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Agricultural innovation: invention and adoption or change and adaptation?

Marijke van der Veen

Abstract

Agricultural innovations are primarily concerned with a need for increasing production (of food, fodder, secondary products) as well as enhancing quality (of produce, production process, growing conditions). This paper reviews current thinking on how improvements and innovations in agriculture arise, what forms they take and what agents are involved. Innovations typically affect one or more of the following areas: crops, animals, growing conditions, implements and management practices. While 'macro-inventions' (radical new ideas) do occur, many concern 'micro-inventions', that is changes or modifications to tools and practices made by skilled practitioners (farmers, craftspeople), rather than by inventors or entrepreneurs. Indeed, agricultural innovations frequently concern not so much the adoption of newly introduced technologies, but the adaptation of existing ones. The term 'agricultural revolution' tends to be used when a number of improvements in separate areas of the farming system co-occur as a complex, and, although these may be introduced gradually, once they reach a critical mass their impact on society may be of a magnitude deserving of the term 'revolution'.

Keywords

Agriculture; farming; innovation; food production; agricultural revolution; adaptation; incremental change; macro-invention; micro-invention.

Introduction

Many of us will be familiar with the 'Eureka' moment of Archimedes, the Greek mathematician and scientist (*c.* 287–212 BC) who discovered the principle of specific gravity while enjoying a bath. In his excitement at having made the discovery, he is said to have jumped out and run into the streets shouting 'Eureka' – 'I have found it' (that is, a solution to the problem he was grappling with). He is, of course, known for many other discoveries, including the Archimedean screw, a water-lifting device that came to be used

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to irrigate agricultural land in the Nile Delta. While Archimedes may genuinely have invented this device, inventions have sometimes been attributed to a famous personality or patron, rather than to the person responsible for the discovery. In fact, more often than not the names of past inventors are not known to us, and, as any patent lawyer will tell us, the process of pinpointing the actual inventor can be fraught with problems, as all human knowledge is cumulative (Dalley and Oleson 2003: 2).

If it is only rarely possible to identify a specific inventor and moment of invention in the historical past and even less so in the archaeological record, how may we be able to study the process of innovation, i.e. the transformation from invention to widespread adoption? This issue of *World Archaeology* is concerned with the nature and significance of innovation in past agricultural systems and in this introduction I try to summarize some key components of this process: what types of innovation do we recognize within agriculture? how and why are innovations initiated? how are they diffused or transferred to others? what obstacles are there to successful transfer? and what specific problems do we encounter when trying to identify innovation in the archaeological record? Agriculture is here taken in the wider sense of farming, namely tilling soil, cultivating crops, rearing animals, management practices and the processing of agricultural produce. Innovation is here taken to mean the process of making improvements and/or solving problems by introducing something new, though importantly these need not be intrinsic improvements and novelties, in the sense of 'never having occurred before anywhere in the world', but are new in being perceived improvements and perceived new ways of doing things by those adopting them.

Types of agricultural innovation

In the context of farming, innovations are concerned primarily with increasing production – of food, fodder, secondary products – and enhancing quality – of produce, growing conditions, production process. They typically involve one or more of the following five areas (after Evenson 1974):

- Crops – biological and/or genetic changes, such as the introduction of new breeds or varieties which have specific advantages, i.e. being higher yielding or more resistant to certain weather/soil conditions; the introduction of new species that extend the farming calendar or the type of farming; new techniques (e.g. grafting); turning plant produce into cash crops, e.g. olive oil (olives), wine (grapes), beer (cereal grain); etc.
- Animals – similar biological and/or genetic changes as listed above; new ways of husbanding the existing animals in ways to make them more productive – e.g. the exploitation of animals for their secondary products (wool, milk, blood, traction) rather than just for their meat and hides; etc.
- Growing conditions – the addition of manure or other fertilizer; raising soil depth; drainage or irrigation; increased soil working (digging, ploughing); terraces to avoid soil erosion or to acquire additional cultivation space; wind breaks; supplying fodder or improved grazing to animals; etc.

