Sustainability in the Food Industry

Chapter 1

Agriculture

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Introduction: Human Food Supply Is a Continuing Challenge

Development of a sustainable agriculture and food system must be an essential part of our long-term economic and environmental planning. Adequate food and a livable environment are both critical to the long-term survival of our species.

Research and development over the past century have provided an impressive and even unexpected surge in production of food across the prime agricultural regions, especially those with potential for irrigation. Adding to these gains have been the extraordinary contributions of plant breeding to high-input production systems and the corresponding advances in fertility and pest management. The fruits of the Green Revolution and the impacts of the International Agricultural Research Centers provide evidence of what a focused public domain program can achieve. At the same time, such an acceleration in food production has come at a price. As with any biological population, human numbers have increased in response to available food and other resources. Human population is likely to reach the current projection of 9.6 billion before it is predicted to level and drop (Brown, 2008). The increasing human population and demands for food, fuel, and other products that depend on nonrenewable natural resources have put an unprecedented pressure on the global life-support system (Tilman et al., 2002). Human activities currently exploit over 40% of total net primary productivity captured by photosynthesis, leaving just over half for the maintenance of all other species.

Perhaps the fragility of the global ecosystem is best illustrated by the current rate of extinction of plant and animal species. Economist and author, Lester Brown, states that we are presently in the midst of the sixth major extinction event in the earth's history, the last of which occurred 65 million years ago, wiped out the dinosaurs, and was likely the result of an asteroid hitting the planet (Brown, 2008). Today's problem is the first such event that is almost entirely a result of human activity and our destruction of habitat. One of the immediate economic and food system impacts is the disappearance of fish and collapse of the fishing industry, with 75% of commercial fish species being removed at unsustainable rates (FAO, 2007). More far-reaching consequences of these human activities include the losses of life-sustaining ecosystem-support services (Daily, 1996). We must acknowledge that our expansion in human population and increase in food production do come at a cost, often one that we are unable to calculate.

Thus, we appear to be reaching a tipping point in the balance between exploitation of natural resources and satisfaction of human wants and needs. Brown's *Plan B 3.0: Mobilizing to Save Civilization* (Brown, 2008), provides an overview of current challenges as well as potential solutions at the global scale. Also, the recent book *Developing and Extending Sustainable Agriculture: A New Social Contract* (Francis et al., 2006) provides an up-to-date catalog of sustainable practices in agriculture, and serves as another prime resource for this chapter.

Technical Research in Agriculture

The agricultural advances during the past century were truly spectacular. While human population increased from 3 to 6 billion people between 1960 and 2000, food grain production increased by a factor of three, easily keeping up with population in aggregate and solving hunger problems in some areas (Kang and Priyadarshan, 2007). The advances in production contributed to nutrition and better health in many areas, yet persistent poverty, especially in sub-Saharan Africa, continues to prevent food from reaching many who most need this basic resource. The inequities in distribution of food appear to be growing today, along with a skewing of the economic situation between rich and poor, North and South, all in the face of food surplus in favored areas. The current move toward biofuels, especially ethanol from maize and rapeseed in the North and from sugarcane and oil palm in the south, provides another challenge to food production and availability.

The increases in food production have been due in large part to expansion of irrigated farmlands and also to increased human productivity, based on mechanization that made the farming work load lighter. This process liberated labor to pursue other activities in the later part of the industrial revolution. Of special importance is the series of genetic advances in our major food crops that has sparked the Green Revolution, uniquely impacting rice and wheat production in Asia and Latin America and maize production in temperate regions. These advances have been coupled with large increases in chemical fertilizer application and use of chemical pesticides. The combination of these components in well-designed and efficient cropping systems has produced synergisms among the new technologies to increase food production.

