Part I

Disciplines

Chapter One

Agricultural Sciences

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Agricultural science may have begun with the Hatch Act of 1887 and the birth of the US land-grant universities in 1862 (Hillison 1996). Actually, it is one of the oldest applications of empirical inquiry, as our current methods of agriculture are the result of thousands of years of trial and error and experimentation in the field. Farming methods slowly improved as humans developed better ways of obtaining reliable knowledge that they then applied. With that being said, however, agriculture science as we know it today really began to take shape between the seventeenth and nineteenth centuries, as the scientific methods born out of Enlightenment thinking were directly applied to farming practices. This form of applied science became institutionalized in the United States in the late nineteenth century with the birth of the land-grant universities in 1862, the establishment of federally funded experiment stations, and extension services meant to communicate scientific breakthroughs to the local farming community (Hillison 1996). This three-way partnership forms the backbone of current agricultural research in the United States (Rosenberg 1997). In point of fact, one could argue that it also forms the backbone of American industry, as technology and farming methods developed by these sciences both increased food supplies and lowered the numbers of workers needed to grow this food, thus providing the workers necessary for industrial development (Thompson and Noll 2014).

This chapter will begin with a brief definition of "agriculture." Before outlining the many different types of agricultural sciences, it is important to recognize the scope of farming practices and thus the varied nature of scientific disciplines that focus on improving these practices. The next section provides a general overview of agricultural science by describing how agricultural science is not one science, but a multidisciplinary field that encompasses work from a multiplicity of scientific disciplines. The third section of the chapter describes the historical movements beginning during the seventeenth century that made the rise and dominance of American agricultural science possible. It

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then outlines the history of the development of agriculture science in the United States and how its structure of scientific inquiry differs in this context from that of Europe's. These latter two sections are particularly important, as many of the social consequences of agricultural research can be found in the early history of these sciences. In the final section, current critiques of these sciences are outlined before the chapter ends with a brief overview of agricultural science today.

Agriculture Defined

While agriculture is currently understood as the cultivation of food crops (such as corn, wheat, and soy), the practice also includes raising animals, plants, and other organisms for production and pharmaceutical purposes. The term covers a considerable amount of human activity, including animal husbandry, wine production, biofuel, dairy, hydroponics, and fiber crops, and activities associated with harvesting, distribution, and food processing (Thompson and Noll 2014). The history of agriculture dates back thousands of years and was largely a place-based practice, bound to specific areas, as the development of various methods of production, processing, and storage were influenced by vastly different climates, technological advances, cultural views, and values surrounding the cultivation of food. However, while farmers in disparate areas practiced diverse techniques and methods, most agricultural practices relied on basic activities of land and animal management that still underlie local differences, such as the practice of irrigation, maintaining the fertility of the soil, and general methods of farming, such as intercropping, grassland grazing, and terrace cultivation. Historically a large percentage of the population worked in agricultural production, but current technological developments have greatly reduced the numbers of people working in the field, especially in the United States (Lyson 2004). One such advancement was the development of large-scale monoculture farming, the most common form of field crop cultivation today. However, other forms are still being practiced, such as both large-scale and small-scale organic agriculture, livestock integrated systems, intensive small-scale operations, and traditional farming practices, such as the cultivation of *milpa* originally used throughout Mesoamerica.

Agriculture Science Defined

While agriculture refers to a set of methods or activities used to transform the environment for the production of the above products, the agricultural sciences are grounded in "the application of scientific methods of inquiry to improve the practice of agriculture" (Thompson and Noll 2014: 1021). Very roughly then, one can understand agriculture science as the use of scientific methods and methodologies to improve agriculture practices. Just as agricultural practices are varied, agricultural science can be understood as a multidisciplinary field of biology that encompasses research in the natural and social sciences (Olmstead and Rhode 2008). Traditionally this work was carried out on a multiplicity of topics, such as production techniques, pest control, minimizing the effects of drought, food distribution, selective breeding of plants and animals, the design and implementation of sustainable production methods, and various social and economic topics surrounding food production, storage, and transportation. In the context of the United States, most agricultural research is made possible by, what David MacKenzie (1991) calls, a triangular partnership between farmers, government agencies that fund and sometimes conduct research, and commercial and non-profit public sector research institutions. This arrangement has lasted for over 100 years and has proven highly successful in supporting cutting-edge agricultural research.

