Chapter 2

Agriculture and the Environment

In October 1998 Hurricane Mitch struck Honduras, Nicaragua, and Guatemala. The storm killed an estimated 10,000 people and caused damages of $5.5 billion to the local economy. Throughout the region agricultural lands were devastated, but not all farmers suffered to the same degree. Conventional farms using chemical-intensive monoculture practices had 60 to 80 percent more soil erosion, crop damage, and other water-caused losses than those farms that practiced more conservation-oriented forms of agriculture such as polyculture, crop rotation, biological pest control, water conservation, terracing, strip cultivation, and agroforestry. The reason? There are likely several, but among the key factors is undoubtedly the fact that more conservation-oriented farming techniques, though less productive than high-input monocropping systems, are more likely to preserve the integrity and biodiversity of the landscape. This in turn renders it more resilient to otherwise catastrophic events.

Agriculture, like any other use of natural resources, has an environmental impact. Some impacts, however, are more acceptable than others. Many agricultural practices today carry high costs both to society and to producers, and they reduce the long-term viability of agriculture. The decaying health of agricultural lands is only occasionally as dramatic as it was in the aftermath of Hurricane Mitch; more often it manifests as a slow loss of productivity, a gradual shift in the crops that the land can support, or the loss of agricultural lands to other purposes altogether, such as urbanization.

In the United Kingdom, 15 percent of all agricultural land has been lost to urbanization. In the future, the highest losses of land due to urbanization and population growth are likely to happen in China, India, Nigeria, Pakistan, Bangladesh, Brazil, and Indonesia, where half of the increase in world population will occur in the next generation.

Of course, the loss of agricultural land and productivity is not just a contemporary problem. It is ancient: Most civilizations collapsed because they destroyed their natural resources, particularly their soil (Hawken 1999). This is true of the Indus Valley civilization, Babylonians, Egyptians, Maya, and many others. The importance of good soil was well understood even in Roman times. In 146 B.C. after winning the Third Punic War, the Romans deliberately salted the fields around Carthage so that they would not produce grain again.

The question today is whether countries can avoid salting their own fields with unsustainable practices and thus avoid the fates of those civilizations. Several key environmental factors must be addressed if that is to happen. These include maintaining soil fertility, reducing conversion of natural habitats and the associated loss of biodiversity, reducing pollution (especially from agrochemicals), increasing the efficiency of water use, minimizing climate change by controlling production of heat-trapping ("greenhouse") gases, and finding ways to cut energy use. In addition, it is essential to evaluate the environmental impacts of new technologies such as gene splicing.

Soil

Sustainable agriculture is really about soil. Soil is more complex than the human brain, and we know even less about it. Soil can reduce or create greenhouse gases, crumble bedrock, and purify all the fresh water on the planet. Healthy soil biota can facilitate some ten times the nutrient uptake and equal or greater biomass production as degraded soils with only a tenth of applied solid nutrients (Kimbrell 2002).

Soil is alive. There is more biodiversity and biomass within soil than there is on top of it. More microbes live in a teaspoon of soil than people on the planet. In the top few centimeters of one square meter of rich healthy soil one can find up to 1,000 ants, spiders, wood lice, beetles, and larvae; 2,000 earthworms, millipedes, and centipedes; 8,000 slugs and snails; 20,000 pot worms 40,000 springtails; 120,000 mites; and 12 million nematodes (Kimbrell 2002).

A key indicator of soil quality and health is organic matter, which in effect is dead biomass—the decaying remains of plants, animals and animal wastes, and microbes. Organic matter is essential for both the maintenance of soil fertility and structure. (Soil structure is what allows rainwater to soak in and plant roots to penetrate; once soil loses its structure it can become bricklike and impervious to water and most plant roots.) Organic matter in soil declines as a result of the conversion of natural habitat to arable land. Carbon typically declines by 30 to 50 percent in just one or two decades after conversion to field crops. Aeration from cultivation speeds up decomposition rates of existing organic matter in the soil. In addition, organic matter is removed in the form of harvested crops rather than being returned to the soil, so it is not replaced at the same rate as in natural ecosystems.