Genetic improvement of crop varieties has been a continuous process since the first people settled in permanent communities and began to extract the most desirable plants from their nearby environment (Plucknett and Smith, 1986). They saved seed of cereals and pulses and propagated cuttings from trees and vines that proved most desirable for their home diets. Often they were plants with the largest edible seeds, those that held tightly in the head or ear or pod rather than shattering and dispersing, and those with the best cooking qualities. Most of the genetic progress in improving yields of crop plants was achieved by women who found these early selections, while men were off hunting, and we have continued to fine-tune their efforts over the past centuries. Rediscovery of Mendel's principles of genetics was a key to understanding the mechanisms of crossing and development of hybrid maize. Genetic selection techniques for important self-pollinated cereals such as wheat and rice were equally successful. The contributions of the International Agricultural Research Centers and their partners in national programs were central to genetic progress in major crops during the last half of the twentieth century. Plants provide three-quarters of the calories and protein to fuel human diets, and it is valuable to explore the advances in the three major cereals, since together they contribute over half of all the energy in our food on a global basis.

Advances in Wheat

Wheat is one of our most important cereals for human consumption (see Figure 1.1, FAS, 2008), with global annual production of nearly

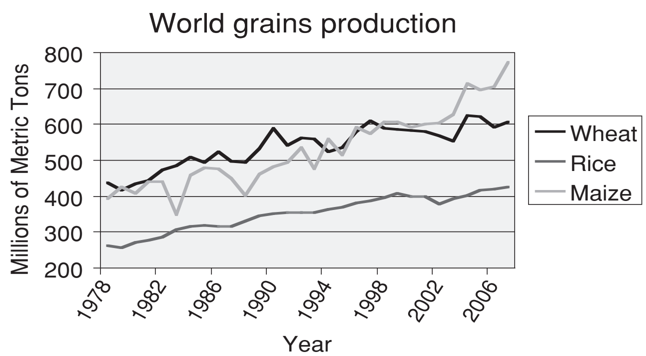

Figure 1.1. World grains production, 1978–2008 (FAS, 2008).

600 million tons (Singh and Trethowan, 2007). Half of the production is in developing countries, and much of the genetic progress can be attributed to improving adaptation to a range of water-limiting conditions through shuttle breeding carried out by the International Center for Improvement of Maize and Wheat in Mexico. Spring wheat can be grown from the equator to as far as 60° north and south latitudes and from sea level to over 3,000 m elevation. Winter wheat provides another type of adaptation to low winter temperatures and after passing through a vernalization phase can sprout early in spring and produce high yields by midsummer. Together, these wheat varieties are adapted to a wide range of ecoregions and have proved to be especially drought tolerant. Some of the highest yields have been achieved in Europe under favorable rainfall conditions, using high levels of fertilizer and growth regulators to prevent excessive vegetative growth and lodging or falling over before harvest. These systems appear to be sustainable, as long as the supply of fossil fuels, fertilizers, and chemicals needed to produce them are available. Finally, the sustainability will depend on environmental regulations and how well we are able to use these inputs without creating excessive nitrate or chemical residue loads on the environment that are detrimental to humans and other species.

Two of the irrigated areas where yields have increased in an impressive way are northwest Mexico where many of these new wheat varieties were developed, and in the Punjab of India and Pakistan where water has been available and double cropping with a summer cereal or pulse crop has been possible. Such systems are sustainable as long as soil fertility can be maintained, subject to the same limitations described for the cereal system in Europe and the availability of increasingly scarce irrigation water. In the case of the Punjab, water tables have been declining as much as 1 m/year due to intensive use of tube wells and irrigation for both winter and summer crops. At this rate, water soon becomes too costly to pump for agriculture.

Competition for water from other sectors is a critical factor. It requires about 1,000 tons of water to produce a ton of grain (Gleick, 2000). Even with the current abnormal rise in basic cereal grain prices, our economic productivity per unit of water is far below that of other industries, and it is also impossible to compete with communities for water needed for public supplies. The real advantage of agriculture in use of water is the potential to intercept rainfall over an extensive area, store this in the soil profile, and use it to grow crops. Once that resource is concentrated—in a stream, reservoir, or groundwater aquifer—it is more valuable to other sectors of society. Even recreational uses and maintaining habitat for wildlife species have higher values for some human societies, at least with the current adequate levels of food production in most areas of the world. This could change as food becomes scarce and water is needed to help supply this basic human need.

