an annual?

Root

The seedling plant has a single main taproot, but this is generally broken during transplanting and the field plant is anchored by nearly horizontal laterals and an extensive fibrous root system.

Stem

Young plants have rosette-like growth habit but later produces stout erect main axis about 1-5m tall. The stem is unbranched but after topping each axiliary bud grows out to produce a branch or sucker.

Leaves

The stem bear large simple ovate leaves arranged spirally. The leaves vary in size, thickness, texture, number, prominence of their veins, depending upon variation in cultivar. They are about 50cm long and sessile. The number varies from 20 -30.

Inflorescence

Inflorescence is terminal on the stalk and multi-flowered. The flowers are about 2-inch-long and most domestic varieties are **light pink** in color. The flower is borne on short stem and has a **five- cleft calyx**, from which emerges the slender corolla tube. The stamens are five in number. Flowers are mainly self-pollinated (with 4% out crossing).

5.1.5. Chemical Constituents of Tobacco

The morphological structure, and the chemical composition of the leaf is known to determine the properties of the leaf and all have important bearing on its quality. Qualitatively, the tobacco leaf does not differ greatly from the leaf of other comparable plants except for its nicotine and closely related alkaloids, however, quantitatively there is variation among commercial types of tobacco in composition.

The most important chemical constituents are:

1. Carbohydrates: The various forms of carbohydrates found in mature leaf, collectively constitute from 25 to 50% of the dry matter. The proportions of the several forms vary ideally in the different types of tobacco. Generally total CH_20 is high in cigarette tobaccos and low in cigar types.

The three principal groups of carbohydrates are:

- **i.** **Reserve carbohydrate**: involved directly in the nutrition and metabolic processes of the cell protoplasm. These include **starch, dextrin, maltose, glucose** and **fructose.**
- ii. **The hemicellulose**: which enter largely into the makeup of the cell wall but upon mild hydrolysis they can yield sugars, which may also function in cell nutrition. Of the two chief groups are **pectins** and **pentosans.**
- iii. **The highly condensed stable forms of cellulose and lignin:** which along with the hemicellulose furnish the framework of the leaf but ordinarily play no part in nutrition

2. Nitrogenous compounds: There is wide variation both in total nitrogen and its distribution between the various forms present in tobacco. In the green leaf the largest component is the **protein fraction** and **nicotine nitrogen** are the second important especially in the later stage of leaf development. In the cured leaf the decomposition products of protein increase and may even exceed the residual protein content

Aspargine and glutamine have been found in the leaf. Nicotine having the formula $C_{10}H_{14}N_2$ the most characteristic constituents of tobacco.

3. Organic Acids: Nonvolatile polybasic acids such as **malic, citric** and **oxalic acids** constitute an important fraction. The metabolism of organic acid is common. In addition, the complex aromatic compound **chlorogenic acid** and its two components **quinic** and **formic acid** occur in leaf

4. Polyphenols: The tannin like substances designated as **polyphenols** occur in the leaf in important quantities. Known to affect the color and other properties of the cured product and play an essential role in the oxidation/reduction process of the growing plant.

5. Ethereal Oils and **Resins:** The ethereal oils and resins occur in the glandular hair of the leaf and the sticky gum, which collects on the hands of workmen handling the green leaves.

6. Enzymes: Experimental evidence has proved the presence of protease, lipase, emulsion amylase, invertase, phosphatase, glycolase, pectase, etc.

7. Mineral constituents: Tobacco leaf has a high content of ash usually ranging from 12 to 25 per cent. The quantity and composition of mineral components affect growth and development of the plant, the combustibility and other elements of quality in the leaf. The content of ash in mature leaf is much higher than that of the stem and root. The ratio of distribution between these parts approximating **12:7:5**. In passing from the lowest to the top most leaf there is a progressive increase in the content of total Nitrogen (including Nicotine) and a decrease in total ash, calcium, magnesium, and pH of the cured leaf.

8. Pigments: During early phase of curing green pigments (chlorophyll a and b) are destroyed by oxidation and xanthophyll and carotene become evident.

5.1.6. Tobacco Ecological Requirements

The requirement varies with the type of tobacco produced.

Temperature: Tobacco is tropical in origin, but it is grown successfully under tropical, subtropical and temperate climates. Normally, it requires about 100-120 days, frost-free climate with an average T° of 20-30°C b/n transplanting & harvesting. In general, the tobacco plant is remarkably sensitive to the environment. Ideal conditions required for successful production of high-quality leaves are long day lengths, and mean temperature of 26°C during the growing season and lastly, a relatively high humidity of 70-80%.