Several fields fall under the umbrella of "agriculture science" including agricultural chemistry, economics, geography, philosophy, marketing, agrophysics, animal science, agronomy, aquaculture, biotechnology, microbiology, environmental science, entomology, food science, soil science, waste management, and ecology. Many of these fields focus on a single aspect of agriculture. In addition to being multidisciplinary, or a field that draws upon many distinct disciplines, it is important to note here that much of agriculture science is also interdisciplinary (Jacobs and Frickel 2009), or a field that integrates knowledge originally developed within distinct fields. In truth, the practice of agriculture by its very nature relies upon and integrates varied sources of knowledge as solving problems in agriculture or developing new methods of production, harvesting, and storage often require such integration. For example, an entomologist working on pest control may have expertise on insects but will often have to draw upon and incorporate knowledge from other fields, such as agronomy, ecology, or soil science to properly address the pest problem. Thus the term *agriculture science* is an umbrella term that encompasses work carried out by various disciplines and often across disciplines. For this reason, one can understand agricultural science to signify the entirety of the agricultural sciences that make up this branch inquiry. This chapter will use both terms interchangeably.

In addition, it should be noted here that agricultural sciences are largely applied sciences, in contrast to pure sciences, though not all research is applied in this field. As illustrated above, agricultural sciences are housed in many different departments, as they each draw upon scientific methods and methodologies developed within these fields. When applied to agricultural practices, such methods provide unique and novel insights. In contrast, pure sciences make deductions from mathematics, logic, and previously accepted facts in search of universally applied laws or fundamental principles (Rosenberg 1997). While agricultural sciences are applied sciences, most scientists working in these fields nevertheless accept that pure science is necessary for applied sciences to flourish, as findings in the more abstract sciences open up new avenues for research on the ground. For example, pure research in chemistry opened up the possibility for new fertilizers, and biological research in genetics paved the way for the creation of genetically modified organisms now used in agriculture.

Historical Roots of Agricultural Science

While the agricultural sciences began in earnest in the United States during the late nineteenth century with backing at both the state and national levels (Rosenberg 1997), improving various areas of agricultural practice through the application of components of the scientific method has a long history. Indeed, it is difficult if not impossible to separate the practice of agriculture from technological development and empirical inquiry. For example, Xenophon (*c.* 430–350 BCE) and Aristotle (384–322 BCE), whose texts are foundational in the development of the sciences, both wrote extensively on agriculture. In addition, Roman texts, such as Columella's (4–70 CE) 12 volumes on agriculture, give detailed descriptions of animal husbandry techniques, selective breeding programs for plants and animals, field crop cultivation methods, orchard management regimens, and descriptions of experiments conducted in these areas. The Romans, and before them the Greeks, used highly developed methods and specialized crops, such as those used for fodder, that were lost after the collapse of the Roman Empire and only rediscovered during the Renaissance (Kingsbury 2009). In truth, the rediscovery of these techniques coupled with the scientific, industrial, and agriculture revolutions of the eighteenth century formed the foundation for the current agricultural sciences that we practice today.

Scientific methodologies were applied to agricultural practices throughout the Enlightenment when the various revolutions listed above shifted people's reliance from tradition to the application of scientific methods and cultivated an insistence on change and progress. These factors powerfully influenced subsequent developments in agriculture and the structure of agricultural systems as a whole (Brantz 2011). According to Kingsbury (2009), the Scientific Revolution and industrial enlightenment combined to spur on agricultural developments that then further supported the other revolutions and spurred further research in agriculture. First, the Scientific Revolution was built upon the idea that the natural world is orderly (not controlled by capricious deities or inherently disorderly) and is thus knowable. Through scientific inquiry, it is possible to both obtain reliable knowledge about the world around us and to manage nature for the benefit of humans. The "industrial enlightenment" signifies the technological advances occurring in conjunction with the Scientific Revolution, including the codification of experiments and observations on agricultural techniques that were then made readily available to the intellectual community through translation and printed materials (Kingsbury 2009).