Advances in Rice

Rice is another important cereal grain (see Figure 1.1, FAS, 2008), also with annual global production over 400 million tons (Virmani and Ilyas-Ahmed, 2007), and 90% grown in Asia. The crop can be grown from 35° south in Australia to 50° north in Mongolia, and from sea level to over 3,000 m elevation. Egypt and Australia have the highest levels of productivity, with average yields over 9 tons/ha. In the latter half of the past century, rice-growing area has increased almost 1.8 times, while yields per hectare have more than doubled on average, resulting in a fourfold increase in global production. Major technological advances have included breeding varieties that are insensitive to photoperiod, and thus can be planted in any month of the year where water and temperature conditions are favorable; semidwarf varieties that respond to fertilizer with more grain rather than vegetative growth; shorter maturity varieties that allow two or three crops per year if irrigation is available; and chemical nutrient and weed management to support the highly extractive practices associated with high yields and multiple crops per year.

In addition to limitations on water, one of the most bothersome issues to emerge over the last two decades with rice has been yield decline in Asia. Although a number of theories have been proposed, it now appears that nitrogen availability at the right times in the crop's life cycle is one of the principal factors (Doberman et al., 2000). Research on this critical issue continues, since rice is such an important component of the diet throughout Asia. There have been a number of concerns, including the possibility of sub-detectable effects of soil pathogens, complex questions of nutrient availability in a continuous cultivation pattern of the same crop, and other potential soil nutrient reasons for the decline. It is essential that this problem be solved for the well-being of millions of people in Asia. The potential for solving the challenge through crop rotation is an obvious route to take, yet the suitability of these lands for rice cultivation and the continuing demand for this popular food crop are overriding reasons to find ways to make continuous cultivation sustainable, as difficult as this may be biologically.

Advances in Maize

Maize is the most important major global cereal crop in terms of total production, nearly 700 million tons annually (see Figure 1.1, FAS, 2008). This is an important cereal in much of Africa and Southeast and East Asia, far from its origin in Guatemala and southern Mexico. As the first cross-pollinated crop to receive major attention from plant breeders, maize has become a model for plant genetic improvement and the most important cereal grain in the United States and several other temperate countries. In addition to selection for crop yield, early efforts focused on increasing protein and oil concentrations in the grain with the hope that this would not reduce grain yields (Johnson, 2007). Development of inbred lines of maize and their heterozygous crosses became the standard for study of population genetics, testing methods, and more recently marker-assisted selection and other microbial techniques. Double-cross maize hybrids (four inbred parents) and then single-cross hybrids (two inbred parents) formed the foundation of the hybrid maize industry in the United States and a model for other countries seeking high yields and wide adaptation of new genetic combinations.

In addition to the hybrids based on inbred lines, pioneering plant breeders with maize introduced population improvement and other types of varieties that could be grown and their seed saved by farmers. This concept was built on knowledge of the pollination habits of maize; 95% of the pollen fertilizing a given ear on a plant comes from another plant—we would say the crop is 95% outcrossing. Thus, 95% of the seed that comes from a variety in the field is a result of crosses with some other series of plants in that field or nearby. By mixing a population of plants with similar characteristics, including grain color and crop maturity, one can harvest seed from the "best" plants in the field and assure that the large majorities are hybrids between two parents in that same field. By starting with a relatively diverse and highly productive variety (population or synthetic variety), it is possible for the farmer to select an improved variety that will be even better for his or her specific farm conditions. It is important to do this selection of plants in the field, choosing those individuals that stand up well, have insect and pathogen tolerance, and are well adapted to the cropping system. Those farmers who select ears, after they are in storage, often have taken the largest ones in hopes that this will increase yields, only to find that these came from the latest maturing and often overly tall plants, both negative attributes not visible in the ears. The development of farmer varieties avoids the need to purchase hybrid seed anew each season, and the strategy has been used with success in a number of developing countries to increase maize production.

A relatively new development in crop improvement has been the introduction of transgenic hybrids of maize, rather mistakenly called GMOs, or genetically modified organisms. This is a misnomer because all of our domesticated crops have been genetically changed since the first farmers chose plants with larger seeds or good food quality to increase and plant near their homes. Transgenic hybrids are made from lines that have one or more genes introduced from another line or species through molecular transfer techniques. They have been used to confer resistance to specific insect pests or specific herbicides. This is an expensive but highly effective way to incorporate special traits into the genetic package, the seed, which can simplify management and possibly reduce input costs. One likely downside to the technology beyond its cost is the potential for developing insects or weeds with genetic resistance to a single type of control when the new hybrids are widely deployed. Farmers are currently urged to use diversity in their planting of these new hybrids and to combine them with other control strategies so that the technology will last longer.