Rain fall: It requires an annual rainfall distribution of between 500-1250 mm. However, excess water may result in the plant becoming thin and flaky. Therefore, tobacco should be ripening without heavy rainfall. Ideal conditions required for successful production of high-quality leaves are liberal and well-distributed rainfall during active vegetative growth stage.

Soil requirements: It can be grown in almost every type of soil. However, best soils for tobacco production are deep, well-drained loamy soils with little or no risk of flooding. Despite tobacco being somewhat tolerant to drought, optimum production is achieved from soils with high water-supply capacity. Because of sensitivity to wet soils, tobacco should not be grown in fields that pond or flood in heavy rains. The optimum soil pH for tobacco production is about 5 to 6.5.

5.1.7. Production of Seedlings

Tobacco seeds are very minute in size and germinating seeds are very delicate. Hence, they have to be raised with great care. The ideal seedling for transplanting is 15 cm in length from bud to root crown with a stem of pencil thickness. It is well hardened, free from disease and has produced no more than 8-10 leaves below the bud at the time of transplanting. An adequate and uniform supply of such seedlings is essential to the production of high-yielding, and quality crops.

1. Choice of Site

Site should be chosen carefully to allow easy supervision. Good supervision of poor site will give better result than a badly managed first- class site. Amount of area is determined based on the amount of seedlings needed for transplanting. For example, flue cured tobacco 1400-1700 seedlings are required to plant a hectare of land. To obtain this population 25-30 thousand of seedlings should be raised, which can be raised on a nursery area of $67m^{2}$ plus equal area for path way and border.

While selecting a nursery site the following points should be considered:

i. Seedbeds should, as far as possible, be located at a warm site. A windbreak on the windward and uphill sides of the site and cleared ground on the downhill side will markedly improve the temperature of the site and minimise the incidence of ground frosts.
ii. A wide range of soil types is acceptable, but the most suitable soils are fertile, well-drained, loamy sands and light sandy loam.
iii. The site must possess good drainage, both surface and internal, must be near an adequate and reliable water supply and should be easily accessible to facilitate supervision.
iv. The site should be away from grading and curing facilities to avoid contamination by tobacco trash.
v. The site should be adequately fenced to prevent entry by animals and unauthorised persons. Only one point of entry at which washing facilities (soap and running water) are available
vi. The site should be permanent with adequate storage space for equipment.
vii. It should be rotated with one or more years of a nematode resistant grass sown immediately after beds have been finally pulled.

2. Preparation

The site should be ploughed deeply, as early as possible (while the soil is still moist), so that maximum decomposition of plant residues can take place. Under very dry conditions the site should be watered to facilitate decomposition.

3. Making up beds

Beds can be any size. However, consideration should be given to ease of access and ease of watering, spraying, pulling, etc. A width of 1 to 1.4 meters has proved to be convenient in most circumstances. Beds should run up and down the slop to facilitate cold air drainage.

The actual method of making up the beds is as follows:

- each path is dug to a depth of 30 cm and the soil thrown on what will be the eventual seedbed.
- the beds are roughly levelled with spade and all partly decomposed organic matter and soil clods removed.
- Rakes are used for the final smoothing and shaping of the seedbed.
- The soil should have a fine tilth and the bed surface should be very slightly convex.
- Sterilization and fumigation of nursery beds are common practice in most tobacco farms. The aims are to control weeds by killing their seeds and destroy nematode and other disease organisms.

Steaming: very effective means of sterilization but it is very expensive, time consuming and troublesome.

Mthylbromide: is very efficient. The gas is applied to individual bed under gas tight (plastic) sheet.

- For effective treatment the soil must be wet. Too dry soil doesn't retain the vapour and too much moisture prevents the penetration of gas.

Solarization: new and cheap technique.

4. Fertilization

Seedbed is expected to produce a substantial number of seedlings rapidly. To achieve this, some fertilizer must be applied. A fertilizer mixture of 6:18:6 (NPK) can be used at a rate of 0.45 kg for 3 m^2 area. Fertilizer should be carefully broadcasted over the surface of the bed and lightly raked into the top 5 cm of soil. Seedbeds should be watered immediately after any top dressing to wash the material of the leaves and prevent burning. Nitrogen application should be avoided within 2 weeks of the plants being pulled, as it might make them too soft to withstand the rigour of transplanting.

