Chapter 35
Agronomy and the Sustainability of Crop Production

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Abstract Lessons learned since the discovery of agriculture suggest that good agronomy as an integrative science is essential for improving the sustainability of current agricultural systems. To meet the challenges of producing sufficient, nutritious food for a growing population, future agronomists will have to combine advances in plant breeding and biotechnology with new approaches to improve the efficiency of nutrient and water use in agricultural production. There is significant potential in many areas to increase yields by bridging the gap between potential and actual yields, but as average yields increase with time, such potential diminishes. The threats of soil degradation and water scarcity will require widespread adoption of conservation practices based on strong extension efforts and the use of new IT technologies. Global change will have positive and negative outcomes in the agriculture of different regions, but will introduce more uncertainty in defining the best strategies to cope with climate variability. The most likely path to the sustainable intensification of production would be through continuous, small productivity improvements rather than through a few revolutionary discoveries, at least in the medium term.

35.1 Introduction

Agriculture started with the domestication of cereals around 10,000 years ago (10,000 BP). Today the same species (wheat, rice, maize) constitute the basis for global food production. Much before 10,000 BP seeds from some grass species were collected and processed to increase digestibility, as part of a diverse diet that included fruits, animals and fish. Climate variations (colder, drier periods) probably led to a reduction in the availability of natural food sources, making it difficult to gather wild plants and to hunt animals in sufficient amounts. That explains why

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F.J. Villalobos, E. Fereres (eds.), *Principles of Agronomy for Sustainable Agriculture*, DOI 10.1007/978-3-319-46116-8_35

humans were forced to move up the trophic chain as herbivores have greater conversion efficiency than carnivores. It was found that productivity of natural grass populations increased with some management operations (e.g. weeding). While doing so these proto-farmers, unconsciously, started selecting plants with favorable characteristics (larger seeds, lack of dehiscence, absence of dormancy), and after harvest, some seeds were saved for planting subsequently in other fields. This process of domestication occurred independently at about the same time in several different areas of the world such as the Far East, Mesoamerica, and in the Near East where wheat and barley originated. Rice cultivation in China began 11,500 years ago, while squash was domesticated in Central America about 9000 years ago. That was the start, and very rapidly a few species of cereals and legumes achieved the desired agricultural characteristics. At the same time early farmers probably observed the advantage of concentrating useful plants in fields which could be protected from herbivores or neighbors and cleaned from other competing plants. This also allowed for a more efficient harvest.

Most hunter-gatherers had a very varied diet of wild plants and animals although in some cases they subsisted almost entirely on meat or on a few plant species. As agriculture developed, some wild species were selected under domestication for different purposes, leading to quite different crops. For instance, *Brassica oleracea* has been selected for its leaves (cabbage), stems (kohlrabi), flower shoots (cauliflower) and buds (Brussels sprouts).

With agriculture started the development of modern civilization whereby increases in food production led to technological development, because food surpluses could be used to feed full-time craftspeople and inventors, leading also to the diversification of human activities. It also led to social stratification, political centralization and militarization by feeding full-time aristocrats, bureaucrats and soldiers. These advantages enabled agricultural societies to eventually displace most hunter–gatherers around the world towards marginal environments.

Early agriculture was rainfed so it could only thrive in areas where enough rainfall could sustain grain production, which in the case of wheat and barley represents a minimum of 200–300 mm/year. In the arid zones, where precipitation was erratic and insufficient to sustain crop production, irrigated agriculture appeared first in 6000 BP in Egypt and Mesopotamia by merely diverting water from rivers to adjacent fields during periods of flood. This soon evolved into sophisticated systems of water distribution which required a strong social organization for operation and maintenance. Interestingly, lack of knowledge about the need to control salinity and excess water from irrigation through drainage led to the decline of some ancient civilizations in the arid areas of the Near East that expanded based on irrigated agriculture.

Continuous cropping of the same field soon showed declining yields due to the loss in soil fertility from extraction and cultivation. This led to shifting cultivation systems such as slash and burn agriculture, a primitive mode of rotation aimed at concentrating mineral nutrients after many years of forest growth and then releasing them by burning the vegetation, which allowed a few years of cultivation with sufficient production. This form of agriculture could be made sustainable if the turnaround time for burning the forest is long enough to allow for building back the natural soil fertility. However, population growth increased the pressure on land use and slash and burn expanded in many world areas and was in the end responsible for the deforestation and land degradation of many regions, when population pressure led to unsustainably low ratios of forest to cropped land.