Chemical Fertilizers

The introduction of manufactured chemical fertilizers, especially during and after the Second World War, brought more convenience to agriculture and spurred the move toward a domination mentality in farmers about how to supply needed crop nutrients in food production. In a few short decades, we abandoned many of the ecological principles, including diverse crop rotations and crop–animal integration, which had been the foundation for much of agriculture and practiced by farmers since before biblical times. In the pursuit of ever-higher yields to increase income and feed a growing human population, with both cereals and increased protein from livestock, we moved away from systems that worked with nature's cycles and resources toward systems that created large and homogeneous fields and attempted to dominate the production environment.

This strategy of supplying needed nutrients to high-demand crops spurred a new industry of chemical fertilizers, especially to supply the major nutrients—nitrogen, phosphorus, and potassium—and starter fertilizers that helped the crop plants in the initial stages of establishment and growth. Fertilizer recommendations were designed to replace those nutrients extracted through the harvested crop, and higher levels just to be sure there was an adequate supply for good rainfall years and maximum crop yields. Yet, too often the early strategies did not include careful nutrient budgeting that took into account other sources of nutrients, such as those in irrigation water, those left over from the previous year, and those available from crop residues that break down and supply needed elements to the next crops. Starter fertilizers help the crop in early stages to mobilize scarce nutrients, especially phosphorus in cold climates, and plants appear to be greener and healthier. Yet, most often these early visible signs of plant vigor are not reflected in yield differences at harvest; thus, the inputs are not economically sound. And overapplication of soluble nutrients such as nitrogen can lead to loss from the field through leaching down the soil profile into groundwater and surface runoff through erosion that reaches streams and lakes. This is a waste of economic resources by the farmer as well as an expense to the environment and to society that has to find ways and resources to remediate the problem.

Good farm managers today are astute nutrient managers who take advantage of all available information from research as well as from their fields and personal experiences. They carefully take into account all sources of nutrients in a complete budget—for example, nitrogen from the previous crop and from soil organic matter, that from irrigation water or anticipated from winter snows and spring rains, that from legume or grass cover crops, all before deciding how much of that essential nutrient to apply. There is technical potential to sample soils and check yields across the field to see where nutrients are most needed and where they are likely to give the highest crop response.

In spite of the best practices in conventional agriculture, we apply increasingly higher levels of nutrients per unit of harvested yield, and most research on chemical approaches to increase nutrient efficiency is becoming more expensive per unit of yield gain. In chemical systems, we have clearly reached the point of diminishing returns to research, at least on the major cereal crops using current research methods.

Chemical Pesticides

Introduction of synthetic chemical pesticides has been another boon to the convenience of farming. Similar to the nutrient situation, increased use of insecticides, herbicides, fungicides, nematicides, and other chemical controls removed the perceived need for crop rotations that had previously contributed to pest management. These products gave quick results by killing insects and weeds within hours, and were seen as a modern solution that would assure protection against pests that had plagued agriculture for centuries. In fact, some of the chemical methods such as weed control through herbicides helped to reduce cultivation and soil erosion. The publicity stimulated by *Silent Spring*, a landmark book by Rachel Carson (1962), created awareness of the unintended side effects, or emergent properties, of the wide application of DDT and other chlorinated hydrocarbons and other pesticides. From the creation of the United States Environmental Protection Agency up to the present, the testing and licensing requirements for new chemicals to be used in agriculture have become much more stringent, and most current chemical pesticides are considered by many to be safe. Others maintain that we should be more cautious about the wide deployment of chemicals whose long-term effects may be hard to determine, and that the precautionary principle should guide our decisions. It is rather surprising that many biologists did not realize that wide use of any specific chemical would result in weeds, insects, and other pests that are resistant to that chemical. The current use of Roundup-Ready© corn and soybeans in a 2-year rotation, with application of the same chemical both years, will further pressure weed species to evolve with resistance. Today, there are more than 1,000 species of insects and weeds that have been shown to have resistance in the field to one or more chemicals (Miller, 2004).