5. Seeding

Seeds of tobacco are long-lived and will remain viable for 20 years or more when stored under good conditions. For seeding:

- Certified seed should always be used.
- Before sowing seeds should be well cleaned and treated with mercury chloride and silver nitrate solutions to control **angular leaf spot** and **wildfire diseases**.
- Seeds with 90 to 95 per cent germination considered as high-quality seed.
- Seed rates are often high (dense population) to force early stem elongation. But excessively high density may result in seedlings with thinner stems and weaker plants. The recommended seeding rate is **28** grams for **335** to **420 m^2**. The ideal plant population is **45-50** seedlings per **30 x 30 cm** square.
- The seed is invariably broadcasted.
- The small size of the seeds makes it very difficult to sow the uniformly. To facilitate uniform seeding/sowing an inert material is mixed with the seed. Ash, sand or any other similar material is used.
- After seeding, the beds are very lightly raked and or a thin layer of sand is scattered over the seeds to bring them into close contact with the soil.

6. Mulching

Mulching is required to protect germinating seeds and seedlings from adverse environmental conditions such as cold, wind, sunburn, moisture loss, etc. Moisture loss from the surface of seedbeds must be kept to a minimum in the weeks immediately after sowing and very young seedlings must be protected from scorch. A fine non-leafy grass is recommended. The grass pieces should be spread evenly on the surface of the beds immediately after sowing. Later weeding and thinning should then be practised. The sides of beds and pathways should also be mulched to prevent the soil drying. Thinning thick patches of tobacco seedlings is also desirable as soon as the plants are big enough to grasp.

7. Watering

Correct watering is probably the most difficult aspect of seedbed management. Incorrect watering seriously decreases rate of growth and can affect uniformity of seedlings. The amount of water applied to the beds should equal the amount lost from them by **evaporation** and **transpiration**. It is true that the beds will lose more water on **hot, windy days.** They will also lose more water when the seedling leaves cover the soil than at an earlier stage of growth. Therefore, the amount of water applied must be varied according to these conditions. It is essential to keep the surface of the bed moist from the time of sowing until seedlings have their roots well down. The first **10 days** are very critical, and the seedbed must be watered carefully. Germination begins **5-7 days** and the frequency will depend on soil type and conditions.

8. Hardening

When the seedlings are 1-2 cm short of transplanting size, watering should be stopped completely and only started again when the seedlings wilt markedly before 10 o'clock in the morning. The process of hardening is then repeated until the day before transplanting. It is normal for burley seedlings to become distinctly yellow during hardening and top dressing should not be applied.

9. Clipping

When seedlings grow unevenly, the largest can be held back by clipping the leaves just above the bud. This will slow growth of larger seedlings and give smaller plants a chance to catch up, thereby improving uniformity. Clipping should be done as soon as definite unevenness is noticed in the beds, and should be done as early as possible, starting when the larger seedlings come through the mulch. Clipping shears should be frequently washed with soap and running water and then rinsed thoroughly to avoid the spread of mosaic and other diseases.

10. Pulling and Transplanting

Transplanting is done 40 to 60 days after sowing. Height is a convenient base for judging when seedling is ready for transplanting. Normally height should be 10-15 cm from the root crown to the bud. The beds should be well watered in the afternoon and again the following morning immediately before pulling. The plants should be pulled individually and the ball of earth surrounding the roots should be disturbed as little as possible. Only sufficient plants for the day's use should be pulled at one time and they should be kept in the shade before being set in the field to avoid unnecessary water loss.

After pulling, the bed should be watered to settle the soil and help the growth of the remaining seedlings, which may be needed later. Transplanting should be done in the afternoon and there should be enough moisture in the soil for successful establishment. Planting is done on ridges. Where well-grown crops are expected ridge spacing should be within the range of 100 - 120 cm. The acceptable spacing is 54-60 cm. Very closer spacing will reduce the size of plants and individual leaves. In most condition the plants should be at least 60 cm apart and distance between the rows should be 90 cm from each other. The tobacco produced will be thinner, pale, light bodied, and have lower nicotine content than where wider spacing is used. With well grown tobacco, plant population of 14500 plants/ha will give good yields and quality.

11. Fertilization after transplanting

Plants grow by absorbing water and mineral elements from the soil and CO_2 through leaves. A number of individual mineral items are necessary to the extent that growth and development will only occur so long as all are adequately available and will be modified or stop if any one of them becomes short supply.