Organic matter is mostly made up of carbon, so soil carbon content is a good indicator of soil fertility. Studies in Michigan indicate that every 1 percent gain in soil carbon content results in a more than 20 percent increase in potential yield. The average carbon content of undisturbed soil is about 2 percent. It falls below 1.5 percent in the first stages of cultivation, and it is less than 0.5 percent in severely degraded soils. Dead biomass (organic matter) makes up 90 percent of all soil carbon. The remainder is made up of living roots, bacteria, fungi, and soil invertebrates.

From the middle of the nineteenth century to the middle of the 1990s—some 150 years—humans converted close to 1 billion hectares of forests, grasslands, and wetlands to farmlands. In virtually every instance, soil erosion rates increased many times from what they had been in the natural habitats. Since 1950 about a third of U.S. cropland has been abandoned due to erosion (Hawken et al. 1999). In the 1980s it was estimated that every second an entire dump-truck load of topsoil was carried past New Orleans in the Mississippi River (Lal et al. 1995 as cited in Hawken et al. 1999). Though improved techniques such as no-till cultivation have reduced erosion in recent years, by the 1990s, 90 percent of American farmland was losing soil faster than it was replaced—on average seventeen times faster. The cost of this loss is estimated at $44 billion over the next twenty years (Hawken et al. 1999). The loss of topsoil means not only the loss of productivity, but also a reduction of the soil's ability to absorb and store moisture, which increases the need for irrigation and the susceptibility to drought. The soil washed from cropland is deposited in waterways, so erosion means increased costs from dredging, flooding, repairing docks, the loss of recreational fishing areas, etc. Scientists have estimated the global cost of soil erosion at more than $400 billion of damage each year to agricultural land and indirect damage to waterways, infrastructure, and health (Pimentel et al. 1995).

Soil erosion is often so gradual that it is not noticed. However, one evening of heavy rains on conventionally farmed land can erode as much as 12 to 15 metric tons of topsoil per hectare (just over 1 millimeter of soil on average). That is far more than the soil can rebuild in a year. When the vegetable matter being produced and left on a field does not match or exceed the organic matter being lost, soil is being mined just as surely as if it were a mineral ore. Even moderate erosion sustained for twenty years can reduce productivity by 20 percent or more. The cost of rehabilitating such lands, which requires more than simply dumping on additional fertilizer and other inputs, would be prohibitive given the current price of most agricultural commodities.

About 30 percent of all agricultural land is devoted to crops and 70 percent to pasture. Croplands are the most susceptible to erosion because of repeated cultivation and the continual removal of plant cover. However, pastureland can be severely eroded as well. In the most severely overgrazed pastures, soil erosion can reach 100 metric tons per hectare per year. At this time, more than half of the world's pasturelands are thought to be overgrazed. Consequently, about 80 percent of agricultural land is moderately to severely eroded and 10 percent suffers slight to moderate erosion (Pimentel et al. 1995).

Soil erosion rates in the United States pale by comparison to those in Asia, Africa, and South America, where losses average 30 to 40 metric tons per hectare per year. All greatly exceed the average rate of soil formation of about 1 to 2.5 metric tons per hectare per year. By contrast, erosion rates in undisturbed forests range from only 0.004 to 0.05 metric tons per hectare per year. (Pimentel et al. 1995)

Since 1945 moderate, severe, or extreme soil degradation has affected 1.2 billion hectares of agricultural land globally, an area the size of China and India combined. Some 80 percent of this degradation has taken place in developing countries (Hawken et al. 1999). Most countries lack sufficient resources to repair degraded land. At least half the time, the degraded soil is no longer able to retain sufficient moisture to make restoration easily possible. By contrast, about 850 million hectares have been slightly degraded but could be restored by good soil conservation practices (Reddy et al. 1997, as cited in Hawken et al. 1999). Since 1960 one third of the world's arable land has been lost through erosion and other degradation, and the rate continues at about 10 million hectares per year.