One striking change in agriculture that is partly a result of the chemical fertilizer and pesticide revolution has been the simplification of farming systems to continuous cultivation of a single species or a simple 2-year rotation, for example, maize and soybeans in the United States Midwest. A corresponding change in livestock production has been the consolidation and concentration of beef, dairy, swine, and poultry into large confinement units that are often separated in management from crop farming. Confinement grain feeding has reduced the demand for forages; thus, there are fewer hectares of pasture and alfalfa, useful in traditional field rotations and in building soil fertility and controlling pests. A side effect of confinement is the creation of a manure problem, the conversion of a high-quality production input into a waste material that needs to be disposed. A number of creative solutions are being implemented such as composting and generation of methane gas from digesters in feedlots. These provide relatively efficient ways to cycle nutrients back into the production process and solve the expensive waste disposal problem.

Postharvest Loss

The Food and Agriculture Organization (FAO) has long recognized the potential for improving food availability that can come with reductions in postharvest loss (FAO, 1981). Postharvest losses have been estimated to be about 21% of the total food in our current supply chain (Niranjan and Shilton, 1994).

Postharvest losses come from every stage after the food has been removed from the plant (ocean or animal), from harvesting, handling, storage, and transport. The reasons and amounts of losses vary greatly and depend on the crop or food and its location. The first means to reduce losses is proper cultivation to prevent any disease or pest problems. Then it is important to plan appropriately for the harvest, planting what is needed (with some overage), harvesting in the correct conditions, and harvesting at the right time. Harvesting should also have minimal physical impacts on the product to prevent accelerated physiological deterioration. Further control measures after the field that reduce losses are proper storage conditions (temperature and humidity), which for some foods can mean immediate cooling.

It is assumed that reducing high postharvest losses requires technological advances. On the contrary, access to the correct means to prevent the losses is the largest hurdle for loss reduction. Limited access to the appropriate means of loss control can cause significant shortfalls. For example, postharvest losses in small-scale fisheries can be among the highest for all commodities (UN Atlas of the Oceans, http://www.oceansatlas.org/html/moreinfo.jsp, accessed June 11, 2008) often due to limited refrigeration and freezer facilities, especially onboard the fishing boats.

Organic Farming

Organic farming is often put forward as an economically viable way of sustainable food production. There has been an annual increase of over 20% in the organic food market in the United States for the past two decades (Om Organics, 2008). This is a significant achievement and one of the only major growth areas in an industry that generally considers food markets as inelastic, only growing with population and as subsequent demand increases.

Organic farmers manage nutrients without application of chemical fertilizer, using a combination of crop rotation of species with different nutrient needs, application of animal manure and/or compost, soil-building cover crops in the sequence, and calculating a careful nutrient budget to assess crop removal as well as potential for building soil fertility over time. Good managers can reduce costs of buying and applying excess nutrients, and at the same time avoid contributing to environmental problems due to nutrient loss from farm fields.

Organic farms are known for use of manure and compost and frequent integration of crops and animals on the same farms to make nutrient cycling more efficient (USDA, 2007). Although there may be excessive cultivation and resulting soil erosion on some organic farms, this approach to agriculture does reduce chemical load in the environment and engenders efficient use of on-farm, renewable production resources.

Another impact of technology has been an increasing industrialization of organic agriculture. The attractiveness of the organic segment of the food industry is increasingly recognized by those in the global agriculture and food sectors, and today over half of all organic food is marketed through large corporate supermarkets rather than small, locally owned, specialized organic food stores. There is concern among many of the founders of the organic food movement that much of the social intent of the original concept is lost, and they are searching for a more restrictive type of certification that would emphasize more than production methods: fair treatment of farm labor, emphasis on local foods, and distribution of benefits to a wider group of citizens.

In contrast to the potentials reported by most authors, there is still debate about potential global production from organic agriculture (Sustainable Food News, 2007). The FAO stated that organic agriculture should be used and promoted for its wholesome and nutritious value as well as the growing income it is providing for developed and developing countries; however, with current yields and land use, it may not be able to feed the 6 billion people on the planet today and the potentially 9 billion in 2050 without judicious use of chemical fertilizers (Sustainable Food News, 2007). We challenge that conclusion, based on personal observations, as the best organic farmers in the Midwest consistently produce crop yields as high if not higher than county averages.