- Implements – more efficient ploughs or ploughs that can cope with different soil types; harvesting machinery; milling equipment; water-lifting devices; etc.
- Management practices – changes in the mode of production; land ownership and inheritance; plot size; availability of labour; a switch to surplus production; etc.

Within each of these areas, the nature of the innovation is important (Grigg 1995: 176). Simple innovations requiring little capital or labour investment or where a benefit may be visible within a short period of time, will be easier to adopt than complex ones which require heavy capital or labour investments, where return on large investments may be uncertain and/or where the investment will pay for itself only over the longer term. For example, the introduction of a new crop may be started by allocating just a small part of the available land to it, allowing an assessment over one or more years before making the decision whether to switch wholesale to the new crop. Equally, the addition of a new fertilizer to a field can be carried out by an individual farmer and the beneficial effect can be judged within a year, in contrast to the construction of terraces, drainage or irrigation canals, which may require cooperation between farmers and may take years to complete, thus entailing a delayed visible and material benefit. Additionally, the introduction of a new large piece of machinery (windmill, watermill, combine harvester) represents a major capital investment, payment for which may have to be upfront, thus requiring the farmer to possess the ability to invest in the future, by sufficient savings, the option to borrow or the availability of partners with whom the investment and the machinery can be shared (private versus communal investment). This immediately highlights the complexity of the introduction and adoption process of innovations. Rarely is it simply a matter of demonstrating the potential improvement of a new practice or implement; in virtually all cases many other factors come into play.

The diffusion process

Long gone are the days when we thought that the 'superiority' of Western technology, once introduced, would solve the 'backward' agrarian economies of poor, developing countries. This attempted transfer of new technologies turned out to be a complex process, fraught with difficulties, primarily because such new techniques and technologies can function successfully only if they can be embedded within local circumstances (e.g. Evenson 1974; Grigg 1970, 1995; Mokyr 1990; Rogers 2003; Rosenberg 1970). Apart from the specific characteristics of the innovation mentioned above, economic, social, cultural, ideological and psychological conditions all play a significant role in the diffusion process.

In terms of economics, what matters is not the intrinsic economic benefit of an innovation (if such a thing exists), but whether it represents a benefit in the local or personal situation and is perceived as such by the adopter or recipient. In most subsistence or self-sufficient economies farmers tend to focus more on security, stability and flexibility, with the aim of feeding the family and minimizing risk, rather than increasing output or profit. The potential of a piece of machinery to increase output may be of little relevance where no increase is sought; or, as Foxhall puts it, 'there is no advantage to increased through-put if the rest of the system does not produce more to put through' (2007: 257).

Equally, labour-saving devices may not be regarded as desirable in situations where family labour is available at a low 'shadow' wage (Evenson 1974: 54), and in situations where people do not 'cost' their time.

The social and political circumstances of the farmer or landowner play an equally important role in the decision-making process around the adoption of innovations (Bayliss-Smith 1982; Grigg 1970, 1995; Spedding 1988). Here the ability to implement change and to take or share risks is crucial, and this is influenced by factors such as differences in land ownership and inheritance, size of the farm, personal wealth, control over the decision-making process, the presence of taxation practices (e.g. tithes, corvée labour), the structure of the household (whether nuclear or extended) and its stage in the lifecycle (presence of children). The prevailing ideology is likewise significant. A society's willingness to challenge nature, the degree of openness to otherness and the existence of taboos and rules will all influence whether maintenance of the status quo or initiatives for change are pervasive. Finally, on a more individual level, the psychological make-up of the farmer influences their readiness to adopt change. Some individuals are eager to try new things, others are not and this inclination is shaped by personal characteristics such as age, education, social standing in the community, ambition, competitive spirit, ability to mix widely, business attitude and so on (Grigg 1995: 174).