Beginning in the later half of the eighteenth century, the Agricultural Revolution was a culmination of the advancement in farming techniques that greatly increased the crop yields of the day (Kingsbury 2009). During this period, Europe reaped the benefits of the implementation of new agricultural practices, such as the enclosure of pastures, the introduction of hardier plant types, a new four-course rotation schedule (Kingsbury 2009), and the use of composted manures from city centers (Atkins 2012). It is estimated that the production of wheat went up from 19 bushels per acre during the early seventeenth century to over 30 bushels by 1840 (Snell 1985). Subsequent developments pushed these yields even higher, as the four-course rotation method produced on average 80% more food (Kingsbury 2009). Further developments in mechanization and plant breeding increased these yields even more. The subsequent availability of food supported further industrial development, as it freed people from the necessity of working on the land, and thus provided the population necessary for the Industrial Revolution.

In addition, the coupling of agricultural research with commercial interests during this time helped shift the reputation of agriculture, from a practice largely performed by the lower class, to the pursuit of landowners and the educated classes. This shift is directly reflected in the scholarly work of the time, as various philosophers, such as John Locke (1632–1704), Jeremy Bentham (1784–1832) and John Stuart Mill (1806–1873) and economists Adam Smith (1723–1790) and Thomas Malthus (1766–1834) wrote extensively on agricultural practices, technology, and the social factors that influence or are influenced by crop production. In fact, foundational work in most if not all of the disciplines that make up the current agricultural sciences can be found during this time period. For example, the chemist Justus von Liebig (1803–1873), often considered the founder of agriculture science, wrote extensively on using controlled experiments to identify practices useful for improving soil fertility and crop yields; the agronomist Jethro Tull (1674–1741) published on tillage in 1733; and Thomas Jefferson discussed the role that agriculture should play in American higher education (Thompson and Noll 2014).

History of Agricultural Sciences in the United States

Like Europe, the United States began to reap the benefits of the implementation of agricultural research during this time. In this context, however, agricultural science became institutionalized in the late nineteenth century with the birth of land-grant universities in 1862 and the establishment of federally funded experiment stations (Hillison 1996). The first agricultural experiment station was established in Connecticut in 1875 (Rosenberg 1997). A little over a decade later, the Hatch Act provided each state with $15,000 a year to support local experiment stations. The act was passed due to increasing political pressure by the farming lobby and, as Rosenberg (1997) argues, the role of the experiment stations was clear from the beginning: “It was to perform the experiments which the individual farmer, lacking time and opportunity, could not” (p. 154). The average farmer did not have the time or the money to perform experiments in a systematic manner, as the loss of one season’s crops could mean the loss of the farm itself. These two developments helped connect two parts of the triangular partnership (farmers, government agencies, and public sector research institutions) that, as MacKenzie (1991) argues, supported cutting-edge agricultural research in the United States for the last 100 years.

Agricultural experiment stations were placed directly under the control of states’ land-grant universities that were originally established in 1862 under the Morrill Act (Thompson and Noll 2014). Land-grant universities provided education in agricultural practice, such as animal husbandry and field crop cultivation. Early in their development, the institutions embraced the agricultural sciences, as the application of the scientific method promised to both raise the status of the American farmer and improve the economic viability of farms (Rosenberg 1997). They conducted and continue to conduct research on a multiplicity of agricultural topics, such as soil fertility, cover crops, and farming methods, both at the university proper and at experiment stations. Similar to MacKenzie’s (1991) triangular partnership, Rosenberg (1997) argues that the United States’ early success in agricultural research was a result of a three-way partnership between universities, experiment stations, and extension services. The last of these was established to disseminate research results, such as new crop types, machinery, and cultivation methods, to the larger farming community (Thompson and Noll 2014). These extension services are state-operated and focus on providing information on advances important within regional contexts, providing training for farmers in all areas of practical farm management, and on recommending efficient fertilizer levels. Today, while the farming landscape has changed dramatically, the three-way partnership forms the backbone of agricultural research and serves as a model for publicly managed and funded approaches to the development and dissemination of research. However, it should be noted that agricultural sciences are also currently being pursued in various commercial and academic contexts outside of this federally funded structure, such as in the large agribusiness corporations.

Ethical and Social Influences

At least two of the current and most serious critiques of American agricultural research and the social consequences of this research can be found in the early history of these disciplines: specifically, the reduction of family farms and the effects of myopically focusing on increasing productivity (MacKenzie 1991; Rosenberg 1997). Indeed, Rosenberg argues that, "we are in retrospect well aware [that] circumstances dictated that the small agricultural producer would not be the most prominent beneficiary of experiment station research and development" (p. 186). Scientists and administrators working in the land-grant system found it more beneficial for their research to work with larger and better funded producers of agricultural products. However, according to Rosenberg (1997), they never considered the consequences of their research as, when successful, it ultimately helped the larger producers gain an advantage over smaller scale producers. Thus the historical structure of American agricultural research could be understood as contributing to the reduction of small farms.