Legislation and Supports

Technologies in agriculture, especially in the United States and the European Union, have been highly successful in raising productivity and increasing production far beyond internal needs and local markets. This has led to major exports of cereals from these regions and growth and later consolidation of grain marketing into a few major corporations.

Although often held up as a model for the success of free market economies and touted as an industry that has benefited farmers in the North as well as food-deficient countries in the South, in fact, the agricultural export industry has brought focused benefits to the larger farm operations and to those supplying industrial agriculture. This includes corporations supplying inputs, commodity traders and exporters. While benefiting these larger operations, the agricultural export industry has often suppressed successful production and skewed markets in many developing countries. The North American Free Trade Agreement is the latest example of this activity of the free market agricultural economy. Far from creating a level-playing field, the legislation and supports in the two major food export countries in North American have favored large-scale operations and funded exports in a number of ways, while small farmers in Mexico have been forced out of farming.

One of the most prominent liberal economists in agriculture, and advisor to presidents from both major parties, is Willard Cochrane from Minnesota. According to Cochrane, long-term attempts to stabilize production and farm incomes through farm programs in the United States have surely done some good by providing subsidies for maintaining prices during hard times and promoting export of food grains (Cochrane, 2003). But they have failed to provide long-term stability, and the result over the course of more than 70 years has been a continuing consolidation of ownership, exit of farmers and farm families, and decline of rural communities. Cochrane further concludes that large regional cooperative projects such as the North American Free Trade Agreement have contributed to greater, rather than lesser, inequities in incomes and success, and are especially destructive for small and family farms in the United States as well as in the other two partner countries.

Another respected agricultural economist in the land grant system, John Ikerd from University of Missouri, maintains that the path toward long-term security in the United States food system is through sustainable agriculture (Ikerd, 2006). In order to solve the negative and unexpected environmental consequences of the current industrial model of agriculture, it is essential to reduce the contamination of waterways and aquifers from pesticide residues and chemical fertilizer nutrients. These residues come from the more than 1.1 billion pounds of pesticide applied annually (Kiely et al., 2004) and over 12 million tons of nitrogen applied annually in the United States (ERS, 2007). The residues in the environment from these chemicals are indicators of the decline in ecological sustainability of present production systems. As Ikerd asserts, recognition of the environmental impacts of conventional agriculture has led to greater scrutiny of the economic and social sustainability of these same systems.

Consolidation has partly been a result of farm support programs (Ikerd, 2008), since payments have been coupled to production, allowing the larger operators to acquire more capital, which is then put into land purchase. With small profit margins on conventional commodity crops, the common wisdom in the western Corn Belt is that a family must farm at least 1,000 acres to earn enough net income to support an adequate lifestyle. As with any conventional wisdom, this represents an average farm size—some farm families add value to products on farm and do well on smaller farms, for example, those that are certified organic and have premiums for their products. Farmers who use imagination to diversify their crops and animal enterprises reduce costs by using primarily internal resources from the farm for maintaining soil nutrition, manage pests through rotation and diversity, and direct market their products often claim that a much smaller farm is adequate.

There is a growing interest in the United States and a strong initiative in the European Union in recognizing the importance of multifunctional rural landscapes, especially as they provide a range of ecosystem services to the larger society. These have been summarized in an the book *Nature's Services: Societal Dependence on Natural Ecosystems* by Daily (1996). One of the services that is already recognized economically and traded on the futures market is carbon credits. There are also federal programs (United States) and regional programs (European Union) that reward conservation-related practices with annual subsidies. One of the clearest mandates on agricultural research in recent years in the United States that supports this new direction was the comprehensive report of the National Research Council on priorities for research in the future. The prestigious panel that assembled this report clearly identified the importance of a multifunctional agriculture and rural community development as the foundation of viability for the rural sector in the United States (National Research Council, 2003), and asserted that agricultural landscapes are important for much more than food production. In so doing, they acknowledge the importance of families, communities, and ecosystem services. Yet we recognize that it will be years before a research establishment, as large and complex as that in the United States, one driven primarily by agricultural production and supported strongly by input and grain companies, will make any major change in direction. It is apparent that we do need a broader approach to marketing in a complex and greener future that includes more environmental concern by consumers and investors.

