1 The Need for Sustainable Food Production Systems

On a global scale, agriculture was very successful in meeting a growing demand for food during the latter half of the 20th century. Yields per hectare of staple crops such as wheat and rice increased dramatically, food prices declined, the rate of increase in food production generally exceeded the rate of population growth, and chronic hunger diminished. This boost in food production was due mainly to scientific advances and technological innovations, including the development of new plant varieties, the use of fertilizers and pesticides, and the growth of extensive infrastructure for irrigation.

Now, in the first decade of the 21st century, our system of global food production must grapple with a sobering fact as it attempts to feed a world population that continues to grow: The techniques, innovations, practices, and policies that have allowed increases in productivity have also undermined the basis for that productivity. They have overdrawn and degraded the natural resources upon which agriculture depends — soil, water resources, and natural genetic diversity. They have also created a dependence on nonrenewable fossil fuels and helped forge a system that increasingly takes the responsibility for growing food out of the hands of farmers and farm workers, who are in the best position to be stewards of agricultural land. In short, our system of agricultural production is unsustainable — it cannot continue to produce enough food for the global population over the long term because it deteriorates the conditions that make agriculture possible.

At the same time, our global food system faces threats not entirely of its own making, most notably the emergence of new agricultural diseases (such as mad cow and Nipah virus) and climate change. These threats underline the importance of moving towards more sustainable agricultural practices.

PRACTICES OF CONVENTIONAL AGRICULTURE

Conventional agriculture is built around two related goals: the maximization of production and the maximization of profit. In pursuit of these goals, a host of practices have been developed without regard for their unintended, long-term consequences and without consideration of the ecological dynamics of agroecosystems. Seven basic practices — intensive tillage, monoculture, irrigation, application of inorganic fertilizer, chemical pest control, genetic manipulation of domesticated plants and animals, and "factory farming" of animals — form the backbone of modern industrial agriculture. Each is used for its individual contribution to productivity, but as a whole, the practices form a system in which each depends on the others and reinforces the necessity of using all in concert.

These practices are also integrated into a framework with its own particular logic. Food production is treated like an industrial process in which plants and animals assume the role of miniature factories: their output is maximized by supplying the appropriate inputs, their productive efficiency is increased by manipulation of their genes, and the environments in which they exist are as rigidly controlled as possible.

INTENSIVE TILLAGE

Conventional agriculture has long been based on the practice of cultivating the soil completely, deeply, and regularly. The purpose of this intensive cultivation is to loosen the soil structure to allow better drainage, faster root growth, aeration, and easier sowing of seed. Cultivation is also used to control weeds and to turn under crop residues. Under typical practices — that is, when intensive tillage is combined with short rotations — fields are plowed or cultivated several times during the year, and in many cases this leaves the soil free of any cover for extended periods. It also means that heavy machinery makes regular and frequent passes over the field.

Ironically, intensive cultivation tends to degrade soil quality in a variety of ways. Soil organic matter is reduced as a result of accelerated decomposition and the lack of cover, and the soil is compacted by the recurring traffic of machinery. The loss of organic matter reduces soil fertility and degrades soil structure, increasing the likelihood of further compaction and making cultivation and its temporary improvements even more necessary. Intensive cultivation also greatly increases rates of soil erosion by water and wind.

MONOCULTURE

Over the last century, agriculture all over the world has moved relentlessly toward specialization. Farming once meant growing a diversity of crops and raising livestock, but now farmers are far more likely to specialize, growing corn for livestock feed, for example, or raising hogs. In crop agriculture, specialization means monoculture — growing only one crop in a field, often on a very extensive scale. Monoculture allows more efficient use of farm machinery for cultivation, sowing, weed control, and harvest, and can create economies of scale with regard to purchase of seeds, fertilizer, and pesticides. Monoculture is a natural outgrowth of an industrial approach to agriculture, where labor inputs are minimized and technology-based inputs are maximized in order to increase productive efficiency. Monoculture techniques mesh well with the other practices of modern agriculture: monoculture tends to favor intensive cultivation, application of inorganic fertilizer, irrigation, chemical control of pests, and specialized plant varieties. The link with chemical pesticides is particularly strong; vast fields of the same plant are more susceptible to devastating attack by specific pests and diseases and require protection by pesticides.

APPLICATION OF SYNTHETIC FERTILIZER

The spectacular increases in yields in the second half of the 20th century were due in large part to the widespread and intensive use of synthetic chemical fertilizers. In the U.S., the amount of fertilizer applied to fields each year increased rapidly after World War II, from 9 million tons in 1940 to more than 47 million tons in 1980. Worldwide, the use of fertilizer increased tenfold between 1950 and 1992; since then, the increase has moderated, but in 2002, the total world consumption of fertilizers was estimated to be 141.6 million metric tons (FAOSTAT, 2005).

Produced in large quantities at relatively low cost using fossil fuels and mined mineral deposits, fertilizers can be applied easily and uniformly to crops to supply them with ample amounts of the most essential plant nutrients. Because they meet plants' nutrient needs for the short term, fertilizers have allowed farmers to ignore long-term soil fertility and the processes by which it is maintained.

The mineral components of synthetic fertilizers, however, are easily leached out of the soil. In irrigated systems, the leaching problem may be particularly acute; a large amount of the fertilizer applied to fields actually ends up in streams, lakes, and rivers, where it causes *eutrophication* (excessive growth of oxygen-depleting plant and algal life). Fertilizer can also be leached into groundwater used for drinking, where it poses a significant health hazard. Furthermore, the cost of fertilizer is a variable over which farmers have no control since it rises with increases in the cost of petroleum.

IRRIGATION

An adequate supply of water is the limiting factor for food production in many parts of the world. Thus supplying water to fields from underground aquifers, reservoirs, and diverted rivers has been key to increasing overall yield and the amount of land that can be farmed. Although only 18% of the world's crop land is irrigated (FAOSTAT, 2005), this land produces 40% of the world's food (Serageldin, 1995; FAO, 2002). Currently, there are more than 44 ha of irrigated land per 1000 people in the world (FAOSTAT, 2005).

All sectors of society have placed rapidly increasing demands on fresh water supplies over the past half-century, but agricultural purposes account for the lion's share of the demand — about 70% of water use worldwide (Postel and Vickers, 2004). Unfortunately, agriculture is such a prodigious user of water that in many areas where land is irrigated for farming, irrigation has a significant effect on regional hydrology. One problem is that groundwater is often pumped faster than it is renewed by rainfall. This overdraft can cause land subsidence, and near the coast it can lead to saltwater intrusion. In addition, overdrafting groundwater is essentially borrowing water from the future. Where water for irrigation is drawn from rivers, agriculture is often competing for water with water-dependent wildlife and urban areas. Where dams have been built to hold water supplies, there are usually dramatic effects downstream on the ecology of rivers. Irrigation has another type of impact as well: it increases the likelihood that fertilizers will be leached from fields and into local streams and rivers, and it can greatly increase the rate of soil erosion.

CHEMICAL PEST AND WEED CONTROL

After World War II, chemical pesticides were widely touted as the new, scientific weapon in humankind's war against plant pests and pathogens. These chemical agents had the appeal of offering farmers a way to rid their fields once and for all of organisms that continually threatened their crops and literally ate up their profits. But this promise has proven to be false. Pesticides can dramatically lower pest populations in the short term, but because they also kill pests' natural predators, pest populations can often quickly rebound and reach even greater numbers than before. The farmer is then forced to use even more of the chemical agents. The dependence on pesticide use that results has been called the "pesticide treadmill." Augmenting the dependence problem is the phenomenon of increased resistance: pest populations continually exposed to pesticides are subjected to intense natural selection for pesticide resistance. When resistance among the pests increases, farmers are forced to apply larger amounts of pesticide or to use different pesticides, further contributing to the conditions that promote even greater resistance.

Although the problem of pesticide dependence is widely recognized, many farmers — especially those in developing nations — do not use other options. Even in the U.S., the amount of pesticides applied to major field crops, fruits, and vegetables each year remains at twice

FIGURE 1.1 Furrow irrigation with gated pipe in coastal central California. Overdraft of the underground aquifers from which the irrigation water is pumped has caused salt water intrusion, threatening the sustainability of agriculture in the region.

the level it was in 1962, when Rachel Carson published *Silent Spring* (Kimbrell, 2002). Ironically, total crop losses to pests have stayed fairly constant despite increasing pesticide use (Pimentel et al., 1991; Pimentel, 2005).