Macro nutrients/major elements: required in large quantity. These are **N, P, K, Ca, S,** and **Mg.**
Micronutrients/minor element: required in small amount but absence can cause death or very poor performance of the crop. These are: **Fe, B, Mn, Cu, Zn, Cl, Mo, Al.**

1. Nitrogen

- Choice of soil depends much on the nitrogen content and its pattern of release.
- Nitrogen is a constituent of the compound which gives its strength **NICOTINE**
- Too much N in leaves lead to an excessive protein content, which is detrimental to combustibility. The leaves will also have undesirable dark green color.

Deficient plants:

- tend to grow upright with leaves developing an acute angle to the stem,
- stems thin and
- maturity delayed

- leaves harvested from such crops **cure out pale** and cured leaf will be dark from thin to trashy lacking texture and of poor smoking quality

Source of Nitrogen

- Animal manure: Limited supply
- Mineral source: Ammonium nitrate, urea

Recommended rate varies from 200-300 kg N/ha for the different types of tobacco depending of the soil type. **Awassa** (urea 235 kg/ha)

2. Phosphorus: Has great importance in tobacco nutrition and usually applied in greater quantity. The most important obvious function of phosphorus is the promotion of ripening and this is linked with increasing carbohydrate content.

Deficiency gives dark green stunted growth of short and pointed leaves which tend to lie nearly horizontal gives an open flat staring appearance and very delayed maturity. Cured leaves lack luster and the lower leaves on the plant may have numerous brown spots.

Recommended rate: 90 -130 kg of P_2O_5/ha: **Awassa** (261 kg DAP/ha)

3. Potassium: Potassium is absorbed and needed in large amounts

Deficiency: Severe deficiency is shown by stunted growth and chlorosis, which spreads inwards from the tip.

Potash can be important through increasing effect of tolerance of some leaf-spot diseases and improving drought resistance. The most and very noticeable effect is its influence on burning or (combustibility) capacity. Tobacco leaf from which potassium has been leached will not burn. Potassium and calcium are normally the largest constituents of ash. They both affect burning capacity. They are found in 1:1 proportion in the leaf.

Recommended rate: **100 - 300 kg** K_2O/ha. Most Ethiopian soils are believed to be rich in K as the parent material of the soil (granite) is rich in K. Thus, it is not applied.

5.1.8. Cultural Practices

A. Ridging

Tobacco performs best if planted on ridges (soil drawn up around the base of the stem during cultivation)

Advantages of ridge planting are:

- Promotes good surface drainage
- It improves root aeration because of the greater surface area of the ridge.
- Ensuring a good depth of loose, broken soil in which the seedling is planted.
- It simplifies fertilizer placement/banding
- It simplifies hand planting
- Increases root area by stimulating development of root growth from the base of the plant.
- It is very effective method of weed control
- It gives support to the plant, which is very useful in storms and high winds.
- It facilitates flood/furrow irrigation.

Disadvantages

- Increases cost of production due to the expense of making the ridge
- Encourages erosion when badly laid out
- In dry spell the root area dries out more severely than in flat land.

B. Weed control

If weeds are growing actively when the crop begin its period of major growth and expansion, then yields as well as quality of the product can be seriously reduced. Weeds may be removed by hand or by a combination of hand, herbicide and mechanical methods. The important point is that they must be removed as early as possible. If labor is not available for early cultivation, then the use of herbicides should be considered.

Herbicides

1. Nitralin (Rlanavin): pre-emergence herbicide effective against Rapoko grass (*Eleusine indica*), other annual grasses and some broad leaf weeds but will not control already emerged perennial weeds like yellow nut seeds (*Cyperus esculentus*). It should be applied on to the land after ridging but before planting holes are dug.

2. Pebulate (Tillatox): Pre-emergence herbicide effective against the same spectrum as Nitralin but in addition it controls yellow nutsedge.

C. Topping and Suckering

Topping and suckering are very important in controlling crop yield and grade composition. Failure to top and sucker will result in low yields of inferior quality tobacco.

Topping

It is an operation, which improves the yield and quality of tobacco. When the flower buds are formed the inflorescence and the topmost leaves are broken off by hand. It consists of breakage of the top or crown of the plant at about the 3rd branch below the flower head.

- topping increases the mass and size of the leaf and alters its chemical composition.
- topping keeps them from producing seed, which forces the synthesized CH_2O and nitrogen material to remain in the leaves for further growth and enrichment.
- topping results in larger, thicker and darker leaves that mature early in more uniformly than do those on untopped plants

Young leaves respond more to topping than old leaves and therefore the earlier plants are topped the more leaves are affected. Early topping when the flower bud is clear the upper leaves (extended bud stage) will allow maximum expansion and development of leaves. Topping should start when 10% of plants are in flower, *i.e.* showing a pink color.