The different agricultural techniques evolved in parallel. Tillage started using the ard which only cuts a small furrow (drill) in the soil and is therefore helpful for sowing but not for weed control, incorporation of residues or clearing new land. The ard appeared around 7000 BP in parallel with the domestication of cattle. In fact, the most primitive form of planting must have used a stick to drill a hole in the ground, place the seeds and covered them with soil, a practice that was used by most indigenous societies. Moldboard plows appeared much later and were designed to turn the soil for more effective weed control. The plow, pulled by man or animals, became popular in Europe around 1500 AD allowing a more complete and deeper soil disturbance, and the upturning of the soil which was the only way to control aggressive weed invasions. The Europeans exported the plow to America, Asia and Africa where it facilitated greatly the expansion of commercial agriculture with limited human labor inputs. In some areas, particularly within the tropics and subtropics, the use of the moldboard plow has become clearly unsustainable due to enhanced soil erosion and land degradation problems.

Animal husbandry also evolved in parallel with crop agriculture. Domesticated animals not only provided for food and clothing but contributed as draft power for tillage, allowed the exploitation as pastures of lands which were unsuitable for crop production, and contributed to nutrient cycling by redistributing nutrients within the agricultural systems. Other domesticated animals had a more specific role like cats as hunters of grain-eating rodents or dogs as guardians in rural areas. Production of animals and their products by grazing pasture and range lands in an extensive fashion is a practice that has ecological values such as contributing to the conservation of biodiversity.

Giant steps forward in agricultural science and technology have taken place in the last two centuries with the development of machinery, breeding of new cultivars, use of mineral fertilizers and pesticides, at an accelerated pace since the middle of the twentieth century. Modernization of agriculture has led to the separation of the different activities that once were all part of the life of farms, and has transformed human society. Prior to mechanization, the manual labor of most farming activities represented a physical effort that required large numbers of farm workers which had very low productivity. Additionally, life as a farm worker was not very pleasant and that was one of the incentives for introducing the mechanization of many farm operations. As technology improved, more specialization was required so that farmers could concentrate on fewer activities for which they had to develop the proper skills and afford the required machinery and infrastructure. Rural societies thus experienced a revolution that changed how farming was conducted and led to land consolidation, fewer farmers, and vast migration movements from rural areas to cities in search of a better life. Before mechanization, farmers exploited crops, pastures and forests using animals for different uses (food, draft, transportation). At that time, life of most of world population was based on agricultural activities, and even by 1950 more than 70 % of the population lived in rural areas. Since the 1950s, the challenge of feeding a population growing at unprecedented rates was more than met by an evolving agriculture in what is now considered one of the most remarkable success stories of mankind. In 1950, there were about 2500 million people in rural areas and about 750 million in the cities. By 2014, the total population had reached 7200 million with almost 4000 million in urban dwellings and yet, agriculture produces now 25 % more calories per capita than in 1950. There continues to be, however, serious limitations in food distribution and access, primarily in rural areas, as evidenced by the persistent existence of extreme poverty and hunger in hundreds of millions of persons in the Planet. Furthermore, there are concerns regarding the sustainability of present agricultural systems as to whether the recent productivity increases have been achieved at the cost of resource base degradation, with the ultimate consequence of a decline in productivity in the future.

Although there is wide diversity among the different agricultural systems currently in existence, commercial agriculture has now been transformed into a set of industries where crops or animals are grown that may provide inputs for each other but operate in isolation. This new specialized agriculture has been very successful in increasing productivity but its long term sustainability remains unclear. In this chapter we will discuss some important issues which represent future threats and challenges to agriculture and food production as it is presently carried out.

35.2 Climate, Soil and Water

Agriculture takes place outdoors and plants are primarily dependent on the weather around them for growth and development, and on the soil for nutrient and water supply. The climate of a location determines what species can be grown and, also, the level of risk that a farmer faces if he selects crops that may be sensitive to the anticipated climatic features. As the climate becomes more limiting, the risk of very low yields or even crop failures increases (risk being the product of probability and impact) and crop choice is reached as a compromise between profit expectations and risks. While agriculture has always been pushing at the margins by approaching the climatic limits of crop viability, farmers are risk avoiders and always try to balance profitability against risk. An additional factor that must be considered is the normal climate variability that agriculture must deal with every season. Some of the variability can be explained by regional phenomena such as the warming of ocean waters in the Pacific, an event called El Niño, which occurs with a periodicity of several years and causes excess rainfall in some regions and drought in others. In some areas such as Eastern Australia, predictive tools based on prior observations of El Niño events coupled with barometric pressure oscillations (El Niño-Southern Oscillation) have been developed to anticipate whether the upcoming season would be wetter or drier than normal. This information is critical to design seasonal strategies leading to the optimization of planting dates, and of investments in the application of fertilizers and other inputs. Seasonal predictions are still in their infancy in many world areas but improving their reliability is essential to greatly reduce the risk levels in farming.