Besides costing farmers a great deal of money, pesticides — including herbicides and fungicides — can have a profound effect on the environment and often on human health. Pesticides applied to fields are easily washed and leached into surface water and groundwater, where they enter the food chain, affecting animal populations at every level and often persisting for decades.

MANIPULATION OF PLANT AND ANIMAL GENOMES

Humans have selected for specific characteristics among crop plants and domesticated animals for thousands of years; indeed, human management of wild species was one of the foundations of the beginning of agriculture. In recent decades, however, technological advances have brought about a revolution in the manipulation of genes. First, advances in breeding techniques allowed for the production of hybrid seeds, which combine the characters of two or more plant strains. Hybrid plant varieties can be much more productive than similar nonhybrid varieties and have thus been one of the primary factors behind the yield increases achieved during the so-called "green revolution." The hybrid varieties, however, often require optimal conditions — including intensive application of inorganic fertilizer — in order to realize their productive potential, and many require pesticide application to protect them from extensive pest damage because they lack the pest resistance

FIGURE 1.2 Broadcast spraying to control codling moth in an apple orchard in the Pajaro Valley, California.

of their nonhybrid cousins. In addition, hybrid plants cannot produce seeds with the same genome as their parents, making farmers dependent on commercial seed producers.

More recently, breakthroughs in genetic engineering have allowed the customized production of plant and animal varieties through the ability to splice genes from a variety of organisms into the target genome. The resulting organisms are referred to as *transgenic*, *genetically modified* (GM), or *genetically engineered* (GE).

Only a few animal species used for food have been genetically engineered as yet — these include pigs with spinach genes that produce lower-fat bacon and cows that produce milk with higher casein levels — but transgenic crop plants are now widespread and important in agricultural production. Between 1996 and 2003, the area planted to genetically engineered crops worldwide increased almost 40-fold, from 1.7 million ha to 67.7 million ha (James, 2003). The U.S., Argentina, Canada, Brazil, China, South Africa, Australia, and India all planted at least 100,000 ha to transgenic crops in 2003. Of the world's soybean crop, 55% was transgenic in 2003, as was 21% of the world's cotton crop (James, 2003).

Although genetically engineered organisms hold many promises — reducing the use of pesticides and irrigation, allowing agriculture on soils too saline for normal crops, and increasing the nutritional value of some crops — there are many concerns about the spread of this and related biotechnologies. The main source of concern is the potential for the migration of modified genes into other populations, both wild and domestic. This could result, for example, in more aggressive weeds or the introduction of toxins into crop plants. Increased use of transgenic crops may also diminish biodiversity, as traditional cultivars are abandoned, and increase the dependence of farmers on the transnational corporations owning the patents on the new organisms.

FACTORY FARMING OF ANIMALS

If you live in a developed country, a large portion of the meat, eggs, and milk that you eat probably comes from large-scale, industrialized operations driven by the goal of bringing these food products to market at the lowest possible unit cost. The animals in these "confined animal feeding operations" (CAFOs) are typically crowded so tightly they can barely move, given antibiotics to prevent the spread of disease, and fed highly processed feed supplemented with hormones and vitamins. Even though they are completely dependent on crop agriculture for the production of feed, CAFOs are disconnected — spatially and functionally — from the fields in which the feed grains are grown.

Factory-farm livestock production is another manifestation of the specialization trend in agriculture. In many ways, factory farming is for pigs, cattle, and poultry what monoculture is for corn, wheat, and tomatoes. The livestock in CAFOs are more susceptible to disease, just as monocropped corn plants are to pest damage, and both require chemical inputs (pharmaceuticals for livestock and pesticides for crops) to compensate. Both factory farming and monoculture encourage the use of organisms bred or engineered for productive efficiency and dependent on the artificial conditions of the industrial process.

Factory farming is criticized by animal rights groups as cruel and inhumane. Laying hens and broiler chickens are routinely de-beaked to keep them from pecking each other; hogs are often kept in pens so small they cannot turn around; beef cattle commonly suffer slow and painful deaths at the slaughterhouse.

There are many other reasons to be critical of the industrial approach to raising livestock. CAFOs, for example, have serious impacts on the environment. Disposal of the massive amounts of manure and urine generated by the confined animals is a huge problem, usually dealt with by treating the wastes in large anaerobic lagoons that leak nitrates into surface streams and groundwater and allow ammonia to escape into the atmosphere. This problem arises because CAFOs by their very nature cannot recycle nitrogen within the system, as is the case on smaller traditional farms where animals and crop plants are raised together. Thus nitrogen becomes a problematic waste product instead of a valuable plant nutrient.

The rise in factory farming is coupled with a worldwide trend toward diets higher in meat and animal products. As demand for meat increases, industrialized methods of animal food production become more profitable and more widespread, replacing more sustainable pastoral and mixed crop–livestock systems.

FIGURE 1.3 A confined animal feeding operation in California's Central Valley.

WHY CONVENTIONAL AGRICULTURE IS NOT SUSTAINABLE

The practices of conventional agriculture all tend to compromise future productivity in favor of high productivity in the present. Therefore, signs that the conditions necessary to sustain production are being eroded should be increasingly apparent over time. Today, there is in fact a growing body of evidence that this erosion is underway. In the last 15 yr, for example, all countries in which Green Revolution practices were adopted at a large scale have experienced declines in the annual growth rate of the agricultural sector. Further, in many areas where modern practices were instituted for growing grain in the 1960s (improved seeds, monoculture, and fertilizer application), yields have begun to level off and have even decreased following the initial spectacular improvements in yield. Mexico, for example, has seen little change in wheat yields since 1980, after climbing from about 0.9 tons/ha in 1950 to 4.4 tons in 1982 (Brown, 2001). For the world as a whole, the rise in land productivity has slowed markedly since about 1990. In the 40 years before 1990, world grain yield per hectare rose an average of 2.1% a year, but between 1900 and 2000, the annual gain was only 1.1 percent (Brown, 2001). From 2000 to 2003, global grain reserves shrank alarmingly every year, from 635 million tons (a 121-d supply), to 382 million tons (a 71-d supply).

Figure 1.4 shows the world's annual per capita grain production for each year from 1961 to 2004, as calculated by the Food and Agriculture Organization (FAO) of the United Nations. These data indicate that after trending upward for many years, per capita production of cereal grains has trended downward since reaching a peak in 1984. This situation is the result of reduced annual yield increases combined with continued logarithmic population growth.

The ways in which conventional agriculture puts future productivity at risk are many. Agricultural resources such as soil, water, and genetic diversity are overdrawn and degraded, global ecological processes on which agriculture ultimately depends are altered, human health suffers, and the social conditions conducive to resource conservation are weakened and dismantled. In economic terms, these adverse impacts are called *externalized costs*. They are real and serious, but because their consequences can be temporarily ignored or absorbed by society in general, they are excluded from the cost–benefit calculus that allows conventional agricultural operations to continue to make economic "sense."

SOIL DEGRADATION

Every year, according to the Food and Agriculture Organization of the United Nations, between 5 and 7 million ha of valuable agricultural land are lost to soil degradation. Other estimates run as high as 10 million ha per year (e.g., World Congress on Conservation Agriculture, 2001). Degradation of soil can involve salting, waterlogging, compaction, contamination by pesticides, decline in the quality of soil structure, loss of fertility, and erosion by wind and water. Although all these forms of soil degradation are severe problems, erosion is the most widespread. Worldwide, 25,000 million tons of topsoil are washed away annually (Loftas et al., 1995). Soil is lost to wind and water erosion at the rate of 5 to 10 tons/ha