Suckering

The extent to which topping affects the crop depends on how effectively subsequent sucker growth is controlled. Complete control of suckers is necessary if the full benefits of early topping are to be obtained. Soon after topping suckers can be produced due to the growth of axillary buds. Suckers can be controlled more easily and far more effectively by using a chemical control agent than by hand methods. The material recommended for this purpose is **SUCKER CONTROL AGENT 504**. This is a contact material that works by burning meristematic tissue in the leaf axils from which suckers would develop. It is essential therefore, that some materials reach every leaf axil on the plant. Very small suckers (2-3 cm) will be killed but larger suckers will not be controlled and must be removed by hand.

Ideally each plant should be treated immediately after topping in the extended bud stage. The suckercide should then be sprayed or poured over the top of the stem so that it runs down the stem contacting each leaf axil on the way. The commercial product should be mixed with water in the proportion of 1 PART commercial product to 25 PARTS of water.

Precautions when using sucker control agent 504

i. It should not be applied when plants are wet from rain or dew. If applied under such conditions, the control period is likely to be less than two weeks.
ii. If rain falls with in two hours of application the control period will also be seriously reduced and the chemical treatment should be repeated.
iii. The material should not be sprayed on plants that are wilting badly.
iv. It is almost inevitable that the material will not reach every single leaf axil consequently some suckers will grow, and these must be removed by hand.

5.1.9. Pests in Tobacco Production

1. Diseases

The list is numerous, among these the principal one's worth mentioning include:

A. Damping off: caused by ***phytium* spp**. principally affecting on the seed bed (all stage of growth)
Symptom: the fungus attacks the stem, at the ground level, which is girdled, by a ring of dead brown tissue. The plants topple over, and the leaves then rot into a shapeless, slimy mass. It spreads under conditions of high humidity caused by over watering, lack of ventilation, too dense seedling population and too dense shade.

Control:

- Proper seed bed management
- Dusting with copper-based fungicide.

B. Anthracnose: Caused by ***Colletotrichum* spp.**
Symptoms: The initial infection appears as pale, water-soaked spots on the seedling leaves closest to the soil. The spots are slightly depressed with the center turning pale brown or gray surrounded by water-soaked halo. The spot remain small forming white areas on the surface and black necrotic lesion on the underside of the leaves. Leaves eventually become wrinkled and distorted.

Control:

- soil fumigation with methyl bromide
- using dithiocarbamate dusts or spray such as Zineb, Thiamin and ferbam
- seed treatment with silver nitrate
- use seeds from clean source

C. Wildfire (Black fire) and angular leaf spot

The causal organisms are ***Pseudomonas tabaci*** for wildfire and ***Pseudomonas angulata*** for angular leaf spot. The two species cause similar disease. The only detectable differences are that ***Pseudomonas tabaci*** produces chlorophyll distracting toxin and ***Pseudomonas angulata*** does not**.**

Symptoms:

Wildfire: The disease is characterized by a markedly yellow halo surrounding a deeper yellow spot. Under wet conditions suitable for an epidemic the necrotic areas enlarge rapidly, and the yellow surrounding may be completely absent.

Angular leaf spot: The spots are much darker than wildfire and without the halo, are limited by the small veins and have angular appearance. In serious attacks the veins also rot and become dark.

Both diseases are spread by heavy rain and general dampness and soft rain are also important. A dry period seems to check wildfire completely, but angular leaf spot will continue to spread at a much-reduced rate. Infection can be transmitted by seed & soil (more important)

Control

- General hygiene: destruction of old debris (inoculum)
- Crop rotation: but needs careful choice of hosts (vegetables & groundnut should not be included)
- Fumigation of seed bed with methyl bromide to decrease infection of seedlings
- Copper based sprays/dusts effective to control (3-7 days interval) is needed.

D. **Frog Eye** caused by ***Cercospora nicotianae***

Symptoms: Small light brown lesions with white like centers from which the name is derived. Reported from most tobacco growing countries and serious under wet condition, a combination of frequent rain and warm temperatures can cause rapid spread.

Control:

- hygiene & destruction of old trash
- once the disease appeared it can be controlled by routine copper based sprays
- dipping seedlings in copper fungicides before transplanting
- use resistant varieties

E. Brown Spot- Caused by ***Alternaria alternata***

Symptoms:

The presence of circular, dark brown, with a definitely zonate necrotic center, usually an outer yellow halo and all surrounded by a pre-halo area. The yellowing is attributed to a chlorophyll destroying toxin. Serious under warm & humid environments.