Similarly, according to Thompson and Noll (2014), "the influence of publicly organized research conducted at experiment stations and the organized attempt to extend those results throughout the world provide the basis for viewing agricultural science … as an applied science with explicit value commitments" (p. 1022). One of the basic commitments of early agricultural scientists included the fundamental belief that increasing productivity was an unproblematic goal of agricultural research (Rosenberg 1997), as most if not all humans are vulnerable to food-borne risk and food and fiber are of paramount importance when meeting basic human needs (Thompson and Noll 2014). The technologies developed from this research placed farmers on what is commonly called the "technology treadmill," as producers who refused or could not afford to implement technological advances commonly found themselves out of business (Hightower 1975; MacKenzie 1991). Again, research focused on improving productivity ultimately favored larger operations with access to more capital and thus helped to increase the numbers of large-scale producers at the cost of family farms. In point of fact, according to Thompson, Ellis and Stout (1991), while current critiques of the agricultural sciences include a wide spectrum of concerns, a group of vocal critics claim that small-scale stakeholder groups were historically ill-served by the three-way partnership above. This last group of critics argues that land grant institutions' predominant goal of increasing yields was the wellspring for many of the current problems faced by American agriculture.

While these are only two of many ethical and social issues currently being addressed in the agricultural sciences, they form the foundation of the first critiques that sparked current debates in this field. In fact, the work of Wendell Berry drew both academic and popular attention to these ethical issues and others surrounding modern agricultural science, industrial agriculture, and the land-grant institution. His best known work, *The*

Unsettling of America (1977), provided a jarring critique of these features of American agricultural research, pointed out the negative social impacts brought about when focusing solely on productivity, and included a lengthy defense of the family farm, thus bringing the plight of small farmers into the public eye (Thompson and Noll 2014).

Over the last 20 years, the agricultural sciences in general and the research priorities of these fields in particular have been subjected to growing criticism (Dahlberg 1988; Johnson 1984; Thompson, Ellis and Stout 1991). These critiques include issues such as the use of genetically modified crops (Doyle 1985), environmental impacts (Jackson and Jackson 2002; Shiva 1992), global hunger (Pimbert 2008), the plight of workers in the United States and abroad (Mizelle 2011), and of various social goals of this research (Hightower 1975; Jackson 1980). However, it should be noted here that the dominant theme in this field is that the agricultural sciences' service to large-scale producers produced benefits that largely outweigh any harms, such as improving the availability of food and fiber products to American citizens and lowering the costs of these staples (Thompson, Ellis, and Stout 1991).

The Green Revolution and Genetic Modification

Both criticisms and beneficial claims concerning agricultural science are clearly found in two common case studies used to outline potential social and ethical impacts of agricultural research: the Green Revolution and genetic modification. The Green Revolution was one of the most controversial applications of the agricultural sciences during the twentieth century (Thompson and Noll 2014). First conceptualized as a strategy for undermining increasing Soviet influence after Word War II, the Green Revolution was primarily a research initiative, funded by the Rockefeller Foundation during the 1950s and 1960s, with the goal of increasing the worldwide production of crops (Anderson and Morrison 1982). While this initiative primarily focused on developing and making available high-yielding crop varieties to farmers in developing countries, it also involved expanding irrigation infrastructure, modernizing farming and management techniques, and making petrochemical inputs available, such as fertilizers and pesticides. If the only factor taken into account is improving access to food and fiber crops, then this initiative can be viewed as a tremendous success, as Green Revolution wheat and rice varieties helped bring about a decade of food surplus in India and other developing countries (Hillison 1996; Thompson and Noll 2014).