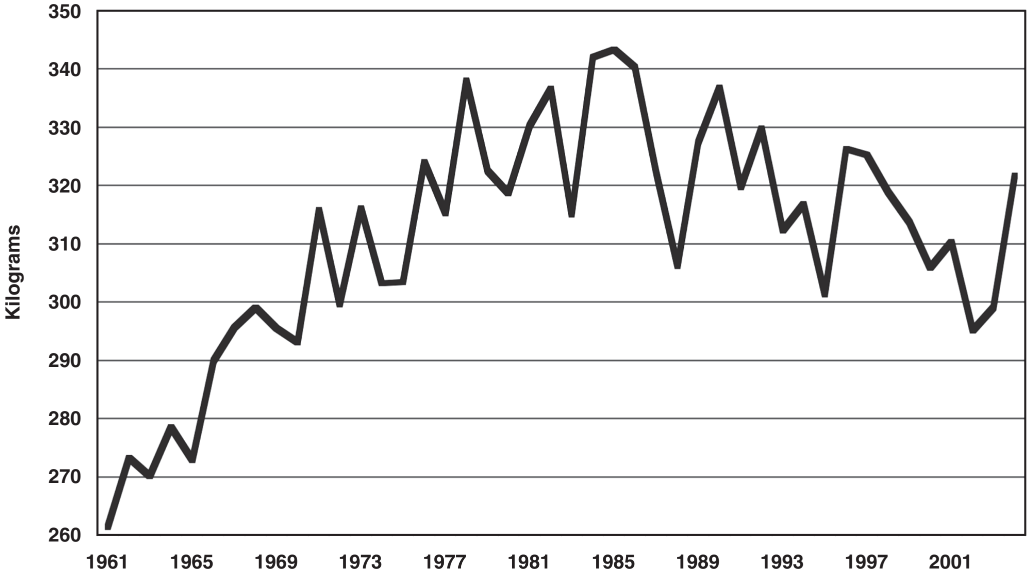

FIGURE 1.4 Worldwide grain production per capita, 1961 to 2004. *Data source*: Food and Agricultural Organization, FAOSTAT database; Worldwatch Institute.

per year in Africa, South America, and North America, and almost 30 tons/ha annually in Asia. In comparison, soil is created at the rate of about 1 ton/ha per year, which means that in just a short period, humans have wasted soil resources that took thousands of years to be built up.

The cause–effect relationship between conventional agriculture and soil erosion is direct and unambiguous. Intensive tillage, combined with monoculture and short rotations, leaves the soil exposed to the erosive effects of wind and rain. The soil lost through this process is rich in organic matter, the most valuable soil component. Similarly, irrigation is a direct cause of much water erosion of agricultural soil.

Combined, soil erosion and the other forms of soil degradation render much of the agricultural soil of the world increasingly less fertile. Some land — severely eroded or too salty from evaporated irrigation water — is lost from production altogether. The land that can still produce is kept productive by the artificial means of adding synthetic fertilizers. Although fertilizers can temporarily replace lost nutrients, they cannot rebuild soil fertility and restore soil health; moreover, their use has a number of negative consequences, as discussed above.

Since the supply of agricultural soil is finite, and because natural processes cannot come close to renewing or restoring soil as fast as it is degraded, agriculture cannot be sustainable until it can reverse the process of soil degradation. Current agricultural practices must undergo a vast change if the precious soil resources we have remaining are to be conserved for the future.

FIGURE 1.5 Severe soil erosion on a sloping hillside following intense winter rains. In this strawberry growing region in the Elkhorn Slough watershed of central California, soil losses exceed 150 tons/acre in some years.

OVERUSE OF WATER AND DAMAGE TO HYDROLOGICAL SYSTEMS

Fresh water is becoming increasingly scarce in many parts of the world as industry, expanding cities, and agriculture compete for limited supplies. Some countries have too little water for any additional agricultural or industrial development to occur. To meet demands for water in many other places, water is being drawn from underground aquifers much faster than it can be replenished by rainfall, and rivers are being drained of their water to the detriment of aquatic and riparian ecosystems and their dependent wildlife. Many of the world's major rivers — including the Colorado, Ganges, and Yellow — now run dry for part of the year as a result.

Agriculture accounts for more than two thirds of global water use. For every person on the planet, there are more than 0.04 ha of irrigated land. Agriculture uses so much water in part because it uses water wastefully. More than half of the water applied to crops is never taken up by the plants it is intended for (Van Tuijl, 1993). Instead, this water either evaporates or drains out of fields. Some wastage of water is inevitable, but a great deal of waste could be eliminated if agricultural practices were oriented toward conservation of water rather than maximization of production. For example, crop plants could be watered with drip irrigation systems, and production of water-intensive crops such as rice could be shifted away from regions with limited water supplies.

The increasing importance of meat in human diets worldwide is another factor in agriculture's rising demand for water, as is the trend toward concentrated grain feeding of livestock. Animal factories use prodigious amounts of water for cooling the animals and flushing their wastes, and many animals drink large amounts of water. Hogs, for example, can consume up to 8 gallons per animal per day (Marks and Knuffke, 1998). And these are just the direct uses of water for raising livestock. Factoring in the water needed to grow the biomass fed to animals, animal-derived food requires at least twice as much water to produce as plant-derived food, and usually much more.

FIGURE 1.6 The San Luis Dam in California. Built in part to hold irrigation water for farms on the west side of the San Joaquin Valley, it is one of an estimated 800,000 dams in the world that trap life-giving silt, destroy riverine and riparian ecosystems, and completely alter natural hydrological functioning.

The difference between the amount of water needed to grow calorie-equivalent amounts of plant food and animal food can be extreme. For example, it takes only 89 liters of water to grow 500 calories of potatoes, but an astonishing *55 times* more, or 4902 liters, to raise 500 calories of grain-fed beef (Postel and Vickers, 2004). If we look at protein alone, the ratio is even more skewed: on average, producing 1 kg of animal protein requires about 100 times as much water as producing 1 kg of grain protein (Pimentel and Pimentel, 2003).

In addition to using a large share of the world's fresh water, conventional agriculture has an impact on regional and global hydrological patterns and the aquatic, riparian, and marine ecosystems dependent on them. First, by drawing such large quantities of water from natural reservoirs on land, agriculture has caused a massive transfer of water from the continents to the oceans. A 1994 study concluded that this transfer of water involves about 190 billion m^3 of water annually and has raised sea level by an estimated 1.1 cm (Sahagian et al., 1994). Moreover, the amount of water that agriculture causes to be moved from the land to the oceans is only increasing; by one estimate the net flow will increase by as much as 30% over present rates (Sahagian, 2000). Second, where irrigation is practiced on a large scale, agriculture brings about changes in hydrology and microclimate. Water is transferred from natural watercourses to fields and the soil below them, and increased evaporation changes humidity levels and may affect rainfall patterns. These changes in turn significantly impact natural ecosystems and wildlife. Third, the dams, aqueducts, and other infrastructure created to make irrigation possible have dramatically altered many of the world's rivers, causing enormous ecological damage. Rivers that once provided valuable "ecosystem services" to human society cannot do so anymore — their wetland, aquatic, and floodplain ecosystems can no longer absorb and filter out pollutants or provide habitat for fish and waterfowl, and they can no longer deposit the rich sediment so important for restoring the fertility of agricultural soils in floodplain areas (Postel and Richter, 2003).

If conventional agriculture continues to use water in the same ways, our rivers will become increasingly crippled and regional water crises will become increasingly common, either shortchanging the environment, marginalized peoples, and future generations, or limiting irrigation-dependent food production.

POLLUTION OF THE ENVIRONMENT

More water pollution comes from agriculture than from any other single source. Agricultural pollutants include pesticides, herbicides, other agrochemicals, fertilizer, animal wastes, and salts.

Pesticides and herbicides — applied in large quantities on a regular basis, often from aircraft — are easily spread beyond their targets, killing beneficial insects and wildlife directly and poisoning farmers and farmworkers. The pesticides that make their way into streams, rivers, and lakes — and eventually the ocean — can have serious deleterious effects on aquatic ecosystems. They can also affect other ecosystems indirectly. Fish-eating raptors, for example, may eat pesticide-laden fish, reducing their reproductive capacity and thereby impacting terrestrial ecosystems. Although persistent organochloride pesticides such as DDT — known for their ability to remain in ecosystems for many decades — are being used less in many parts of the world, their less-persistent replacements are often much more acutely toxic.

Pesticides also pose a significant human health hazard. They spread throughout the environment by hydrological, meteorological, and biological means, and so it is impossible for humans to avoid exposure. In its 2003 edition of *Human Exposure to Environmental Chemicals*, the Centers for Disease Control reported that all of the 9282 people they tested had pesticides and their breakdown products in their bodies, and the average person had detectable amounts of 13 different pesticides (Schafer et al., 2004). Pesticides enter our bodies through our food and our drinking water. Pesticide contamination of groundwater has occurred in at least 26 states, and an EPA study in 1995 found that of 29 cities tested in the Midwest, 28 had herbicides present in their tap water. If all the drinking water sources in the U.S. at risk for pesticide contamination were properly monitored for the presence of harmful agents, the cost would be well over U.S.$15 billion (Pimentel, 2005).