Control

- Hygiene is the first & most management measure control
- Can be controlled by the copper fungicides
- Seed may carry infection & disinfection with silver nitrate
- Resistant varieties
- Seed bed fumigation with methyl bromide
- Biological control: application of non-pathogenic ***Alternaria*** isolates to the leaves.

F. Tobacco mosaic virus (TMV)

Tobacco is very susceptible to TMV though it also affects closely related crops.

Symptom:

The classical symptom is the mottled leaf appearance. Dark green blistering on the upper side, neurotic spots and mosaic scorch around veins are some of the symptoms. Varied symptoms are observed due to the difference in TMV strains, their interaction and environmental influences on the host.

Control

- Hygiene (simple but tedious)
- Complete destruction of old debris
- Forbidding of tobacco usage (smoking, chewing, sniff) in the field/nursery (mechanically transmitted)
- Hand washing with soap/milk
- Rouge out any odd infected plant in the field (continuous supervision)
- Proper rotation
- Use of resistant cultivars

2. Parasitic Plants

These groups of plants are unable to synthesize or to absorb materials necessary for their own growth. The plants will be partially or completely dependent on the host plant. This dependency results in stunting, due to inability to support adequately both its own growth and the parasite.

Example: Broomrape- ***Orobanche* spp** and Tobacco witchweed - ***Striga generoides***

3. Insects

Diseases cause much greater financial loss than the insects do. Insects damages the roots, destroy the leaves and buds, reduce leaf quality, and transmit several important tobacco diseases.

A. Tobacco budworms (*Heliothis virescens*)

Control: Foliar sprays for budworm control with 1 or three solid-cone or hollow-cone nozzles can be used.

B. Tobacco hornworms (*Manduca sexta*)

Control: Early topping, early transplanting, effective sucker control, and fertilization. On a large space, stalk cutting and root destruction immediately after harvest reduce overwintering hornworm populations.

C. Aphids

Control: Remedial applications of a foliar insecticide at the economic threshold level before populations become too high should be applied.

D. Tobacco flea beetle (*Epitrix hiritipennis*)

Control: An insecticide should be applied when the base of the lower leaves has a netted appearance or densities exceed 60 beetles per plant.

E. Tobacco splitworm

F. Nematodes

Control: Rotation is effective for both root-knot species and again should provide the basis for management of nematodes.

5.1.10. Harvesting/Reaping and Post-harvest Handling

The leaves of tobacco are ripe and ready to harvest when they turn a lighter shade to green and have thickened. Fire cured types are harvested when they are fully ripe when the leaves showing light yellow patches or flecks.

Generally, there are two methods of harvesting:

A. Priming: is the picking of individual leaf when they are fully ripe starting (beginning) with the lower three or four leaves of commercial size followed by 4-5 successive pickings of 2-4 leaves each at interval of about 5-10 days. Leaf is ready for priming when it is **yellow - cream color** with tinges of green along the veins. The successive harvesting of the lower leaves causes gains in weight of the remaining upper leaves. The weight gain together with the avoidance of translocation of materials from the leaf to the stalk during curing results in primed leaves that weigh 20 -25% more than the leaves on cut stalks. To avoid breakage of leaves do not prime early in the morning or soon after rain, when they are brittle. After priming, leaves are placed in baskets, bins, sacks, etc and conveyed to curing barns.

B. Stalk cutting: the stalks are cut off near the base and left on the ground until leaves are wilted. Stalk cutting is done when the middle leaves are ripe. The stalks are then hung upon a lath holding 6-8 stalks. The stalk may be spitted to hasten drying. In East and central Africa including Ethiopia flue-cured, air cured, and fire cured tobacco are all harvested by cutting individual leaves. The lowest leaves ripen 80-100 days after planting. During transporting primed or stalk-cut leaves care should be taken to avoid **bruising** which can be caused by folding the green leaf surface disrupts the tissue to the extent of inhibiting yellowing and reducing sugar content- bruising of leaf must be avoided.

Post-harvest handling

Curing

Tobacco curing is also known as color curing because when tobacco leaves are cured, the intention is to change their color and reduce their chlorophyll content. Curing of tobacco is not a simple drying process but involves a series of physical and chemical changes that begins when the plant is cut and ends when the plant is dry. The major steps in the curing process include wilting, yellowing, browning and fixing the color, and drying.