Rogers, in his textbook *Diffusion of Innovations* (2003: 169), draws on these aspects to categorize the stages an individual may pass through during the adoption process – knowledge, persuasion, decision, implementation and confirmation – and he stresses the nature of communication channels and the importance of certain individuals: opinion leaders who exert influence from within, and change agents who represent specialists from outside (ibid.: 27). Moreover, people, he argues (ibid.: 279–99), can be categorized into innovators (enterprising, intelligent, willing and able to take risks), early adopters (respected by peers, well educated, socially integrated and successful, or using the adoption of innovations as a means of moving up), the early and late majority (more cautious, less financially flexible, followers and, in the case of late majority, sceptics) and the laggards (averse to change, socially isolated, precarious economic position). Unfortunately, and almost inevitably, this categorization incorporates concepts of 'progress', even though non-adoption may make good local sense, and focuses on the adoption of externally introduced technologies, rather than on local adaptations – an issue I will come back to below. A further aspect that makes his classic study of the diffusion process less helpful to archaeologists is the fact that, in the past certainly, the transfer of knowledge and techniques will have involved a much wider array of actors than Rogers envisages in his modern study, ranging from skilled labourers and their apprentices in workshops and fields to inventors and entrepreneurs, and from authors of agricultural treatises and guilds to merchants (e.g. Dyer 1997: 306; Hilaire-Pérez and Verna 2006: 539; Rosenberg 1970: 55). In fact, the labels 'inventor' and 'entrepreneur' may not always be applicable to the pre-modern era.

An example of the interplay of social and economic factors is Mazzotti's (2004) case study of the diffusion of modern olive machinery in eighteenth-century Europe. The adoption was successful only in instances where the change in machinery was accompanied by a change in the traditional way of life. The new, mechanized mills in his study depended for their success on continuous, regular and synchronized functioning, which meant an increase in the workload of labourers (longer hours and fewer breaks). Only in the new trading centres (e.g. Genoa and Provence), where individual ownership of land and machines meant that the new elite could acquire control over the entire manufacturing process, was it possible to introduce the required labour changes. In contrast, in parts of rural Italy and Portugal the working of the existing mills was achieved not with skilled labourers but with temporarily hired peasants, who would earn some extra money by working a few hours in the mill as and when their farm work allowed. Here the self-sufficient economies and the communal or feudal landownership systems made mechanization either irrelevant or impossible to implement. Additional factors may have been proximity to markets and good communications.

Reasons for change

Key questions in the innovation process are, of course, why and when innovations occur, and by whom they are initiated. The need for change, the desire for change and the flash of genius are all components of this debate. While external factors such as population growth and environmental change will, undoubtedly, play a role in some instances, the incentive for change is likely to have been a more powerful ingredient. Schmookler defines an invention as '(a) a new combination of (b) pre-existing knowledge which (c) satisfies some want', and he stresses that innovations were often demand-induced, not supply-led: 'without the "wants" there would not be a problem to solve' (1966: 10, 12). In addition, Evenson (1974: 55) points to the role of 'inducements' in adaptive inventions, such as the need to adapt to new soil and climate conditions as part of colonization; for example, the settlement of the prairie soils in the American Midwest meant the need for new types of mouldboard plough and other implements. In contrast, Dalley and Oleson (2003: 25–6) underline how the potential recognition of individual effort and accomplishment may represent a powerful trigger for innovation. They also draw attention to the importance of intellectual climate – in their case the existence of a well-funded, more or less independent research institute, the Museion at Alexandria, where Greek and Egyptian traditions merged – and to the desire of some rulers to broadcast their prestige to others through technological success.

This leads to the question whether innovation is a top-down or a bottom-up process. Dalley and Oleson (2003: 2) give an example of the former: a royal patron – King Dionysius I of Syracuse (430–367 BC) – who is said to have set up a 'think tank' to solve a particular problem, in this case a problem of military rather than agrarian technology:

> At once, therefore, he [Dionysius] gathered skilled workmen, commandeering them from the cities under his control and attracting them by high wages from Italy and Greece as well as the Carthaginian territory. For his purpose was to make weapons in great numbers .... After collecting many skilled workmen, he divided them into groups in accordance with their skills, and appointed over them the most conspicuous of citizens, offering great bounties to any who created a supply of arms .... In fact the catapult was invented at this time in Syracuse, since the ablest skilled workmen had been gathered from everywhere into one place. The high wages as well as the numerous prizes offered the workmen who were judged to be the best stimulated their zeal.
>
> (Diodorus Siculus *The Library of History*: 14.41.3–4, 42.1)

Here again we hear of the beneficial effect of bringing together skilled people from different regions and traditions.