Fertilizer leached from fields is less directly toxic than pesticides, but its effects can be equally damaging ecologically. In aquatic and marine ecosystems it promotes the overgrowth of algae, causing eutrophication and the death of many types of organisms. Nitrates from fertilizers are also a major contaminant of drinking water in many areas. Rounding out the list of pollutants from crop lands are salts and sediments, which in many locales have degraded streams, helped destroy fisheries, and rendered wetlands unfit for bird life.

Where factory farming has become the dominant form of meat, milk, and egg production, animal waste has become a huge pollution problem. Farm animals in the U.S. produce far more waste than do humans (Marks and Knuffke, 1998). The large size of feedlot and other factory farming operations poses challenges for the treatment of these wastes. As noted above, the wastes are typically treated in large anaerobic lagoons not well suited to protection of the environment. Some of the nitrogen from the wastes leaks out of the lagoons and into underlying aquifers, adding large quantities of nitrates to the groundwater and eventually to rivers. Even more nitrogen from the

THE GULF OF MEXICO'S HYPOXIC "DEAD ZONE"

Every summer, a large area of the Gulf of Mexico near the mouth of the Mississippi River loses most of its dissolved oxygen and thus its ability to support nearly all species of marine life. It has been appropriately named the "dead zone." The size of the dead zone varies, but in recent years it has been alarmingly large; in 2002 it encompassed about 8500 square miles, nearly the size of New Jersey. The dead zone has many direct negative effects on human society, most notably threatening the important commercial fisheries of the Gulf coast region by killing fish and shrimp directly, compromising the ability of many species to reproduce, and altering migration patterns.

The dead zone is a direct result of massive amounts of nitrogen and phosphorus leaching out of the agricultural lands of the Mississippi River basin and causing excessive growth ("blooms") of phytoplankton in the Gulf. When the phytoplankton die, their decomposition by bacteria uses up much of the oxygen dissolved in the water. The relatively calm summer weather prevents mixing of the water column, resulting in the sustained hypoxic (low oxygen) conditions that kill fish and bottom-dwelling organisms.

The dead zone phenomenon shows the multifaceted and interrelated ways in which conventional agriculture impacts the environment. Irrigation, intensive tillage, monoculture, over-application of inorganic fertilizer, and factory farming of animals all play a role in causing unnaturally large amounts of nitrogen and phosphorus to flow into the Gulf of Mexico.

A little more than half of the excess nitrogen (an estimated 56%) comes from the inorganic fertilizer applied to fields in Kansas, Missouri, the Dakotas, Arkansas, and the other agricultural states in the Mississippi's vast watershed. Much of this nitrogen leaches into the region's rivers because much more nitrogen is applied than can be taken up by plants or chemically bound in the soil; excess fertilizer is applied because monocropped high-yield varieties require it for maximum production. And even more nitrogen ends up in the rivers because of irrigation and the erosion caused by intensive tillage.

About 25% of the excess nitrogen, and an even greater proportion of the excess phosphorus, comes from the animal waste produced by hog, poultry, and cattle CAFOs. These nutrients find their way into the rivers from manure spills, leaching of manure-treatment lagoons, and leaching from the excess treated manure applied to fields.

Ironically, if the Mississippi River and its tributaries were not so thoroughly engineered for human purposes — dammed for flood control and irrigation, channelized and locked for shipping—its healthy aquatic and wetland ecosystems and functioning floodplains would be able to remove much of the excess nitrogen and phosphorus from the rivers before these nutrients reached the Gulf of Mexico. Since much of the altering of the rivers in the Mississippi's watershed was done for the sake of agriculture — irrigation and transport of agricultural commodities — this is just one more way in which conventional agriculture is implicated in a continuing environmental disaster with huge impacts on human society.

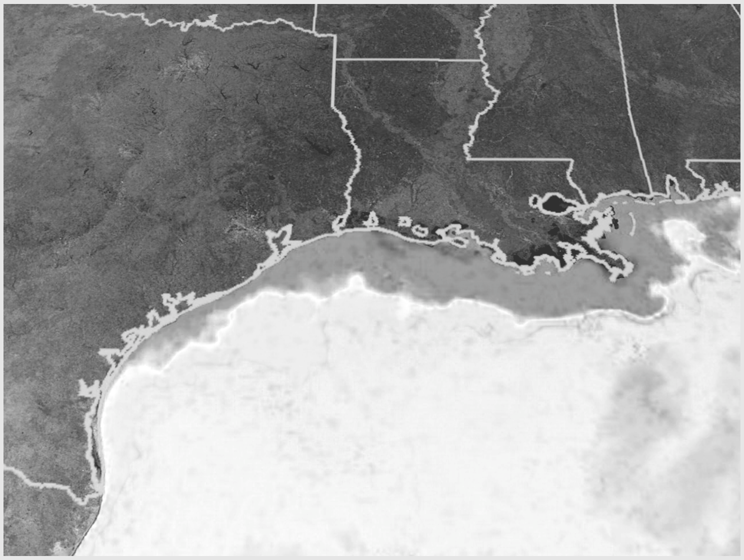

FIGURE 1.7 Satellite image of the "dead zone" in the Gulf of Mexico. The darker areas indicate highly turbid waters with high concentrations of phytoplankton fed largely by agricultural runoff from the huge Mississippi River basin. The phytoplankton in the blooms will die and sink to the bottom, causing bacterial decay that removes oxygen from the surrounding water. *Source*: NASA.

wastes converts to ammonia and enters the atmosphere, where it combines with water droplets to form ammonium ions. As a result, the rainwater downwind of livestock feeding operations often has extremely high concentrations of ammonium ions. Although most treated animal waste is ultimately applied to fields as fertilizer, the phosphorus and nitrogen it contains is beyond useful levels for most crops. Furthermore, factory farms often have so much waste to get rid of that they apply more treated waste to fields than the soil can accommodate, and do so year-round, even at times in the crop cycle when fields and crops are unable to absorb it. The excess nitrogen and phosphorus finds its way into streams, rivers, and the local drinking water supply.

Through all these various avenues, tons of nitrogen and phosphorus from animal waste and inorganic fertilizer make their way into lakes and rivers and then into the oceans, creating large "dead zones" near river mouths. More than 50 of these dead zones exist seasonally around the world, with some of the largest — in the Chesapeake Bay, Puget Sound, and Gulf of Mexico — off the coast of the U.S.

Dependence on External Inputs

Conventional agriculture has achieved its high yields mainly by increasing agricultural inputs. These inputs comprise material substances such as irrigation water, fertilizer, pesticides, and processed feed and antibiotics; the energy used to manufacture these substances, to run farm machinery and irrigation pumps, and to climate-control animal factories; and technology in the form of hybrid and transgenic seeds, new farm machinery, and new agrochemicals. These inputs all come from outside the agroecosystem itself; their extensive use has consequences for farmers' profits, use of nonrenewable resources, and the locus of control of agricultural production.

The longer conventional practices are used on farmland, the more the system becomes dependent on external inputs. As intensive tillage and monoculture degrade the soil, continued fertility depends more and more on the input of fossil-fuel–derived nitrogen fertilizer and other nutrients.

Agriculture cannot be sustained as long as this dependence on inputs remains. First, the natural resources from which many of the inputs are derived are nonrenewable and their supplies finite. Second, dependence on external inputs leaves farmers, regions, and whole countries vulnerable to supply shortages, market fluctuations, and price increases. In addition, excessive use of inputs has multiple negative off-farm and downstream impacts, as noted above.

Loss of Genetic Diversity

Throughout most of the history of agriculture, humans have increased the genetic diversity of crop plants and livestock worldwide. We have been able to do this both by selecting for a variety of specific and often locally adapted traits through selective breeding, and by continually recruiting wild species and their genes into the pool of domesticated organisms. In the last 100 yr or so, however, the overall genetic diversity of domesticated plants and animals has declined. Many varieties of plants and breeds of animals have become extinct, and a great many others are heading in that direction. About 75% of the genetic diversity that existed in crop plants in 1900 has been lost (Nierenberg and Halweil, 2004). The United Nations Food and Agriculture Organization estimates that as many as two domesticated animal breeds are being lost each week worldwide (FAO, 1998).