These losses may be underestimates, because the degradation of arable land is masked by increases in agricultural productivity. For many commodities, the amount of land in cultivation has not changed drastically over the past fifty years—productivity increases have allowed more to be produced on the same amount of land. But for many agricultural commodities, the land used today is not the same land that was used thirty years ago. That land is often degraded and virtually useless; the producers have moved on to greener pastures, so to speak. Consequently, the overall impact of land lost through agricultural production may be at least double what the current areas of use would imply. No one has good data on this phenomenon, but globally the land used and abandoned in the last fifty years may be equal to the amount of land used today.

Degradation has resulted from soil compaction, water and wind erosion, and the depletion of minerals and organic matter through overplanting, intensive harvesting without replenishing the soil, and overgrazing. In addition, where rainfall is inadequate there is considerable salt buildup (salinization) from improper irrigation and poor drainage. Some 20 percent of the world's irrigated land has suffered reduced productivity from salinization (Ghassemi et al. 1995, as cited in Gleick 2000). This situation is the most dramatic in the lands surrounding the Aral Sea, where extensive irrigation has caused the the volume of the lake to fall by three-quarters since 1960 and the remaining water to become salty (FAO 2003). The area that was irrigated with all this water, 8 million hectares, is losing fertility because of salt buildup.

Nothing protects soil as much as permanent cover. Dense forests provide the best cover, but even grasslands offer substantial protection and reduce soil erosion to negligible amounts. Annual crops, on the other hand, leave soils exposed for weeks and sometimes many months before plants grow enough leaves to cover the ground. Often crop residues are removed after (or as part of) the harvest, leaving the soil exposed to the elements for many months before the next planting season. Roots and leaves of annual crops can never provide as much erosion protection as the dense root systems and overlapping leaves and stems in natural grasslands or multistoried forests. Even perennial crops are, for the most part, a far cry from the soil protection afforded by any natural ecosystem.

Biodiversity and Habitat Loss

The Food and Agriculture Organization of the United Nations (FAO) estimates that in developing countries alone at least 13 million hectares of forest are lost to agriculture each year. This conversion affects massive numbers of species. These same forests provide ecosystem services (such as water and nutrient flows between different species and habitats) that protect downstream agricultural areas and provide them with the gradual release of much-needed fresh water. Large enough forests can even have a distinct impact on local climate.

The wholesale conversion of natural habitat—whether forest, savanna, wetlands, or other—inevitably results in the loss of biodiversity and ecosystem functions. In the United States since the 1930s, depending on the region, from 30 to 80 percent of edge habitat and natural waterways have been removed as farms have gotten bigger (Kimbrell 2002). The disappearance of these woodlots, hedgerows, windbreaks, and grass-covered waterways, plus the draining of wetlands and the channeling of many streams, has eliminated the last vestiges of natural habitat on many farms. These changes, designed to create more uniformity within and between farms, have reduced or eliminated the breeding, foraging, and migration routes of many species. They have also resulted in increased soil erosion. This process has happened in many other parts of the world as well. In addition to habitat conversion, habitat degradation is occurring worldwide from shortened fallow periods, soil erosion, and poor water and nutrient management.

Converting natural habitat and using intensive monocrop farming techniques has turned some species into pests (Kimbrell 2002). This is true of native as well as introduced species—grackles, blackbirds, red-winged blackbirds, sparrows, crows, rabbits, pigs, deer, cane toads, guavas, cheat grass, crabgrass, etc. By providing vast areas of food and by eliminating the diversity that would support competition from a wider array of species, modern agriculture has reduced the number of species that can live in large areas of the landscape while allowing a few to become dominant.