More usually, the top-down concept is postulated because certain innovations are thought to require centralized control and investments beyond the scope of an individual or small community – a classic example being presented by Wittfogel's *Oriental Despotism* (1957), in which he claimed that large-scale irrigation systems in Asia could develop and be successfully maintained only through centralized state coordination and administration. Today, there is a much greater emphasis on the bottom-up perspective, with the recognition that agricultural change is frequently achieved in small steps (see below). A good example of this approach is the detailed historical and archaeological research carried out in al-Andalus, the region of Spain under Muslim control during the medieval period, and the Balearic Islands (e.g. Glick 1970; Kirchner 2009). Here the extensive irrigation systems introduced during this period are interpreted as having been 'conceived, created and managed by peasant groups without any significant state intervention whatsoever' (Kirchner 2009: 152); indeed, the local clan-based society is seen to have been capable of organizing the level of cooperation needed to manage these hydraulic systems. Another example of bottom-up innovation is that of the large-scale drainage of European wetlands in the Middle Ages carried out by village communities, and the building of many mills by consortia of peasants (Dyer 1997: 307).

Clearly, the role of local landlords, rulers or the state can be both beneficial and detrimental in terms of technological change. They may have the superior intellectual training, capital, resources and power needed to encourage and invest in new initiatives, bring people together, back inventors and entrepreneurs, or implement new technology, but their desire to hold onto the status quo or their demand for high rents and dues may also, at times, have stifled any peasant initiatives (Dyer 1997: 305–7; Mokyr 1990: 179–83). In reality, the top-down/bottom-up approach is too simplistic an instrument to study the complexity of technological change. There are many preconditions for innovations to be successful, ranging from the attitudes of the individual to the attitudes of society at large. What is needed is the presence of a cadre of people intellectually and mentally willing and able to challenge existing ways of doing things, a prevailing ideology open to adopting change, as well as social, economic and political circumstances that encourage or demand change and are nourishing by offering economic, social or personal reward (Mokyr 1990: 12). Of course, in many instances, small local adaptations are the norm, as are failures, U-turns and diversions. Needless to say, the complexity of factors involved rules out any one-dimensional answer to the questions of 'why' and 'when'; reasons will have been diverse and highly specific.

Agricultural innovation and the issue of scale

Many authors have implied that innovations in agriculture are different from those in other spheres. First, ecological relationships and natural phenomena play a more active role here (Evenson 1974; Rosenberg 1970): most crops, animals and husbandry practices are best suited to particular types of environment, in terms of daily and annual temperature ranges, rainfall, altitude, topography, soil conditions, day length, etc. Here the technological specificity of an innovation needs to fit not only local socio-economic characteristics, but also environmental ones, and these variations matter not just on the macro-scale, but also on a micro-scale (such as variations in soil quality within an individual farm). More importantly, many improvements in agriculture are small, incremental steps (Dyer 1997; Evenson 1974; Rosenberg 1970), though not implying that these occur only within agriculture. For example, when farmers experiment with better weed control, new types of fodder, improvement in seed germination, modifications to tools, etc., this is not always seen as 'innovation', since these alterations are often 'induced' from minor changes in circumstance or by chance recognition, and not made by specialist inventors. Crucially, we are looking here not simply at farmers *adopting* newly introduced technologies, but *adapting* existing ones (Evenson 1974: 55; see also Hilaire-Pérez and Verna 2006: 537). These types of improvement, usually referred to as 'routine innovations', 'sub-inventions' or 'micro-inventions', concern changes or modifications to tools and practices which skilled practitioners – with their intimate understanding of landscape and resource – can be expected to make, and which, today, certainly would not be subject to patent law (Schmookler 1966: 6). Small and incremental as they may be, they are significant nevertheless: they highlight how non-codified knowledge is acquired through direct exposure to and participation in the work process, passed from practitioner to apprentice, from farmer to son. Here we see technical skills embodied in the human agent (Rosenberg 1970: 555). In addition, these micro-inventions are often also crucial in modifying and complementing macro-inventions (radical new ideas) to make them suitable for adoption (Mokyr 1990: 13).