- Curing is one of slow starvation process and it involves:

- Process of slow drying
- Decomposition of chlorophyll until green color disappears from the leaf and changes in the nitrogen compounds including release of ammonia.
- Hydrolysis of starch into sugars and respiration or fermentation of sugars
- Mineral salts also crystallized out

Particularly in the case of air-cured tobacco all the sugars are used up but in flue and fire cured tobacco considerable quantity of sugars remain. Loss of nicotine during curing range from 10 -33%
Too rapid drying kills the tissue pre-maturely. This in turn prevents the decomposition of chlorophyll, which results in undesirable green color. It also stops some of the other desirable reactions. During curing there is a decrease in total weight of up to 88%, which includes loss of dry matter of 12 to 20%.

Tobacco barns: The tobacco barns (or kiln) are used for curing and usually are high enough to hold 3-5 tiers of suspended leaves or stalks.

A. Methods of curing

Curing methods vary with the type of tobacco grown, and tobacco barn design varies accordingly. Depending on the method of harvesting, the maturity of leaves at the time of harvesting as well as the type of end product required, there are four principal methods of curing.

1. Air Curing

This is a natural process and curing under normal atmospheric conditions is done on wood or grass. Air curing, being a larger process, keeps the leaf alive until the initial sugar content has been oxidized away. The leaf should be yellow before it dries out after which the process of drying is gradually increased by increasing the ventilation. The curing is done in huge, tight barns sometimes up to 100m long equipped with numerous ventilating doors that can be opened or closed to regulate the humidity and temperature. The Relative Humidity (RH) at the beginning should be about 85% but after the leaves begin to turn brown a lower humidity that permits rapid drying is advisable. A condition called pole sweat or house burn occurs when the humidity exceeds 90% for 24-48 hr. with the temperature above 15°C. This condition causes injured, partly cured and even fully cured leaves to begin to soften and decay.

This damage is prevented by the use of artificial heat to lower the RH and promote drying. Artificial heat is also required when temperature drops below 10^{o}C so that curing process often than drying may continue, source of heat can be gas or coal. Air-cured tobacco is hung in well-ventilated barns and allowed to dry over a period of 4-8 weeks. Air cured tobacco is low in sugar, which gives the tobacco smoke a light, sweet flavor, and high nicotine content. Cigar and burley tobaccos are air cured.

2. Flue Curing

This process concerns the major part of the world's tobacco production. The objective in this method is to hasten the early curing stages so that drying will be completed while the leaves are still a light-yellow color. All starch are convert to sugar but not reduced further. Flue cured or bright tobacco is riper and of a lighter green than other types when curing begins. When drying is too rapid, the humidity in the barn can be increased wetting the floor and the walls, and when the humidity is too high the roof ventilators are opened.

For flue-curing, a large sheet iron pipe connected to top of the furnace usually extended to the far site of the barn, along it for a short distance, and then turned back and out through the wall on the furnace side. Ventilation is provided for incoming air by opening near the bottom of the barn, and for the departing moist air by ventilating doors in the roof. The cold incoming air can be passed over hot flues inside the barn. Most furnaces are fired with wood, cool, propane gas, and stove oil/furnace oil. The combination gas passes through the tobacco by forced air ventilation or exhaust fans.

The stages in flue curing are:
a) Yellowing of leaf: After the barn has been filled in one day, all the ventilators are closed & the temperature is maintained at 90-100°F with 85% RH. When the leaf starts to become yellow at the tip and around the edges the temperature is raised slightly until the yellow color spreads to the mid-rib. During this process the temperature is raised gradually to 100-115°F and the ventilators are partly opened. The time taken for this stage is 36-48 hrs.
b) Fixing the color: Ventilation gradually increased and the temperature increased in order to kill the leaf, destroy the enzymes, fix the yellow color and to dry out the web of the leaf. The temperature is gradually increased from 46-57°C. The process takes 12-20 hr.
c) Drying the leaf: The drying of the web is completed at 57-60°C with all the ventilators open. After which the bottom ventilators are closed and the midrib is dried out by gradually increasing temperature to 71°C. This stage takes approximately 50 hr.

Note that flue curing requires considerable skill and experience and it is usual to inspect the bans several times during the night. Flue-cured tobacco is originally strung onto tobacco sticks, which hung from tier poles in curing barns. The process will generally take about a week. Heat-curing the tobacco without exposing it to smoke, slowly raising the temperature over the course of the curing. This method produces cigarette tobacco that is high in sugar and has medium to high levels of nicotine.

3. Fire Curing

The usual system of fire curing is to allow the tobacco leaf to yellow and wilt in the barn without fires for 3-5 days. Then start slow fires to maintain the temperature at 32-35°C until yellowing is completed; and finally raise the temperature to 52-54°C until leaves are dry. The fires are kept up to 3-5 days or more. The smoke from the open wood-fires in the barn imparts the characteristic odor and taste to the tobacco desired for pipe, chewing plug and sniff. Fire curing produces a tobacco low in sugar and high in nicotine.