In the meantime, the genetic bases of most major crops and livestock species have become increasingly uniform. Only six varieties of corn, for example, account for more than 70% of the world's corn crop, and 99% of the turkeys raised in the U.S. belong to a single breed (FAO, 1998).

The loss of genetic diversity has occurred mainly because of conventional agriculture's emphasis on short-term productivity gains. When highly productive varieties and breeds are developed, they tend to be adopted in favor of others, even when the varieties they displace have many desirable and potentially desirable traits. Genetic homogeneity among crops and livestock is also consistent with the maximization of productive efficiency because it allows standardization of management practices.

For crop plants, a major problem with increasing genetic uniformity is that it leaves each crop as a whole more vulnerable to attack by pests and pathogens that acquire resistance to pesticides and to the plants' own defensive compounds; it also makes crops more vulnerable to changes in climate and other environmental factors. These are not insignificant or hypothetical threats. Every year, crop pests and pathogens destroy an estimated 30 to 40% of potential yield. Plant pathogens can evolve rapidly to overcome a crop's defenses, and global commerce and genetically uniform farm fields allow these new virulent strains to spread rapidly from field to field and continent to continent. In a report on crop diversity and disease threats released in 2005, researchers identified four diseases with the potential to devastate the U.S. corn crop, five that could threaten potatoes, and three with the potential to harm U.S.-grown wheat (Qualset and Shands, 2005). In late 2004, for example, a new soybean rust (a type of fungus) appeared in the southern U.S. and began to attack the soybean crop. None of the commercial soybean varieties planted in the U.S. are resistant to it, and scientists are concerned about the potential impact on the U.S.$18 billion soybean harvest as the rust spreads north.

Throughout the history of agriculture, farmers — and more recently, plant scientists — have responded to outbreaks of disease by finding and planting resistant varieties of the affected crop. But as the size of each crop's genetic reservoir declines, there are fewer and fewer varieties from which to draw resistant or adaptive genes. The importance of having a large genetic reservoir can be illustrated by example. In 1968, greenbugs attacked the U.S. sorghum crop, causing an estimated $100 million in damage. The next year, insecticides were used to control the greenbugs at a cost of about $50 million. Soon thereafter, however, researchers discovered a sorghum variety that carried resistance to the greenbugs. No one had known of the greenbug resistance, but it was there nonetheless. This variety was used to create a hybrid that was grown extensively and not eaten by greenbugs, making the use of pesticides unnecessary. Such pest resistance is common in domesticated plants, "hiding" in the genome but waiting to be used by plant breeders. As varieties are lost, however, the valuable genetic reservoir of traits is reduced in size, and certain traits potentially invaluable for future breeding are lost forever. There may very well be a soybean variety somewhere in the world resistant to the new soybean rust, but will plant scientists locate it before it goes extinct?

Increasing vulnerability to disease is also a serious concern for domesticated animal species as they lose their genetic diversity, but perhaps more serious is increased dependence on methods of industrial food production. Livestock breeds that are not adapted to local conditions require climate-controlled environments, doses of antibiotics, and large amounts of high-protein feed.

Loss of Local Control Over Agricultural Production

Accompanying the concentration of agriculture into large-scale monocultural systems and factory farms has been a dramatic decline in the number of farms and farmers, especially in developed countries where mechanization and high levels of external inputs are the norm. From 1920 to the present, the number of farms in the U.S. has dropped from more that 6.5 million to just over 2 million, and the percentage of the population that lives and works on farms has dropped below 2%. Data from the 2000 U.S. census show that only 0.4% of the employed civilians in the U.S. listed their occupation as "farmer or rancher" (U.S. Census Bureau, 2005). In developing countries as well, rural people who work primarily in agriculture continue to abandon the land to move to urban and industrial areas, which will hold an estimated 60% of the world's population by 2030. As shown in Figure 1.8, there are now far more people in the world whose livelihoods are nonagricultural than there are people who grow food, and this gap continues to widen over time.

Besides encouraging an exodus from rural areas, large-scale commodity-oriented farming tends to wrest control of food production from rural communities. This trend is disturbing because local control and place-based knowledge and connection are crucial to the kind of management required for sustainable production. Food production carried out according to the dictates of the global market, and through technologies developed elsewhere, inevitably severs the connection to ecological principles. Experience-based management skill is replaced by purchased inputs requiring more capital, energy, and use of nonrenewable resources. Farmers become mere instruments of technology application, rather than independent decision-makers and managers.

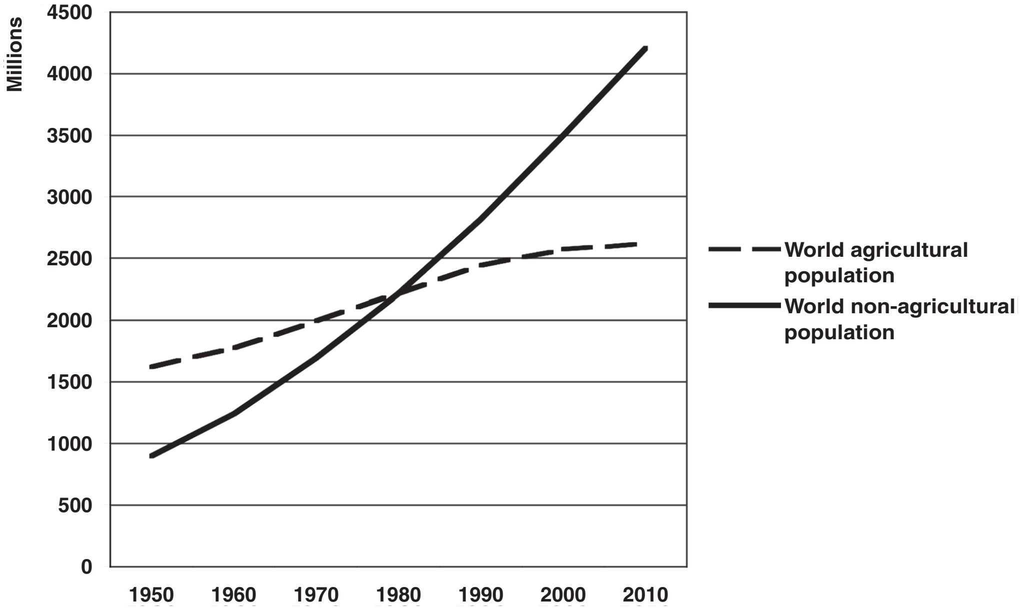

FIGURE 1.8 Number of people worldwide involved in agriculture and not involved in agriculture. *Source*: Data from FAOSTAT (2005). Figures for 2010 are projections.