Consequences of Current Approaches and Paths Forward

Although the high-technology approach to agriculture has resulted in rapid increases in productivity and production, and one consequence is an increased availability of food to many, there have been some unexpected and negative consequences (Horrigan et al., 2002). The focus on crop yields and maximizing profits as a single strategy has led to economic, environmental, and social problems (Shrestha and Clements, 2003).

Keoleian and Heller (2003) summarized these consequences. They found that rapid conversion of prime farmland to urban development led to less stable and less arable land being used for agriculture resulting in increased erosion, and irrigation leading to depletion of topsoil exceeding regeneration and rate of groundwater withdrawal exceeding recharge in major agricultural regions. Losses to pests are increasing, despite use of chemicals. With a 10-fold increase in insecticide use from 1945 to 1989, there was a concurrent increase in losses from insects from 7 to 13% (Pimentel et al., 1991). More recent estimates suggest that there is a loss of 37% of all crops, globally, due to pests (insects, pathogens, and weeds), in spite of massive applications of pesticides (Pimentel and Pimentel, 2008). There is a reduction in genetic diversity, since today only 10–20 crops provide 80–90% of the world's calories (Brown, 1981). Such lack of biodiversity makes the supply more susceptible to pests and disease, leading to declining economic conditions for farmers, especially as production moves from smaller farms to larger, industrial farms. This is because the price of crops is low, yet investment is high. This means that increasingly only the larger operations are able to make both ends meet.

Thus, we have a complex global food situation, where large amounts of food are lost to pests, costs of inputs are increasing rapidly, there is competition between production for food and fuel, and great inequities exist between the North and South. While many in the world are undernourished, a number of countries in the North are seeing overconsumption and obesity as growing health challenges. These themes are expanded, as both social and economic impacts of the current food system are discussed in Chapter 6.

There is a heavy reliance on fossil fuels resulting in an imbalance in energy input and output that further burdens the system and environment. On a global scale, agriculture significantly contributes to greenhouse gas (GHG) emissions, producing between 17 and 32% of all global human-induced GHG emissions (Bellarby et al., 2008). This includes land and livestock direct emissions, fossil fuel use in farm operations, production of agrochemicals, and energy costs of the overall food system. The largest contributors are conversion of land to agriculture and direct emissions from land and animals. For example, excess use of fertilizers releases nitrous oxide, a GHG, and fertilizer release of nitrous oxide is the single largest contributor to GHG in agriculture (Bellarby et al., 2008). This does not even include GHG contribution for the production of fertilizers. Livestock is the largest user of land, using one-third of the world's arable land due to the shift away from grazing to the growth of livestock feed crops (Compassion in World Farming, 2008). This has caused major deforestation and other native vegetation destruction. Such conversion is a net release of carbon, given that native vegetation, such as trees, stores more carbon than crops like soy (Bellarby et al., 2008).

Bellarby et al. (2008) suggest that the significant environmental impacts of agricultural production can be mitigated with a number of approaches. These focus on shifting farming practices to alternatives that provide carbon sequestration rather than emission such as improved cropland management (such as avoiding bare fallow/using cover crops and appropriate fertilizer use), grazing-land management, and restoration of organic soils as carbon sinks. Further, since meat production is inefficient in its delivery of energy to the human food chain and at the same time is a significant source of GHG emissions, a reduction of meat production and consumption could provide major improvements. It has been suggested that a reduction in the size of the livestock industry is the simplest, quickest and probably the only effective method of cutting GHGs from animal production to the extent that is necessary to limit the future increase in global warming (Compassion in World Farming, 2008).

The challenges in agriculture and the global food system are many and complex. It is certain that neither single nor simple solutions can be found to resolve all the problems outlined above, and any changes in strategy must take into account the overriding need to provide adequate food for a growing world population. The last several decades have demonstrated that impressive increases in food production can be achieved, while we have also learned that there are often unanticipated consequences, or emergent properties, of any widespread application of new technologies. What we need is balance, careful study of available alternatives, and assessment of the multiple economic, environmental, and social impacts of proposed changes. Most important of all, we need to accept that there are limits to growth, and an essential focus for future technologies in agriculture must be to improve the qualitative dimensions of farming systems and rural life, and not just increased yields and total production.

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