35.2.1 Climate Change

Imbedded in the climate variability that agriculture has experienced since its invention, there is now a general consensus that the climate is currently warming as CO_2 concentration increases due to human activities (burning of fossil fuels, deforestation). The average temperature of the Earth has increased about 0.8 °C since 1880, while the magnitude of future warming is uncertain depending on the Global Circulation Model used and the future scenario of CO_2 emissions. One may expect a temperature increase of 1–4 °C with CO_2 concentrations between 500 and 700 ppm by the end of this century. The possible impact of this global change on agriculture has been studied mainly using simulation models (Chap. 33) that predict a general decrease in agricultural productivity. However most studies have not fully considered the positive effects of elevated CO_2 concentration on photosynthesis and assume that agricultural systems do not adapt to change. Nevertheless, crop management will adapt to and mitigate, at least partially, any possible effects of environmental change. On the other hand a higher CO_2 concentration leads to lower canopy conductance and will increase photosynthesis in C3 plants. Some of the main effects of global warming on crop performance include:

- Accelerated crop development with shortening of the growing cycle in annual species. This would reduce yields but may be offset by earlier plantings and/or by changing the cultivar (using longer cycle or responsive to photoperiod varieties).
- Increased evaporative demand: many studies have concluded that ET will increase with global change as reference ET (Chap. 10), which is calculated with meteorological data only, will increase as air temperature and vapor pressure deficit (VPD) increase. This is misleading as the increase in CO_2 concentration will increase canopy resistance, i.e. stomatal aperture will be reduced. In the end, the increase in VPD due to warming may be offset by partial stomatal closure, so ET probably will hardly change.
- While global warming should lead to a global increase in precipitation, it is not possible at this time to predict future changes in precipitation at the regional level with any degree of certainty. Many models predict an increase in the frequency of extreme events, droughts and floods, as the hydrologic cycle intensifies due to global change. However, such predictions have not been validated yet and should be taken with caution, although agriculture would be much more vulnerable to an increase in the frequency of extreme events than to a gradual change in temperature.

– Changes in biotic factors (changes in the incidence of insects, diseases, weeds) may occur but the actual outcome is hard to predict. Some pests would be more damaging than at present and others would be less, while new pests may emerge in locations where they did not exist now. For instance milder winters may favor survival of insects while warmer springs would promote growth of C4 weeds which compete favorably with C3 crops.

Agriculture has contributed in the past to global change primarily through the change in land use as agricultural lands greatly expanded since the 1800s until 1960. Since that time, the surface area devoted to crops has remained more or less constant and its contribution to greenhouse gas emissions has been modest relative to those from industry and transportation. While there are agricultural practices that contribute to mitigation (e.g. minimum tillage, Chap. 18), the capacity of agriculture to mitigate global warming by sequestering carbon is also modest relative to options derived from changes in the energy and transportation sectors. Emphasis should be placed on adapting agriculture to global change using the combination of breeding × agronomy × management that has been so successful until now, while at the same time, taking advantage of mitigation options that may also contribute to the sustainability of agriculture (see below).

35.2.2 Soil Degradation

Over the centuries, the conversion of lands for use in crop production has included the development of fragile areas which are prone to degradation. Exploitation of soils without maintaining their fertility by restoring nutrient extraction and their physical properties (Chap. 26) also leads to soil degradation. Exposure of bare soil surfaces to rainfall and tillage operations enhance the rate of natural soil loss or erosion of the surface layers which normally are the most fertile. A single soil erosion episode represents an amount of soil loss that exceeds by orders of magnitude the rate of soil formation. Despite the advances in methods of Earth observation, there are no good statistics of the degree of soil degradation around the world but estimates indicate that the problem is very relevant, requiring periodic monitoring to assess its severity in the different regions. Soil erosion will continue to be a major threat to sustainability of agricultural systems around the world. The expansion of conservation agriculture (Chap. 18) is helping in many areas to control erosion but it requires the adaptation of agricultural techniques (machinery, cultivars, pest control) to site specific conditions and cannot be used in all agricultural systems. There are soils that require periodic tillage to maintain some physical properties and in some regions, crop residues needed to protect the soil surface as part of conservation agriculture are used for animal feed and therefore are not available for soil protection. Intensification may lead to the production of enough crop residues to both uses. Soil salinization is another threat to sustainability that affects possibly up to 15–20 % of world irrigated area. Again new monitoring methods can reduce the risk and help to introduce salinity control measures to prevent the problem (Chap. 22).