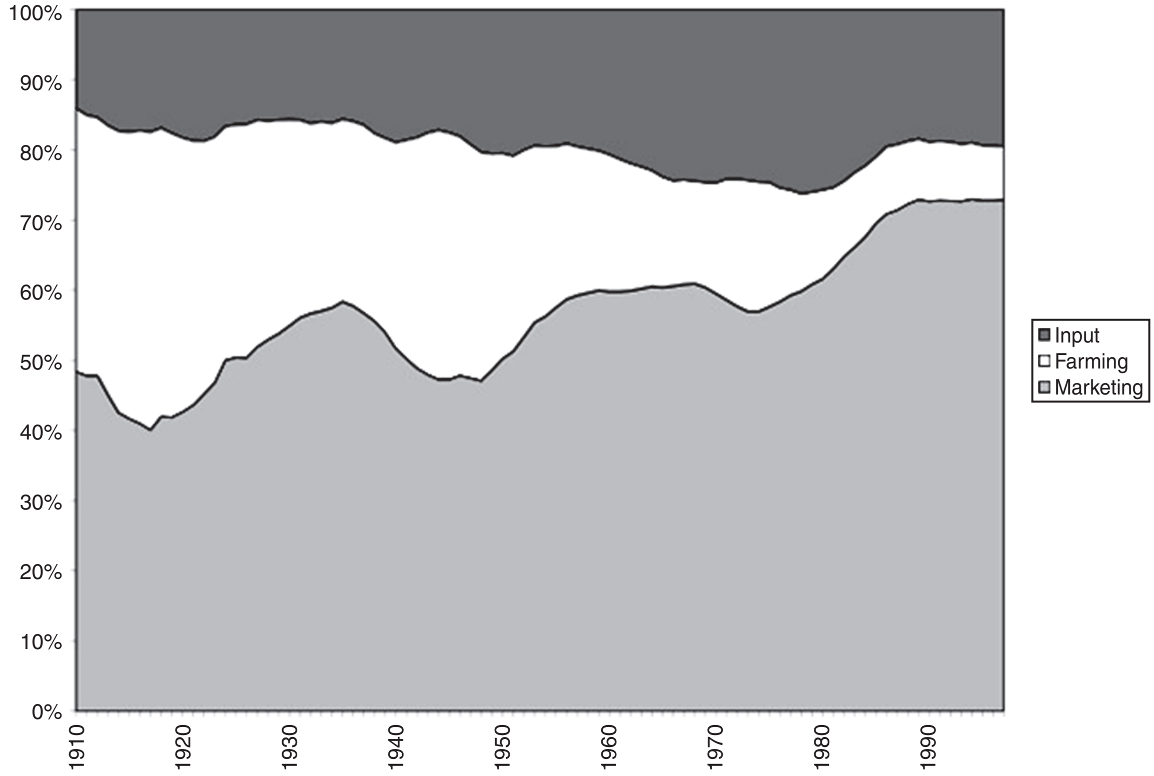

FIGURE 1.9 U.S. farmers' declining share of the consumer food dollar, 1910 to 1997. Marketing represents all services performed after food leaves the farm gate. The farmers' share includes payments to local governments and hired labor. Inputs include all purchased, nonfarm inputs. *Source*: Data from Stewart Smith, University of Maine, 2005.

Smaller-scale farmers seem to have little power against the advancement of industrial agriculture. Smaller farms cannot afford the cost of upgrading their farm equipment and technologies in order to compete successfully with the large farm operations. Moreover, the increase in the share of the food dollar going to distributors and marketers, coupled with cheap food policies that have kept farm prices relatively stable, has left many farmers in a tightening squeeze between production costs and marketing costs. Their share of the consumer food dollar, as shown in Figure 1.9, has dropped from almost 38% to less than 8% (Smith, pers. comm.).

Faced with such economic uncertainty, there is less incentive for farmers to stay on the land. One trend is for larger farmers to buy out their smaller neighbors. But when agricultural land is adjacent to rapidly expanding urban centers, such as in California, the incentive instead is to sell farmland at the inflated value it has as urban land. Because of this dynamic, the agriculturally rich Great Central Valley of California has seen the loss of hundreds of thousands of hectares of farmland to development since 1950, and the rate of loss of agricultural land in the state as a whole averaged 49,700 acres annually from 1988 to 1998 (Kuminoff et al., 2001).

In less developed countries, the growth of large-scale export agriculture has an even more ominous effect. As rural people — who were once able to feed themselves adequately *and* sell surplus food to city-dwellers — are pushed off the land, they migrate to cities, where they become dependent on others for their food. Since more of the food produced in the countryside is destined for export, increasing amounts of food for the expanding urban areas must be imported. Because of this dynamic, exports of food to developing countries from developed countries increased fivefold between 1970 and 1990, and during the 1990s, developing countries increased their food imports at the rate of 5.6% per year (FAO, 2003). In the period between 1980 and 2000, the quantity of coarse grains exported from developed nations to developing nations more than tripled (FAOSTAT, 2005). This imbalance threatens the food security of less-developed countries and makes them even more dependent on developed countries.

GLOBAL INEQUALITY

Despite increases in productivity and yields, hunger persists all over the globe. In some countries, such as India and much of Africa, the percentage of chronically hungry people has actually increased in recent years (FAO, 2004). There are also huge disparities in calorie intake and food security between people in developed nations and those in developing nations. At the beginning of the 21st century, the world reached a dubious milestone: the number of overweight people (about 1.1 billion) grew roughly equal to the number of underweight people (Gardner and Halweil, 2000). This statistic indicates that the unequal distribution of food — which is both a cause and a consequence of global inequality — is at least as serious a problem as the threats to global food production.

Developing nations too often grow food mainly for export to developed nations, using external inputs purchased from the developed nations. While the profits from the sale of the export crops enrich small numbers of elite landowners, many people in the developing nations go hungry — an estimated 815 million in 2002 (FAO, 2004). In addition, those with any land are often displaced as the privileged seek more land on which to grow export crops.

Besides causing unnecessary human suffering, relationships of inequality tend to promote agricultural policies and farmer practices that are driven more by economic considerations than by ecological wisdom and long-term thinking. For example, subsistence farmers in developing nations, displaced by large landowners increasing production for export, are often forced to farm marginal lands. The results are deforestation, severe erosion, and serious social and ecological harm.

Although inequality has always existed between countries and between groups within countries, the modernization of agriculture has tended to accentuate this inequality because its benefits are not evenly distributed. Those with more land and resources have had better access to the new technologies. Therefore, as long as conventional agriculture is based on First World technology and external inputs accessible to so few, the practice of agriculture will perpetuate inequality, and inequality will remain a barrier to sustainability.

RUNNING OUT OF SOLUTIONS

During the 20th century, food production was increased in two ways: by bringing more land under production and by increasing the land's productivity — the amount of food produced per unit of land. As detailed above, many of the techniques that have been used to increase productivity have a great many negative consequences that in the long term work to undermine the productivity of agricultural land, and in many cases these techniques have approached their physical and practical limits. Conventional means of increasing productivity, therefore, cannot be relied on to help meet the increasing food needs of an expanding global population — a population that surpassed 6 billion in 2004, according to U.N. estimates.

However, increasing food production by cultivating more land is also problematic. Most of the land on the Earth's surface that is amenable to agriculture has already been converted to human use, and of this chunk of land, the proportion that can be farmed is actually shrinking due to urban expansion, soil degradation, and desertification. In the coming years, the growth of cities and industrialization will continue to claim more agricultural land — and often the best land, too. In addition, climate change threatens to take large areas of agricultural land out of production, especially in the tropics, where warming and drying may accelerate desertification in some areas and rising sea levels will inundate low-lying land.

Figure 1.10 shows the problem graphically. In the mid-1980s, the regular annual increases in the area of arable land worldwide observed since the 1970s (and earlier) ceased, and shrinkages have been observed in the periods 1988 to 1992, 1994 to 1995, 1997 to 1999, and 2001 to 2003.

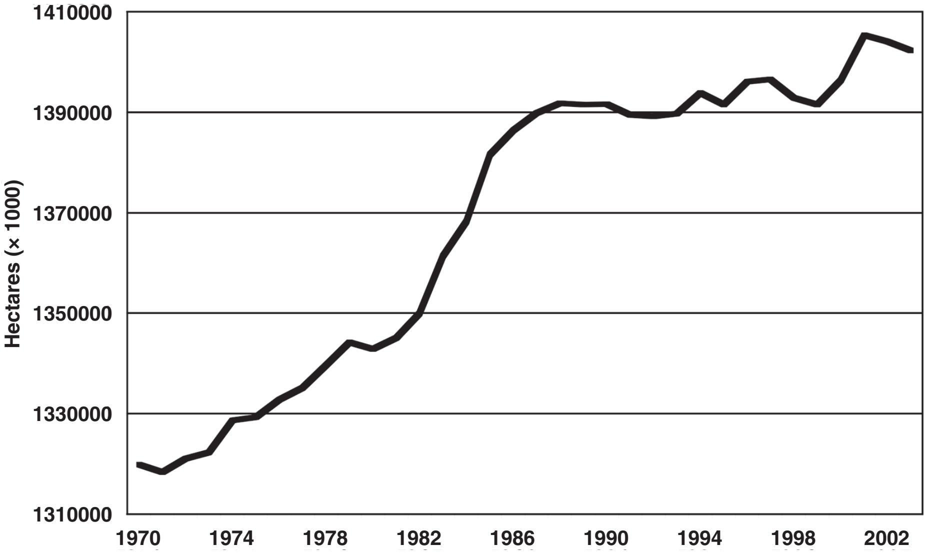

FIGURE 1.10 Worldwide arable land area, 1970 to 2003. As the total amount of arable land remains about the same each year, population growth continues its upward trend. *Data source*: Food and Agriculture Organization, FAOSTAT database, 2006.

Neither is it possible to bring much more land under cultivation through irrigation. In most drier regions, water is already scarce and there is no surplus available for increased agricultural use. Developing new supplies of water, moreover, has increasingly severe environmental consequences. In some areas that rely on groundwater for irrigation, such as Saudi Arabia and parts of the U.S., the amount of water available for irrigation will actually decrease in the future because of overdrafting and increasing nonagricultural demands.