4. Sun curing

Sun-cured tobacco dries uncovered in the sun. This is done by exposing the leaves to the sun. This method is used in Turkey, Greece, Bulgaria, Macedonia, Romania and Mediterranean countries to produce Oriental tobacco. But it is common practice to air-cure for the first 2-3 days, and then leaves are put in heaps for 24-36 hours to terminate before they are exposed to the sun for complete curing. The method is intermediate between the air and flue curing methods, both in duration and effects. The process is entirely dependent on natural condition. Sun-cured tobacco is low in sugar and nicotine and is used in cigarettes. In India sun curing is used to produce so called “white” snuffs, which are fine, dry, and unusually potent.

B. Handling the cured product

Dry cured tobacco will be brittle and cannot be handled without breakage. This is particularly the case when high heat has been used. Cured leaves contain 24 to 32% moisture. But, tobacco leaf in general is hygroscopic material and will quickly absorb moisture, or 'condition' as it called in humid environment, to become soft and pliable. In many regions the natural atmospheric moisture would suffice to make the leaves pliable. But extremes may occur and hence preventing the leaf from being too most and exposed for spoilage and moistening the leaf to avoid breakage would be essential till the product is destined for market. The leaves are usually graded according to size, color and texture. There are many and variable grading standards. The leaf is usually baled using hessian and sent for auction markets. The tobacco leaf is left to mature in the bales for 1-2 years before used for manufacturing.

Tobacco manufacturing

Baled leaves usually stored for a period of up to 2 years in a redried form [whole (often) or shred]. Leaves are conditioned immediately after opening the package using pressure stem. The leaves are then trashed/cut into rag (shreds). The size of cut is an important property, which affects smoking characteristics and cigarette hardness. The finer it is the more complete the combustion. Modern machines use rotary cutters with a set of self-sharpening knife width of cut vary from **0.488mm-0.508 mm** (small) to **0.794-0.907 mm** coarse cut.

Flavoring and other additives

Four purposes of additive practices:

- To mask faults such as bitterness and harshness and soften smoking taste, etc. Spices and perfumes are sometimes added to create a pleasing aroma from the tobacco.
- To remedy the loss of some flavor components removed by filtration in the smoking of filter cigarettes.
- To produce very distinctive non-tobacco aromas and tests, example the use of cloves in Indonesian Crete cigarettes and mentholated cigarettes
- To retain moisture and make the tobacco less susceptible to atmospheric changes. The materials used are known as HUMECTANTS, *e.g.* **glycerin**.

Blending

Mixing together several different grades from several different countries by the manufacturer to get certain quality (brand). The blends of cigarette often use flue-cured, Burley, Oriental, etc., grown in different regions and different leaf size (rag) to constitute unique brands. Tobacco paper fed from large bobbins receives a continuous depart of tobacco rag around which it is rolled and gummed, and the solid rod is then cut into appropriate length. At some stage the brand mark is printed and if the cigarette has a filter, the filter plug is added. This simple operation requires a very complex piece of equipment to ensure that each cigarette is near identical, with very minimum deviation from a precise specification (length, and density/wt etc.). The output of the machines is about 2000 (old) to 4000 (new) cigarettes per minutes.

Cigarette paper:

- It is physically important to form a continuing tube, and also to influence smoke
- It must be porous
- It must have a pleasant appearance and
- Burn well with good ash.

The degree of porosity will affect the speed of burn and hence its temperature and the combustion products. **Flax** paper is commonly used with the addition of:

- Calcium carbonate: for porosity & combination (permeability)

- Magnesium carbonate: to improve ash color, example Titanium oxide: if required, to whiten the ash
- Potassium nitrate: to give the ash better adherence

Filter: A second non-tobacco part of the cigarette, which has a vital influence on the smoking characteristics. The use of filter for cigarettes is generally accepted to reduce/modify inhalation of certain particles and influence smoking characters. It is made from **cellulose acetate fiber** or paper with carbon incorporated in.

Cigar

Cigar making is used to be a hand process for long time. But due to high labor cost of hand rolling there is a trend to using machines. Mechanized processing utilizes blended filler.

Pipe tobacco

Blend before cutting, leaf may be pressed to 'bake' and the cake is either cut into rags/graduated form or plugs (small quantity of leaf pressed and backed into permanent desired shape and wrapped).