The maintenance of soil fertility in the long term is essential to ensure the sustainability of agriculture. This is particularly important concerning phosphorus, as sources for P fertilizers are limited (Chap. 26). Efforts here should focus on P recycling and on increasing the availability of soil P to plants. In the case of N, the availability of N fertilizers will depend on energy prices so the inclusion of legumes in crop rotations would be a partial solution when needed. Nevertheless, the use of synthetic N fertilizers in agriculture is extremely efficient in energy terms. If N concentration in grain is around 2 %, each additional kilogram of N added to the crop will support a yield increase of 50 kg. The average energy required for producing the N fertilizer is 77 MJ/kg (Chapter 7) and since the energy content of grain is around 18 MJ/kg, the marginal efficiency would be $900/77 = 11.7$. Innovative approaches for improving the efficiency of N fertilizer use will reduce N fertilization rates and the consequent non-source pollution which affects surrounding ecosystems and water quality in many intensive production areas.

35.2.3 Water Scarcity

Irrigated agriculture expanded greatly in the second half of the twentieth century, increasing from 120 to about 300 million ha. In fact, given that the productivity of irrigated systems is about 2.75 times more than that of rainfed systems on a worldwide basis, today the production of sufficient food relies significantly on irrigated agriculture. Irrigation expansion has come at a cost from the environmental point of view. On the one hand, the construction of reservoirs for irrigation has changed the natural environment and had an impact on river ecology. On the other hand, the return flows from irrigated lands constitute a major source of non-point pollution, which is unavoidable to some extent if irrigated agriculture is to be sustainable. This is because the maintenance of salt balance through drainage is essential to prevent salinization of large irrigated areas. Additionally, irrigated area expansion and production intensification require large amounts of water, to the point that irrigation is the primary consumer of the water diverted by man for various uses. More of two thirds of diverted water is consumed in irrigation worldwide. Contrary to other uses (for example, domestic) where water used can be recovered and reused after appropriate treatment, much of the water used in irrigation is evaporated and thus leaves the basin. While a fraction of the irrigation water can be reused, as irrigation becomes more efficient, such fraction diminishes and the ET process dominates irrigation water use. With efficiency increases, due attention must be paid to the maintenance of salt balance in areas of low rainfall and/or where saline waters are used for irrigation.

An emerging problem that threatens the sustainability of irrigation in some areas is the excessive use of groundwater beyond the long-term supply. Groundwater usage may exceed aquifer recharge in droughty years provided that the excess extraction is eventually replenished in the long run. However, long-term decline in water table depth as it is occurring now in some regions of China and India, among others, is an indication of unsustainable use. In extreme cases, land subsidence can reduce aquifer capacity permanently or cause sea water intrusion in coastal areas with the permanent deterioration of water quality. Better assessment of groundwater resources combined with recharge programs and wise and strict resource management can bring solutions to this problem.

At present, irrigation is under scrutiny by the other sectors of society that perceive that its share of water usage is too high. This is particularly critical in areas or times of water scarcity, where competition with other uses becomes fierce and urban and other demands have higher priority. Thus, while there is a need to expand irrigation as one option for production intensification to meet future food demands, competition for scarce water with other sectors, including the environment, is going to restrict such expansion forcing irrigated agriculture to do more with less water. Although many advanced technologies are available for improving irrigation management, widespread dissemination has been limited so far. The time has come for many irrigated areas to promote on a large scale the adoption of efficient irrigation practices in order to meet both increased productivity needs and societal goals. Independent certification of efficient use of water in food production with appropriate indicators will be welcomed by consumers and the rest of the society.

Promoting the efficient use of water in rainfed agriculture is also a very promising goal for production intensification in the future. The approaches should focus on other factors co-limiting yields (such as nutrients) and on accepting more risks, abandoning the conservative approaches to rainfed farming that avoided risk but that had little reward on good years. Acceptance of more risk in rainfed farming requires new tools such as reliable seasonal forecasts, and advisory services that will assess risks quantitatively and will offer flexible options adapted to local conditions. In its simplest view, risk equals the product of probability by impact, and the avoidance of extreme events that could impact the viability of farming irreversibly causing famine has dominated past rainfed strategies. In this regard, the resilience of the agricultural system, that is its capacity to recover after a perturbation, is critical for the sustainability of the system. As new technologies and policies enhance the resilience of rainfed systems, accepting more risk will lead to productivity increases in the future.