There remain small but significant areas of land that could be farmed but are now covered by natural vegetation. Some of this land is in the process of being converted to agricultural use, but this way of increasing the amount of cultivated land also has its limits. First, much of this land is tropical rain forest, the soil of which cannot support continual agricultural production. Second, this land is increasingly being recognized for its value to global biological diversity, the carbon dioxide balance of the atmosphere, and maintenance of the Earth's climatic patterns. Because of this recognition and the efforts of environmental groups, a large proportion of the planet's remaining wild lands will be off-limits to agricultural conversion.

Exacerbating the problem of limited arable land is a trend toward meat-intensive diets worldwide. In the 30 yr between 1973 and 2003, the world's population increased 61%, while at the same time worldwide meat production increased by more than 133% (FAOSTAT, 2005). The amount of meat produced per person, which has risen steadily since data on meat production began being collected in 1961, surpassed the 40 kg/person level in 2004.

Because the conversion of plant biomass into animal protein is highly inefficient, a large amount of plant biomass is needed to produce meat. For example, about 43 kg of plant biomass go into creating 1 kg of beef flesh (Pimentel and Pimentel, 2003). This means that a diet rich in meat requires much more land (and much larger expenditures of fossil fuel energy) to support than a vegetarian diet. Already, more corn and soybeans go to fattening livestock worldwide than to feeding human beings (in the U.S., seven times more grain is fed to livestock than is consumed by humans). As people increase both the total number of calories they consume, and the proportion of these calories that come from meat, they place increasing demands on the Earth's limited supply of arable land.

THE PATH TOWARD SUSTAINABILITY

The only option we are left with is preserving the long-term productivity of the world's agricultural land while changing consumption and land use patterns to more equitably benefit everyone, from farmers to consumers. The first part of this challenge for the future defines the subject of most of this book; the latter part, touched on in the final two chapters, will rely to a large extent on the reconceptualizations of agriculture offered herein.

Preserving the productivity of agricultural land over the long term requires sustainable food production. Sustainability is achieved through alternative agricultural practices informed by in-depth knowledge of the ecological processes occurring in farm fields and the larger contexts of which they are a part. From this foundation we can move towards the social and economic changes that promote the sustainability of all sectors of the food system.

WHAT IS SUSTAINABILITY?

Sustainability means different things to different people, but there is general agreement that it has an ecological basis. In the most general sense, sustainability is a version of the concept of sustained yield — the condition of being able to harvest biomass from a system in perpetuity because the ability of the system to renew itself or be renewed is not compromised.

Because "perpetuity" can never be demonstrated in the present, the proof of sustainability always remains in the future, out of reach. Thus it is impossible to know for sure if a particular practice is in fact sustainable or if a particular set of practices constitutes sustainability. However, it is possible to demonstrate that a practice is moving away from sustainability.

Based on our present knowledge, we can suggest that a sustainable agriculture would, at the very least:

- have minimal negative effects on the environment and release insignificant amounts of toxic or damaging substances into the atmosphere, surface water, or groundwater
- preserve and rebuild soil fertility, prevent soil erosion, and maintain the soil's ecological health
- use water in a way that allows aquifers to be recharged and the water needs of the environment and people to be met
- rely mainly on resources within the agroecosystem, including nearby communities, by replacing external inputs with nutrient cycling, better conservation, and an expanded base of ecological knowledge
- work to value and conserve biological diversity, both in the wild and in domesticated landscapes
- guarantee equality of access to appropriate agricultural practices, knowledge, and technologies and enable local control of agricultural resources

THE ROLE OF AGROECOLOGY

The agriculture of the future must be both sustainable *and* highly productive if it is to feed the growing human population. This twin challenge means that we cannot simply abandon conventional practices wholesale and return to traditional or indigenous practices. Although traditional agriculture can provide models and practices valuable in developing sustainable agriculture, it cannot produce the amount of food required to supply distant urban centers and global markets because of its focus on meeting local and small-scale needs.

What is called for, then, is a new approach to agriculture and agricultural development that builds on the resource-conserving aspects of traditional, local, and small-scale agriculture while at the same time drawing on modern ecological knowledge and methods. This approach is embodied in the science of *agroecology*, which is defined as "the application of ecological concepts and principles to the design and management of sustainable food systems."

Agroecology provides the knowledge and methodology necessary for developing an agriculture that is on the one hand environmentally sound and on the other hand highly productive and economically viable. It opens the door to the development of new paradigms for agriculture, in part because it undercuts the distinction between the production of knowledge and its application. It values the local, empirical knowledge of farmers, the sharing of this knowledge, and its application to the common goal of sustainability.

Ecological methods and principles form the foundation of agroecology. They are essential for determining (1) if a particular agricultural practice, input, or management decision is sustainable, and (2) the ecological basis for the functioning of the chosen management strategy over the long term. Once these are known, practices can be developed that reduce purchased external inputs, lessen the impacts of such inputs when they are used, and establish a basis for designing systems that help farmers sustain their farms and their farming communities.

Even though an agroecological approach begins by focusing on particular components of a cropping system and the ecology of alternative management strategies, it establishes in the process the basis for much more. Applied more broadly, it can help us examine the historical development of agricultural activities in a region and determine the ecological basis for selecting more sustainable practices adapted to that region. It can also trace the causes of problems that have arisen as a result of unsustainable practices. Even more broadly, an agroecological approach helps us explore the theoretical basis for developing models that can facilitate the design, testing, and evaluation of sustainable agroecosystems. Ultimately, ecological knowledge of agroecosystem sustainability must reshape humanity's approach to growing and raising food in order for sustainable food systems to be achieved worldwide.

THE HISTORY OF AGROECOLOGY

The two sciences from which agroecology is derived — ecology and agronomy — had an uneasy relationship during the 20th century. Ecology had been concerned primarily with the study of natural systems, whereas agronomy dealt with applying the methods of scientific investigation to the practice of agriculture. The boundary between pure science and nature on the one hand, and applied science and human endeavor on the other, has kept the two disciplines relatively separate, with agriculture ceded to the domain of agronomy. With a few important exceptions, little attention was devoted to the ecological analysis of agriculture until the mid-1990s.

An early instance of cross-fertilization between ecology and agronomy occurred in the late 1920s with the development of the field of crop ecology. Crop ecologists were concerned with where crops were grown and the ecological conditions under which they grew best. In the 1930s, crop ecologists actually proposed the term *agroecology* as the applied ecology of agriculture. However, since ecology was becoming more of an experimental science of natural systems, ecologists left the *applied ecology* of agriculture to agronomists, and the term agroecology seems to have been forgotten.

Following World War II, while ecology moved in the pure science direction, agronomy became increasingly results-oriented, in part because of the growing mechanization of agriculture and the greater use of agricultural chemicals. Researchers in each field became less likely to see any commonalties between the disciplines and the gulf between them widened.

In the late 1950s, the maturing of the ecosystem concept prompted some renewed interest in crop ecology and some work in what was termed agricultural ecology. The ecosystem concept provided, for the first time, an overall framework for examining agriculture from an ecological perspective, although few researchers actually used it in this way.

Through the 1960s and 1970s, interest in applying ecology to agriculture gradually gained momentum with intensification of community and population ecology research, the growing influence of systems-level approaches, and the increase in environmental awareness among members of the public. An important sign of this interest at the international level occurred in 1974 at the first International Congress of Ecology, when a working group developed a report entitled “Analysis of Agroecosystems.”

As more ecologists in the 1970s began to see agricultural systems as legitimate areas of study, and more agronomists saw the value of the ecological perspective, the foundations of agroecology grew more rapidly. By the beginning of the 1980s, agroecology had emerged as a distinct methodology and conceptual framework for the study of agroecosystems. An important influence during this period came from traditional farming systems in developing countries, which began to be recognized by many researchers as important examples of ecologically based agroecosystem management (e.g., Gliessman, 1978a; Gliessman et al., 1981).

As its influence grew, agroecology helped contribute to the development of the concept of sustainability in agriculture. While sustainability provided a goal for focusing agroecological research, agroecology’s whole-systems approach and knowledge of dynamic equilibrium provided a sound theoretical and conceptual basis for sustainability. In 1984, a variety of authors laid out the ecological basis of sustainability in the proceedings of a symposium (Douglass, 1984); this publication played a major role in solidifying the connection between agroecological research and the promotion of sustainable agriculture.