However, the initiative is often viewed as a mixed success, as these surpluses came at a price. The Green Revolution crop varieties did improve productivity and thus led to a greater availability of food at lower prices, but small-scale farmers could not stay in business due to lower profit margins. Second, the high-yielding crop varieties were made to be used in conjunction with expensive fertilizers and/or pesticides. Again, small-scale farmers could not afford these inputs and were thus forced out of farming. In fact, according to Pimbert (2008), the decline in agriculture commodity prices coupled with the increase in price for production inputs has led to rising bankruptcies and poverty within rural farming communities. It is estimated that "200,000 farms disappeared between 1966 and 1995" alone (Pimbert 2008: 22). Finally, the increased mechanization of farming led to the large-scale unemployment of landless laborers, as they were no longer needed to perform these tasks. All three of these factors have led to critiques of the Green Revolution centering on the claim that the industrialization of worldwide agriculture caused the disenfranchisement and disempowerment of already marginalized groups. Vandana Shiva (1992) has been particularly vocal in her criticism of the Green Revolution on the above social grounds, as well as the environmental damage caused by increased production. This case study clearly illustrates how the goal of increasing productivity can lead to unintended social consequences and, as will be discussed below, it this tension that influences current agricultural sciences, as factors previously understood as externalities, such as the environmental and social impact of research, are now areas of research themselves in the field.

Second, there are numerous social and ethical debates occurring in the public sphere on various impacts of genetically modified organisms. While most of our production increases within the last 100 years are due to selective breeding and not to genetic modification (Boyd 2001; Greger 2011; Noll 2013), within the last 20 years, new methods of modifying agricultural plants and animals developed directly out of current work in genetics: specifically, genetic engineering. The development of these methods, produced from the direct application of research in biology and genetics, greatly improved crop yields, the drought resistance of plants, and reduced crop predation by pests, thus improving agricultural production as a whole (Chassy 2007). These innovations occurred relatively recently, with the first genetically engineered plant being produced in the early 1980s (James and Krattiger 1996). By 1996, the Environmental Protection Agency had granted 35 approvals to commercially grow 8 genetically engineered crops and, by 2000, scientists developed "golden rice," which was the first genetic engineering project aimed at increasing the nutrient value of food.

Especially prominent debates on genetic modification include disputes over the ownership and patenting of genetic resources, potential health risks of these products, whether or not such products should be labeled, which types of transformations are or are not acceptable, animal welfare issues, and potential ecosystem effects (Lynas and Tudge 2014; Thompson and Noll 2014). While the modification of agricultural plants and animals has a long history, the current technological advances are providing novel new ethical and social issues that will increasingly impact both the application of this technology and work in various agricultural sciences, such as that in genetics, the societal impacts (if any) of such products, and the identification of any potential environmental costs.

Agricultural Sciences Today

At least three influences impacted the shape of current agricultural sciences: (1) new breakthroughs in the pure sciences; (2) social and ethical critiques of agricultural sciences; and (3) the social movements surrounding food that influenced policy and economic factors. The first two influences were touched upon above, with new breakthroughs in genetics paving the way for novel applications in agricultural sciences and social critiques sparking a renaissance in agricultural research focusing on various societal impacts of agricultural practices. The third influence can be understood as another response to the social and ethical critiques outline above. However, this response took the form of social movements that greatly impacted both the political (as some agricultural research is publicly funded) and economic landscapes; landscapes that deeply influence both farming practices and, as will be discussed below, the goals and aims of current agricultural sciences. While this development may at first appear surprising, in fact, it is part and parcel of the historical development of the agricultural sciences for the following reasons: (1) most agricultural sciences are applied sciences and thus cannot be separated from current social developments and (2) as mentioned above, a primary goal of the land-grant institutions and research stations is to perform research useful for local farmers who are themselves effected by their consumers' desires. The final section of this chapter will briefly describe each of the three influences before going on to give a description of the current state of the field.

While ethical critiques began in earnest around 1975 when Glenn L. Johnson (1918–2003) published a series of articles calling for attention to normative issues surrounding agricultural sciences, scholars from a multiplicity of fields now reflect on the social and ethical aspects of agricultural research, such as the methods used, the efficacy of studies, and the social impacts of such research. For example, three sociologists working in agriculture, Lawrence Busch, Frederick Buttel, and William Lacy, have long histories of publishing on various political and economic aspects of agriculture science (Thompson and Noll 2014). In addition, there is a plethora of work that examines normative issues surrounding American agriculture, such as that which focuses on feminist critiques of agriculture (Sachs 1996; Shiva 1992), local food initiatives (Delind 2011; Sbicca 2012; Werkheiser and Noll 2014), selective breeding and genetic modification (Boyd 2001; Greger 2011; Noll 2013; Shiva 2000), and alternative farming systems (Fairlie 2010). In addition, philosophers, such as Paul Thompson, have written extensively on agriculture practices and systems. Paul Thompson was the first ethicist appointed to an agricultural research university, Texas A&M, and is the current W.K. Kellogg Chair in Agricultural Food and Community Ethics at Michigan State University. Indeed, this appointment was the first of many, as today several land-grant institutions have appointed experts working on social and ethical aspects of agricultural science. This trend at institutions and the above scholarly work illustrates how many research administrators and scientists within the land grant institution have accepted the critics' call for agriculture research to address a larger spectrum of social goals (Thompson, Ellis, and Stout 1991).