35.3 The Role of Plant Breeding

The development of modern plant breeding technologies after 1950 has produced new cultivars which are highly productive and widely adapted. The major plant feature that has been improved in the major crops is its harvest index whereby current varieties have HI values that are 50 % greater than those of 50 years ago.

The success of the recent agricultural intensification has often been attributed to the new varieties without recognizing that varieties or agronomic inputs produce nothing in isolation. It was the combination of new varieties and new agronomy together with adequate management what has enhanced the productivity of agricultural systems until now.

Plant breeding techniques are nowadays more powerful and more efficient due to genetic engineering which has led to the production of new cultivars labeled ‘transgenic’ crops (Genetically Modified Organisms, GMO). Transgenic crops have been highly successful so far by addressing crop features than are related only to a few genes. For example, the quality of the seed may be improved (e.g. yellow rice) or the plant may acquire insecticidal properties (e.g. BT maize or cotton) or resistance to a given herbicide (e.g. resistance to Roundup in soybean). The primary goals were to reduce production costs (by applying less pesticides) and, by reducing/eliminating usage of some pesticides, to contribute to improved human health and to the environment. The improvements in farm profitability have been such that transgenic soybeans, maize and cotton have been widely adopted in less than 20 years, not only in the USA where more than 90 % of the three crops are now transgenic, but also in some developing countries, as India or China. Plant breeding efforts to produce transgenics are now being extended to other crops to address biotic stresses or crop quality problems.

By contrast, the promises of improving plants against abiotic stress (drought/ salinity) using GMOs have not been fulfilled so far. This is firstly due to the complex nature of the problem. What is drought? Is the pattern of water deficit the same every year? Should we look for plants that are “water savers” or “water expenders”? The former would grow slowly thus allowing more soil evaporation to occur but would generally have more water for completing seed growth, thereby ensuring a high HI. On the contrary a “water expender” leads to higher biomass production and probably higher yield in good years at the expense of lower HI and yield in bad years. Thus, the best cultivar for rainfed conditions depends on local conditions (climate, soil) and changes from year to year. Furthermore, the tight relationship between assimilation and transpiration (Chap. 14) must be considered. Water use efficiency is mostly dependent on the evaporative demand (air VPD) so little can be achieved by breeding for high WUE under specific conditions. Breeding for high WUE could result in cactus-like cultivars that would keep their stomata closed most of the time! Breeding efforts should be directed instead at manipulating development to fit the most probable drought patterns and to tuning stomatal aperture to periods of low VPD.

Despite the success of the first transgenic crops, there are concerns on the use of this technology mostly related to perceived risks in food safety and the environment, and to the loss of autonomy of farmers for seed production. The risk for humans is unfounded and unfair as there are strict regulations regarding food safety and environmental impact assessment during the breeding process. Additionally, the improved GM varieties are allowing an important reduction in pesticide use thus reducing a potential toxic effect. The other concerns deal with broad social issues and intellectual property rights and is beyond the scope of this book. Is agricultural technology such as transgenic crops which are in the hands of a few private companies a real menace to small farmers around the world?

Plant breeding has been extremely effective not only in contributing to increased productivity, but in adapting crops to new environments. This will be even more important as global warming continues and crops will have to be adapted to warmer environments or to cold areas of the higher latitudes that until now have not been suitable for agriculture. Every major crop species has many thousands of different varieties offering wide adaptation that can be tested and adapted to specific environments through conventional and modern plant breeding combined with new agronomy and management, thus, as in the recent past, crop adaptation will be a very important target for the future of agriculture.

35.4 Alternative Agricultural Systems: Organic Farming

The intensification of agricultural production of recent decades with the extensive pesticide use and the episodes of environmental non-point pollution have given way to alternative movements that question mainstream agricultural practices, viewing them as unsustainable and unhealthy. As a result, other forms of agriculture have been proposed, some based on avoiding the use of synthetic chemical inputs and others that combine different practices using extensively traditional knowledge. These alternative movements have been met with positive views from some urban societies around the world that perceive 'industrial' agriculture as a threat to human well-being and to the environment.