During the 1990s, agroecology matured into a well-recognized approach for the conversion to sustainable food systems. Agroecological research approaches emerged (Gliessman, 1990), several textbooks were published (Altieri, 1995; Pretty, 1995; Gliessman, 1998), websites were developed (www.agroecology.org), and academic research and education programs were put into motion. The establishment of an Agroecology Section for the Ecological Society of America in 1998 signaled a major change in how ecologists thought about agriculture, and the regular presentation of symposia, oral papers, and posters on agroecology at annual meetings of the American Society of Agronomy showed the embracing of the ecological approach.

Today, agroecology continues to straddle established boundaries. On the one hand, agroecology is the study of ecological processes in agroecosystems. On the other, it is a change agent for the complex social and ecological shifts that may need to occur in the future to move agriculture to a truly sustainable basis. Together, these complementary thrusts forge the way toward achieving sustainable food systems.

Important Works in the History of Agroecology

Year	Author(s)	Title
1928	K. Klages	“Crop ecology and ecological crop geography in the agronomic curriculum”
1938	J. Papadakis	*Compendium of Crop Ecology*
1939	H. Hanson	*“Ecology in agriculture”*
1942	K. Klages	*Ecological Crop Geography*
1956	G. Azzi	*Agricultural Ecology*
1962	C.P. Wilsie	*Crop Adaptation and Distribution*
1965	W. Tischler	*Agrarökologie*
1973	D.H. Janzen	“Tropical agroecosystems”
1974	J. Harper	“The need for a focus on agro-ecosystems”
1976	INTECOL	*Report on an International Programme for Analysis of Agro-Ecosystems*
1977	O.L. Loucks	“Emergence of research on agro-ecosystems”
1978b	S. Gliessman	*Memorias del Seminario Regional sobre la Agricultura Agricola Tradicional*
1979	R.D. Hart	*Agroecosistemas: Conceptos Basicos*
1979	G. Cox and M. Atkins	*Agricultural Ecology: An Analysis of World Food Production Systems*
1981	S. Gliessman, R. Garcia-Espinosa, and M. Amador	“The ecological basis for the application of traditional agricultural technology in the management of tropical agroecosystems”
1983	M. Altieri	*Agroecology*
1984	R. Lowrance, B. Stinner, and G. House	*Agricultural Ecosystems: Unifying Concepts*
1984	G. Douglass (ed.)	*Agricultural Sustainability in a Changing World Order*
1990	S. Gliessman (ed.)	*Agroecology: Researching the Ecological Basis for Sustainable Agriculture*
1995	M. Altieri	*Agroecology: The Science of Sustainable Agriculture (3rd edition)*
1995	J. Pretty	*Regenerating Agriculture: Policies and Practice for Sustainability and Self-Reliance*
1998	S. Gliessman	*Agroecology: Ecological Processes in Sustainable Agriculture*
2004	D. Rickerl and C. Francis (eds.)	*Agroecosystem Analysis*
2004	D. Clements and A. Shrestha (eds.)	*New Dimensions in Agroecology*

FOOD FOR THOUGHT

1. How does the holistic approach of agroecology allow for the integration of the three most important components of sustainability: ecological soundness, economic viability, and social equity?
2. Why has it been so difficult for humans to see that much of the environmental degradation caused by conventional agriculture is a consequence of the lack of an ecological approach to agriculture?
3. What common ground is there between agronomy and ecology with respect to sustainable agriculture?
4. What are the issues of greatest importance that threaten the sustainability of agriculture in the town or region in which you live?

INTERNET RESOURCES

Agroecology
www.agroecology.org
A primary site for information, concepts, and case studies in the field of agroecology.

Earth Policy Institute
www.earth-policy.org
Led by the well-known eco-economist Lester Brown, this organization is dedicated to providing a vision of an eco-economy and a roadmap on how to get there. The website provides information on major milestones and setbacks in building a sustainable society.

Food and Agriculture Organization of the United Nations
www.fao.org

Food First: Institute for Food and Development Policy
www.foodfirst.org
Food First is a nonprofit think-tank and “education-for-action center” focused on revealing and changing the root causes of hunger and poverty around the world.

Pesticide Action Network International
www.pan-international.org
Pesticide Action Network (PAN) is a network of over 600 participating nongovernmental organizations, institutions and individuals in over 90 countries working to replace the use of hazardous pesticides with ecologically sound alternatives.

Sustainable Table
www.sustainabletable.org
Sustainable Table is a consumer campaign developed by the Global Resource Action Center for the Environment.

Worldwatch Institute
www.worldwatch.org
A nonprofit public policy research organization dedicated to informing policy makers and the public about emerging global problems and trends, and the complex links between the world economy and its environmental support systems. Food and farming are key support systems they monitor.

RECOMMENDED READING

Altieri, M.A. *Agroecology: The Science of Sustainable Agriculture*. 3rd ed. Boulder, CO: Westview Press, 1995. An important pioneering work on the need for sustainability and a review of the kinds of agroecosystems that will help lead us toward it.

Brown, L. Feeding everyone well. *Eco-Economy: Building an Economy for the Earth.* New York and London: W.W. Norton & Co, 2001, 145–168. An in-depth analysis of the crises facing food production systems and the kinds of strategies needed to eradicate hunger and achieve food security.

Clements, D. and Shrestha, A., (eds.) *New Dimensions in Agroecology.* New York: Food Products Press, 2004. An important collection of contributions from prominent agroecologists that covers the state of the art in agroecological research, showing the progress that has been made over the last decade in scientific thinking and research in agroecology.

Douglass, G.K., (ed.) *Agricultural Sustainability in a Changing World Order.* Boulder, Colorado: Westview Press, 1984. Proceedings of a landmark symposium that helped define the trajectory for future work on the interdisciplinary nature of agricultural sustainability.

Freyfogle, Eric T., (ed.) *The New Agrarianism: Land, Culture, and the Community of Life.* Washington, D.C.: Island Press, 2001. An exciting collection of essays and writing that paint a hopeful vision for reestablishing a new relationship between humans, their food, and the communities in which they live.

Gliessman, S.R., (ed.) *Agroecology: Researching the Ecological Basis for Sustainable Agriculture*. Ecological Studies Series #78. New York: Springer-Verlag, 1990. An excellent overview of what research is needed to identify the ecological basis for sustainable agroecosystems.

Halweil, B. *Eat Here: Reclaiming Homegrown Pleasures in a Global Supermarket*. Washington, D.C.: Worldwatch Institute, 2004. An engaging analysis of the current crisis in farm and food systems, accompanied by a convincing argument for reconnecting what we eat with how and where food is grown.

Jackson, W., Berry, W., and Colman, B., (eds.) *Meeting the Expectation of the Land*. Berkeley CA: Northpoint Press, 1986. A collection of contributions from a diverse set of experts, designed to inform the general public of the people- and culture-based elements that are needed to make the transition to a sustainable agriculture.

Kimbrell, A., (ed.) *The Fatal Harvest Reader: The Tragedy of Industrial Agriculture*. Washington, D.C.: Island Press, 2002. An important collection of essays that vividly portray the devastating impacts of the current industrial agricultural system on the environment, human health, and farm communities, and present a compelling vision for a healthy, humane, and sustainable agriculture for the future.

Miller, G.T., Jr. *Living in the Environment: Principles, Connections, and Solutions*. 14th ed. Belmont, CA: Brooks/Cole, 2004. One of the most up-to-date textbooks in the field of environmental science, with a focus on problem solving.

Postel, S. and Richter, B. *Rivers for Life: Managing Water for People and Nature*. Washington, D.C.: Island Press, 2003. Explains the ecological and economic value of healthy riverine systems and how human alteration of rivers — in part to provide water for irrigation — has completely altered the ecology and hydrology of rivers, imperiling both their dependent wildlife and the human societies that depend on healthy rivers for their "ecosystem services."

Pretty, Jules N. *Regenerating Agriculture: Policies and Practice for Sustainability and Self-Reliance*. Washington, D.C.: Joseph Henry Press, 1995. An extensive review of the need for redirection agricultural policy and practice, and the steps that are taking place to create the change.

Rickerl, D. and Francis, C., (eds.) *Agroecosystem Analysis*, Monograph #43 in the *Agronomy Series*. Madison, Wisconsin: American Society of Agronomy, 2004. A valuable review of agroecology as a field of inquiry that seeks to provide an ecologically based assessment of the structure, function, multidimensionality, and spatial scale of sustainable food systems.