In addition, social movements occurring over the last 20 years have greatly impacted research currently being performed in the agricultural sciences. While academics largely ignored Wendell Berry's (1977) critiques of agricultural science and land grant institutions (Thompson and Noll 2014), his popular works helped focus public attention on these issues and sparked a citizen lead movement to rebuild and support local food production structures. This work and current bestselling books, such as those by Pollan (2009; Pollan and Kalman 2011) and Kingsolver, Kingsolver, and Hopp (2008) have largely succeeded in mobilizing the public on a wide range of issues concerning agriculture. The result has been the creation of local food movements around the country, with the express aims of rebuilding and supporting small-scale farming operations through community supported agriculture projects, such as community gardens and local food sourcing. These movements are a response to a wide range of critiques of the agricultural system, such as the economic consolation of agriculture, food health scares (see the recent *E. coli* contamination of spinach in 2006), the desire for non-genetically modified foods, the claim that smaller operations are more environmentally "sustainable," a rejection of current industrialized practices and/or selective breeding programs, and a strategy for the revitalization of rural areas (Feenstra 2002; Lyson 2004). Thus these social movements can be understood as at least a partial reaction to some of the technological developments made possible by the agricultural sciences.

While these three impacts are generally seen as a separate issue from the agricultural sciences, in actuality, they have had a large impact on the design and goals of current research projects. For example, the local food movements have greatly increased the economic demand for "organic," "sustainable," and environmentally responsible agricultural products and led to the creation of government certifications to ensure that farmers are using these methods of production. These changes in the economic and social contexts impacted current agricultural science at both land-grant institutions and in the public sector, as they spurred an increased amount of research on organic methods of production, the reintegration of livestock into farming systems, mitigating the environmental impacts of farming, improving the long-term sustainability of diverse types of agriculture, and the various social and economic impacts of small-scale and large-scale operations (Delind 2011; Jackson and Jackson 2002). Certainly, as the needs of the local farming populations shift, land grant institutions are increasingly responding to these economic and social changes. This development is not surprising as, as mentioned above, a primary goal of the land grant institutions and research stations is to perform research useful for local farmers. Thus the types of research performed are meant to reflect the current needs of the larger community.

In reality, current agricultural science is doing just this, with American agricultural scientists conducting cutting-edge research on a multiplicity of topics now aimed at social goals beyond simply increasing production; social goals such as increasing the sustainability of farming methods, reversing or stemming climate change by trapping greenhouse gasses in soil, fighting desertification, and developing area-specific crops and farming methods to help fight hunger in areas with poor growing conditions, be those urban or rural areas. While the land-grant institution was seen in the past, at least by critics, as the wellspring for many of the current problems faced by American agriculture. Today the three-way partnership between universities, experiment stations, and extension service forms the backbone of current research that has far-reaching implications well beyond the United States' borders and is our best hope for addressing many "wicked" or overly complicated issues that we face today.

Bibliographic Essay

Agricultural science has a long history, beginning alongside the birth of empirical methods of knowledge production. In fact, it is one of the oldest applied sciences and for this reason literature on this topic is vast. However, when looking at the history of agricultural science both within the United States and beyond, there are clearly identified developments that served as historical turning points for the field. Thus, a student interested in gaining greater knowledge of the historical development of agricultural science can turn to the following literatures: (1) the history of agricultural development prior to the Enlightenment; (2) agricultural sciences during the Enlightenment; (3) the history of agricultural science in the United States; and (4) critiques and current literature in the field. Studying literature in these areas should provide readers with a detailed overview of the field and how it developed over time.