Finally, several authors have highlighted the occurrence of a 'technological complex', when a number of interdependent innovations, some of which may already have existed but been under-used, break through more or less simultaneously and co-occur with wider changes in society and economy (Dyer 1997; Myrdal 1997; see also Sherratt 1983; Watson 1983). In these instances the term 'agricultural revolution' is sometimes used; see below.

This leads us to the issue of scale. Can we identify the earliest occurrences of inventions, such as the earliest evidence for milking or the earliest example of rotary olive crushers, or should we be focusing instead on establishing when these inventions were transformed into innovations, by having been taken into widespread usage? Research projects using a large regional and temporal scale may occasionally be able to recognize actual inventions and their subsequent diffusion, but are more likely to identify the moment of innovation, i.e. the time when technological change has become widespread and embedded within communities. With individual occurrences of inventions, how do we know whether we are dealing with an artefact of the fragmentary archaeological (and historical) record, with a failed innovation or with the inventor or early adopter? Here a smaller scale would be beneficial, focusing on the particular site where the invention was discovered and studying other forms of available evidence, to help determine the specific conditions or circumstances that gave rise to the presence of the invention and to get closer to identifying the 'inventor'.

To date, most studies have concentrated on situations where a change in scale is visible, be that the Secondary Products Revolution (see below) or introductions of new machinery. For example, in her study of olive cultivation in ancient Greece, Foxhall (2007: 132) highlights that the smaller scale of Greek compared to Roman farming and its concomitant lack of specialized production meant that the equipment for olive processing was basic and multi-purpose during most of the Archaic and Classical periods. Olive presses and rotary olive crushers, i.e. a switch to more specialized and permanent installations, become more common only in the later fourth century BC (from the time of Phillip II) when changing political circumstances under Macedonian rule required an increase in the scale of production.

Another example concerns the introduction of new crops from tropical India and Africa into the early medieval Islamic world. The combination of these so-called summer crops with 'new' water-lifting technology (the water wheel), as well as changes in land tenure, allowed a significant expansion of the agricultural year and effectively doubled the productive capacity of the land in parts of the Middle East, North Africa and Muslim Spain (Watson 1983). This innovation and the subsequent economic growth are thought to have both stimulated the flourishing of Islamic culture at that time and be encouraged by it. The water wheel was, of course, not new – examples are known from the Roman period – but not until it was combined with a wider range of crops that needed to be grown in summer, when rainfall in the Middle East is insufficient and irrigation thus essential, was its true potential realized.

In all instances where scholars have identified major changes in agriculture and have spoken of a 'revolution', notably the Neolithic Revolution (Childe 1936), the Secondary Products Revolution (Sherratt 1983), the Agricultural Revolution of the Early Islamic world (Watson 1983) and the Agricultural Revolution of the eighteenth and nineteenth centuries in Britain (Overton 1996), archaeologists have subsequently found evidence that the changes described by these 'revolutions' emerged earlier than their proponents had put forward. Thus current evidence suggests that the domestication of crops and animals was often a protracted process (e.g. Barker 2006; Fuller et al., this issue; Harris 1989), that milking of domestic animals started as early as the Neolithic (e.g. Craig et al. 2000, 2005; Greenfield, this issue), that the water wheel was used from the early first millennium AD and some South Asian and African crops were cultivated well before the early Islamic period (e.g. Pelling 2008; Rowley-Conwy 1989; Samuel 2001) and that the improvement of cattle and other domestic animals was already under way in the fifteenth and sixteenth centuries (e.g. Beckett 1990; Davis and Beckett 1999; Thomas 2005). Here we need to decide what matters, or, rather, what we aim to establish. Are we interested in recording the *earliest* occurrence of a new agricultural practice or in establishing the point in time when the new practice – or, more likely, a package of new practices and techniques – had become *embedded* and its long-term effect had started to impact on society at large? I would argue that the former is certainly important, but that the latter is possibly more significant, and that establishing regional variation in this process is of particular interest. The use of the term 'revolution' in these instances does not, or should not be taken to, refer to the *time period* taken to achieve the changes, but instead, highlights the ultimate magnitude and significance of the change, the time period when the changes reached *critical mass*.