The most popular alternative agriculture system is organic farming based on using only organic fertilizers such as manure and plant protection methods that forbid the use of synthetic pesticides and are founded on biological pest control. Eliminating pesticide use has been welcomed by consumers and reduces the environmental impact of agriculture but organic farming has also established a set of rules without scientific basis, particularly those related to soil fertility, which are solely based on the naïve idea that natural is good and synthetic is bad. Molecules such as nitrate, are exactly the same independent of the origin of the fertilizer, so they produce the same benefits to the crop or may lead to the same environmental problem (groundwater pollution). Thus when their systems are based on following a set of strict rules, organic farmers may be condemned to low yields/income if organic fertilizers are scarce and/or expensive. Often, additional land is needed to fix the N needed in the soil through the use of cover crops. While organic agriculture has been very successful in finding a market niche among the urbanites of affluent societies, the feasibility of expanding organic farming beyond a relatively small share of world agricultural production is highly questionable. Global N fertilizer production in 2010 was around 100 Mt N. If we eliminated completely synthetic fertilizers we would require legumes incorporated into the soil as green manure. Assuming an average input of 100 kg N/ha/year, that would take 10^9 ha which is clearly impossible to achieve as total arable land is only 1.5 10^9 ha. In other words, green fertilization would reduce current world productive arable land to one third of the current value.

35.5 Agriculture as an Energy Source

Primary production is an inexhaustible source of energy and therefore has been used by man since long ago. It was during the energy crisis of the late 1970s when agriculture was first considered as a potential source of energy, either through novel, energy crops or using some of the main crops for converting biomass and grain into fuels. Since that time, most of the energy crops have not fulfilled their initial promises (although newly tested C4 species such as *Miscanthus* might be a viable option) and the focus has shifted to ethanol production from sugarcane and maize, with some attention paid to converting edible oils into biodiesel. The contribution of fossil fuels to global warming and the high prices of oil in the recent past have fostered policies for promoting the use of biofuels produced in agricultural lands, particularly in South (sugarcane) and North America (maize). Globally, while the use of biofuels reduces greenhouse gas emissions, the competition between food and energy production is the subject of debate in ethical and environmental terms. For instance, the incentives for producing biofuels have contributed to the expansion of oil palm production at the expense of food crops or of the maintenance of tropical forests thus increasing deforestation. This debate is sided by proposals to use only crop residues as the energy source. This promise of "second generation" biofuels based on the use of residues by conversion of cellulose to sugars, which would then turn into alcohol has been achieved in technical terms, although production costs are still high relative to those of biofuels from sugarcane or maize. The claim that by using only crop residues there is no competition with food production is not valid for two reasons: first, crop residues do have an important role in soil conservation and in maintaining soil organic matter (Chap. 18), and as animal fodder in many agricultural systems and second, if sugars can be produced, then they could also be used for food production.

The relative capacity of agriculture as a potential energy producer may be quantified by comparing the energy contained in food products, against the energy burnt in fossil fuels. The total global consumption in 2010 of liquid fossil fuels (gasoline, refined fuel oils, etc) which is mostly used in transportation was around 70 million barrels/day which is equivalent to 135 10^{12} MJ/year. For the same year, global agricultural production was 3866 Mt of dry matter (Table 35.1) which corresponds to a total energy of 71 10^{12} MJ which is less than 50 % of the energy of liquid fuels. The EU has established the goal of supplying 10 % of fuel as biofuels by 2020. If that rule is applied globally it would require 13.5 10^{12} MJ which is equivalent to almost 20 % of agricultural production.

Table 35.1 Global crop production in 2012 classified by crop type and equivalent energy captured

Crop type	Crop production Mt dry matter	Energy content MJ/kg	Equivalent energy EJ
Grain	2276	17	38.70
Oil	450	27	12.15
Legumes	317	19	6.03
Sugar	307	17	5.22
Starch	230	17	3.91
Fruits	157	17	2.67
Vegs	74	17	1.27
Non food	38	17	0.65
Other	15	17	0.26
Total	3866		70.85

35.6 The Role of Research, Extension and Information/ Communication Technologies

The returns on past investments in agricultural research have been so high that some have termed agricultural research as the best business of the public sector ever. Modern agricultural research started in the last decades of the nineteenth century, primarily in Germany, USA and England. After the Second World War, in view of the need to produce more food for a growing population, there was an initiative led by private foundations and some countries to develop a system of international agricultural research which eventually became the Consultative Group of International Agricultural Research (CGIAR) with research centers located in developing countries. The CGIAR developed the first cultivars of dwarf wheat and rice that were more productive than existing tall cultivars, leading what was later called 'the Green Revolution'. All countries have since developed their agricultural research systems which have contributed to the sustained increases in food production worldwide since 1950.