For example, when reading important texts in the history of agricultural development prior to the Enlightenment, readers should pay particular attention to the first attempts at using rudimentary empirical methods to improve agricultural practices and make note of the agricultural methods used during this time. In this time period, Xenophon and Aristotle both wrote extensively on agriculture. Aristotle's *Politics* includes sections on the soil and Xenophon's *Oeconomicus* discusses daily life on the farm (Strauss 1970). In addition, Roman texts, such as Columella's 12 volumes on agriculture, discussed various agricultural practices and gave descriptions of experiments conducted in these areas (Columella and Ash 1941). See Victor Hanson's (1999) *The Other Greeks: The Family Farm and the Agrarian Roots of Western Civilization* and Signe Isager and Jens Skydsgaard's (1995) *Ancient Greek Agriculture: An Introduction* for a detailed overview of agricultural developments in Greece, and Mark Tauger's (2010) *Agriculture in World History* for an overview of developments during the Classical period and beyond.

The second area of literature about agricultural science during the Enlightenment is also pivotal for understanding the historical development of the field, as this period can be understood as the birth of the modern agricultural sciences (Kingsbury 2009). Here scientific methods born out of the Scientific Revolution both increased agricultural production and shaped the disciplines that we know as agricultural sciences today. Important works during this period include those by various philosophers who wrote on the applications of technology and changing economic and social factors that influenced agriculture, such as John Locke, Jeremy Bentham, and John Stuart Mill and economists Adam Smith and Thomas Malthus. A third literature that is important during this period includes those by the chemist Justus von Liebig, the agronomist Jethro Tull, and the agrarian and politician Thomas Jefferson (Thompson and Noll 2014). Again, see Tauger (2010) for a general overview and Kingsbury (2009) for a superb history of the development of agriculture science during this time.

These first two areas of literature provide the background for a better understanding of the development of agricultural sciences in the context of the United States, as early work in agricultural science was influenced by European thinkers. Unlike Europe, however, agricultural science became institutionalized in the late nineteenth century with the birth of land-grant universities and the establishment of federally funded experiment stations (Hillison 1996). These developments helped form the triangular partnership (farmers, government agencies, and public sector research institutions) that MacKenzie (1991) argues supported cutting-edge agricultural research in the United States for the last 100 years, and continues to support it today. MacKenzie's (1991) essay "Agroethics and Agricultural Research" and Rosenberg's (1997) book *No Other Gods: On Science and American Social Thought* each provide historical overviews of this important period. In addition, Alan Olmstead and Paul Rhode's (2008) *Creating Abundance: Biological Innovation and American Agricultural Development* outlines the historical development of crop-specific farming practices (such as tobacco, cotton, and dairy), and technological advances in the United States.

The fourth and final area of literature is the largest by far, as it encompasses key texts in both the numerous social and ethical debates and current developments in the field. Here it is important to note that it is simply not possible to list all of the current literature in agricultural science proper, as the subject is vast, with experts working in many different highly technical fields. However, it is possible to gain an understanding of the larger structure of the field and the social and ethical influences that helped shape current research, again, the literature is vast in this area and continues to grow. For this reason the following review will be cursory at best but is adequate for gaining a basic understanding of the field today.

Over the last 20 years, the agricultural sciences in general and the research priorities of these fields in particular have been subjected to growing criticism (Dahlberg 1988; Johnson 1984; Thompson, Ellis and Stout 1991). The result of these critiques was, in addition to work on increasing productivity and improving farming practices, the expansion of the scope of current agricultural research to include work in the neglected areas identified by the critiques. The work of Shiva (1992) on the Green Revolution, Pimbert's (2008) critique of global food systems, Mizelle's (2011) history of animal husbandry methods, the development of slaughter houses, and worker conditions, and Lyson's (2004) work on the connections between farms and community each provide interesting insights into these critiques. Also, Thompson, Ellis, and Stout's (1991) essay on "Values in the Agricultural Laboratory" and Thompson and Noll's article "Agricultural Ethics" (2014) provide excellent overviews of these critiques and outline how US agricultural scientists are rising to the challenge of addressing these social issues.

Other important works include those on specific subtopics in this field such as Kingsbury's (2009) *Hybrid: The History and Science of Plant Breeding*, which provides an exhaustive history of plant breeding that includes discussions on genetic modification technology, organic agriculture, and other important topics in current agricultural science; Tauger's (2010) *Agriculture in World History* that includes a chapter on current developments in American agriculture; and Fairlie's (2010) *Meat: A Benign Extravagance* that discusses various different farming systems used for both field crop and meat production, the accepted methods of measuring efficiency, and the political and normative influences that are currently shaping farming practices.