This volume

This volume concentrates on innovations within agricultural systems and the first significant innovation here is, of course, the domestication of plants and animals. This innovation involved both genetic and behavioural changes – it rendered crops and animals dependent on humans for their reproductive survival and forced people to increase their labour input and decrease their mobility. Interestingly, Fuller, Allaby and Stevens suggest that it may not have been a deliberate invention, or, for that matter, a labour-saving one. A second critical step concerns the Secondary Products Revolution, when, in addition to primary products (meat, bone and hide – products that could be extracted only once in the animal's lifetime), people learned to exploit animals for products that could be obtained repeatedly through their lifetime (e.g. milk, wool, traction), representing a very marked increase in productivity. A review of the latest evidence and a discussion of origins versus widespread use are presented by Greenfield. Selective breeding, to produce animals with specific characteristics, is a logical further step, and MacKinnon discusses the identification of such breeds in the archaeological record of Roman Italy and compares this evidence with the ancient textual records. Two papers provide examples of the need for innovation and improvement in order to adapt crops to new ecological circumstances. Barber presents evidence for experimentation with mulching and soil textures to facilitate the introduction of a tropical crop, sweet potato, into new environments (subtropical Easter Island and temperate New Zealand), while McCoy and Graves discuss the creation of terraced fields and windbreaks to open up additional, previously marginal farmland in Hawai'i in response to the demand for more food and surplus. Krasilnikoff shows that irrigation projects designed for field rather than garden cultivation in ancient Greece were few and primarily confined to the Classical and Hellenistic periods, and demonstrates that the motivations for and implications of this change in scale were many and complex. Crabtree draws attention to the impact of trade on agricultural production by illustrating how both rural estates and monastic centres in early medieval England start to specialize production (especially wool) in order to engage with the new trade opportunities, while Walshaw highlights how trade contacts and the process of Islamization on Africa's Swahili Coast result in the introduction of and specialization in a new South Asian crop, rice, even though its cultivation was more labour intensive and risky than that of the traditional crops.

Conclusion

Above I have tried to sketch how innovations in agriculture, and other spheres, arise from a complex concurrence of circumstances, in which the social, economic, cultural, ideological and psychological characteristics of specific individuals and communities can either enable them to seek new solutions and improvements or encourage them to be early adopters, while a different set of such circumstances may lead them to seek stability and continuity, to resist or be sceptical of change or to delay adoption of change until forced to do so. The multiple factors involved and the diversity of solutions available may seem daunting, but many new studies are now starting to demonstrate that the study of agricultural innovation is rewarding and exciting. While the inventor and early adopter may, for the moment, appear hard – if not impossible – to pin down in the archaeological record, identifying the immense variety of local circumstances that led to periods of stability or stagnation as well as to periods of innovation and rapid change is definitely within our reach. An important factor in understanding agricultural change is the realization that many changes and improvements are small and incremental rather than large and radical, and involve adaptations to fit with (new) local circumstances, rather than wholesale adoptions of technologies brought from outside. While large and radical changes do occur and inventors and entrepreneurs do play a role in the process, agricultural innovation often also concerns different actors, namely ordinary farmers and ordinary craftspeople in their fields or barns, as well as a different type of knowledge transfer, namely that from farmer or craftsperson to child or apprentice. These sub- or micro-inventions may appear small and inconsequential, but their significance is nonetheless considerable. Agricultural innovations, small and large, have been catalysts for bigger changes, such as tying people to land, land ownership, population growth, specialization and social hierarchy, wealth and prestige acquisition, colonization of agriculturally marginal land, increases in production, trade and exchange, urbanization and, ultimately, the rise of the state and our own modern world. The production of sufficient food has not only underpinned all these developments, it continues to be a major player in world events today.

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