Along with agricultural research, some countries such as the USA developed in parallel a system for disseminating the new results among farmers to promote adoption of new techniques as they were developed by researchers. Agricultural extension has also been very successful and there are many examples of successful adoption of new techniques that were experimented locally and tested by extension. Many of the newly developed techniques require adaptation to local conditions as a prerequisite for adoption by farmers. Without a good extension system, farmers hesitate in adopting new ideas that have not been adapted and tested locally, and progress is slower. Also, being extension part of the public sector, they are independent of private corporations and free of biases towards certain varieties or products. Agricultural extension started in the USA before the end of the nineteenth century and has been largely responsible for the expansion and productivity increases of US agriculture. Other countries have created effective extension systems but many developing countries have not invested sufficiently in agricultural extension, and this is limiting the rate of adoption of effective solutions that increase productivity and sustainability. One limitation is the huge number of small farmers that exist in many countries which will require a very large extension force to carry out the work in the field, if extension is to be conducted in the way it has been until now (face to face). However, new communication technologies such as cell phones which are readily available in most areas could serve as innovative ways to reach the large populations of small farmers effectively.

In general, communication technologies have accelerated the access to vast amounts of information but cannot guarantee its quality. Information delivered by private companies is often biased towards the benefits of their products and sometimes it escapes regulations on false advertising. It is common to see web pages where companies mention "studies performed at different universities" (without more detail) to support their products. Public research/extension systems will be required to address the needs of farmers and the whole society in particular providing assessments concerning the long term or large scale effects on agricultural systems (e.g. soil erosion).

Given the predictions of increase in global population and economic development, it is estimated that 70 % more food will have to be produced by 2050 (see below). The magnitude of this challenge cannot be underestimated given the current productivity trends of the major crops. Agricultural research will play an important role in meeting this challenge as it has done in the past, provided that governments around the world realize the difficulties ahead and invest sufficient resources to tackle the research issues related to increasing production in a sustainable fashion. The associated extension efforts, which will be badly needed, will increasingly be based on the use of crop simulation models and the development of decision support systems tailored to the specific needs of the farmers and communicated through the web.

Box 35.1 Visualizing the Future

A farmer in 2050 is planning to sow wheat by November 1. By October 15 a sampling robot is sent to the different fields of the farm where it automatically samples the soil in different locations and produces maps of nutrient (nitrate, P, K) and soil water content, which the farmer checks against similar observations obtained 2 weeks ago from a satellite service that he subscribes. The robot also takes some samples that are packed and sent to the regional research center to test for soil pathogens or insects. On the same day, his drone flies over the farm and collects visual and NIR images to map the weed spots in the fields to be sown. Then the farmer looks at a DSS that shows the estimated soil water content in the different fields. With that data and the local rainfall forecast for the next 2 weeks, the system connects with the web sites of seed companies, collects information on the different cultivars available,

(continued)

Box 35.1 (continued)

runs a simulation model of the crop based on a reliable seasonal weather forecast and compares which are the best options, considering seed price, expected yields, product prices and local availability. The farmer buys online the seed required.

The same DSS builds also a map of recommended application of N, P, K and contact herbicide and calculates the quantities to be ordered by checking the actual stocks. The farmer compares online the prices and conditions of different suppliers and confirms the order. According to weather forecasts dry conditions are expected by October 22 and 23 with rainfall afterwards. These are appropriate for applying the N and the herbicide. By October 20 an email is received from the regional research center advising the use of an insecticide at a given rate along with the seed. The farmer confirms online the use of the insecticide which is registered on an external database of pesticide use.

On October 22 the robot fertilizer-sprayer goes to the fields and applies urea at variable rates depending on need. It also sprays herbicide only on the spots where weeds had been previously detected. After the job is done the farmer confirms online the amounts of N and herbicide used in each field. This information goes to the external databases for subsequent N fertilizer and pesticide use.

On November 1 the robot seed drill is sent to the fields to sow and to apply localized P and K fertilizers at variable rates. The planter will follow always the same path as all other machinery to avoid compaction due to traffic.

35.7 Food Security and Food Safety

Following a sharp increase in food prices in 2008, concerns for food security, understood as a situation where all humans will have access to sufficient and nutritious food, have increased around the world. Food security is now high in the agenda of many countries that are planning for an uncertain future where, at the same time that global food trade is reaching historical levels, food sovereignty issues related to the capacity of each country to be self-sufficient in food production are increasingly important given the current political climate. Food trade is balancing supply and demand in an effective manner and is the major instrument now to cope with instability in production caused by extreme weather events and by changes in food demand due to diet changes or other features of economic development.

Food safety refers to health issues from the standpoint of ensuring that marketable foods are both healthy and nutritious. Health-related problems in food productions appear periodically (for example, the mad cow disease caused by dubious animal feeding practices) and attract substantial attention from a society that is more and more distant from agriculture and food production processes.

Periodically, episodes of food contamination by chemical or biological agents occur in many countries and generate alarms regarding food safety. One important source of contamination is the use of untreated waste water for irrigation that still takes place in many world areas and that must be avoided by appropriate water treatment. Alarms due to food contamination cause great concern among consumers and this is rightly forcing more control and regulation of food production processes from farm to fork. Agronomists must ensure that products leaving the farm are always safe for consumption, the major issue being inadequate pesticide usage. Another important goal is to enhance the nutritional qualities of the food produced. Content in terms of protein, essential amino acids, vitamins, and other nutritional factors must be enhanced where possible by good agronomy. Other interesting aspect refers to the positive interactions between nutrition and health of certain agricultural products such as red wine, nuts, and olive oil among others, that have proven health-related benefits but where the content of the chemical products responsible for those benefits depends in part on the growing conditions. Finally, given the increasing importance of gastronomy in affluent societies, agronomists should focus more on issues related to ensuring product quality from the gastronomic viewpoint.

Although predictions vary, it is estimated that agricultural production should increase by 70 % to meet the demand of nine billion people expected in 2050. Is the world going to provide food security for all by 2050? First of all it is important to consider that not all agricultural products are used directly for food. Around 10 % is devoted to industrial crops including biofuels. The remaining 90 % is shared between food (65 %) and animal feed (35 %), which results in an overall efficiency of crop production for food of 0.65. This low efficiency is due to the low conversion efficiency of animals mainly for meat production. Here, there are ample differences in efficiencies among animals, chickens being the most efficient and cows the least (Table 35.2). However, ruminants exploit rangelands (which occupy more land that is used in agriculture) that otherwise would not be used for food production and this must be taken into consideration when addressing meat production in global food assessments. Calls have been made to reduce meat consumption in the developed

Table 35.2 Distribution of uses of edible crops and all crops circa 2012. The efficiency of conversion for energy is taken 1 for human as direct consumption. Using this Table a general efficiency of global crop production to food of 0.65 can be estimated as the weighted average of the efficiencies taken the fraction of use as weighing factors

	Edible crops	Total crops	Efficiency
	Fraction used	Fraction used	Fraction
Humans	0.65	0.5915	1
Pork	0.12	0.1092	0.1
Dairy	0.09	0.0819	0.4
Beef	0.05	0.0455	0.03
Chicken	0.05	0.0455	0.12
Eggs	0.04	0.0364	0.22

countries and this could have an impact on future food security. For instance if feed for meat production was reduced by half, the overall efficiency would increase from 0.65 to 0.74, a 14 % increase in calories available to humans. Such a drastic change would be difficult to achieve as it is doubtful that it would free as many calories for humans as computed above, as animal feed includes residues and other non-food components, in addition to the consumption of pastures. On the other hand there are clear health-related advantages of reducing the amount of animal products in human diets, particularly in countries of high consumption where obesity is a growing problem.

Another area where improvements will contribute to future food security is reducing food waste. It is estimated that up to one third of global food production is wasted before it can be consumed by humans. The nature of waste varies in different food chains but generally speaking, food waste in poor areas is primarily due to post-harvest losses caused by pests. By contrast, in the affluent countries the majority of food losses occur at the consumers' end of the chain. Although efforts are being made to reduce waste, much of it is related to social and cultural factors which, as in the meat consumption patterns, are difficult to change.

How can then agronomy contribute to food security in the future? We must make current agricultural systems more sustainable without losing sight of the need to intensify production in existing farmlands. The option of expanding agriculture has significant ecological limitations and is not going to be sustainable as most of the best lands have already been put in production. Thus, the sustainable intensification of production by introducing new techniques adapted to local conditions should continue that path of increased productivity. Ample opportunities exist around the world for increasing both agricultural productivity and sustainability by using good agronomy and appropriate crop management practices.

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