Modern agriculture is reducing the genetic diversity of food crops as well. There are some 7,000 crop species that are available for cultivation, but 90 percent of the world's food comes from only thirty of these. Most domestication and crop-selection programs have focused on higher yields, pest resistance, and fast-growing crop varieties. These varieties now dominate over half of all the land planted to rice, corn, and wheat. The same general trend is true for livestock as well. A sixth of some 3,800 breeds of domestic animals common a century ago no longer exist. This loss in diversity makes all of agriculture more vulnerable to diseases and climatic changes. Agriculture that is vulnerable is likely to have larger environmental costs because as crops fail in one area demand will stimulate production in others.

Agriculture also has substantial impacts on freshwater and marine habitats. For those who are concerned about the global environment, the connections between agriculture and marine sources of pollution and biodiversity loss have been increasingly clear. The dead zone in the Gulf of Mexico (a large and growing area that does not support life) is caused by Midwestern agricultural pesticide runoff. Similar dead zones in the Baltic are also caused by agricultural runoff. Before reaching the sea, this same runoff has already destroyed the habitat of countless freshwater rivers and streams. The main threats to the Great Barrier Reef off the coast of Australia and the reefs off the east coast of Central America are agricultural in origin. In both of these reef areas suspended solids from erosion, and pollution from agrochemicals are the main threats to coral reefs and all the species dependent on them. In short, the impact of agriculture is not just on terrestrial habitats or the fields that are cultivated from them but also on the adjacent freshwater and marine habitats that are polluted.

Direct habitat loss and modification are not limited to more traditional forms of crop and livestock production. Today, the fastest growing form of food production is aquaculture. Shrimp and tilapia aquaculture have caused considerable damage to fragile coastal areas (e.g. wetlands, mangroves, mudflats, salt flats, estuaries, etc.). Large-scale commercial marine aquaculture affects not only the resident biodiversity of the area, but also everything that migrates through the area. Salmon aquaculture, the first of many forms of open ocean net-cage aquaculture, has been shown to have a tremendous impact on benthic communities (the organisms that live in the sediments on the bottom of the ocean), food chains, and particular species through the spread of disease.

Effluents and Pollution

Once input-intensive agricultural production systems are in place, one of their most damaging impacts comes from the use of agrochemicals. The damage depends on the nature of the crop, its requirements, and the physical and biological environment in which it is grown. In addition, the scale of production and the information available to the farmer also influence the use of agrochemicals. There are, for example, different types of fertilizers and different ways to use them, just as there are different ways to fight pests even among farmers producing the same crop. Some practices are preferable to others because they reduce environmental damage.

In the United States, fertilizer use was 800,000 metric tons in 1946. The next year use had exploded to 17 million metric tons as a result of the perceived opportunity to feed many parts of the world whose agriculture had been disrupted after World War II (Kimbrell 2002). Globally, from 1960–1995 nitrogen fertilizer use increased sevenfold and phosphorous use increased 3.5 times (Tilman et al. 2002). Unless there is a dramatic increase in the efficiency of fertilizer use or unless the costs increase, usage of both will increase another threefold by 2050.

Unfortunately, the effectiveness of fertilizer applications diminishes over time. Synthetic fertilizers can reduce the ability of soil to produce or make nutrients available to plants. The application of concentrated forms of nitrogen by farmers reduces the activity of nitrogen-fixing bacteria in the soil, and it increases the populations of other organisms that feed on nitrogen. As the balance of organisms changes over time, applications become less effective. In the United States in 1980, 1 metric ton of nitrogen produced 15 to 20 metric tons of corn. By 1997 the same amount of fertilizer produced only 5 to 10 metric tons of corn (Kimbrell 2002).

Moreover, there is evidence that only 30 to 50 percent of all nitrogen and 45 percent of phosphorous applications contribute to the growth of the target crop (Tilman et al. 2002). In the early 1990s U.S. farmers applied 56 percent more nitrogen to their crops than was present in the crops harvested (Hawken et al. 1999). Excess nutrients are easily leached from soil by rain, which carries them into streams and lakes. This is especially true for soils low in organic matter, which is the case in much large-scale agriculture. A study by the U.S. Environmental Protection Agency (EPA) shows that about 72 percent of rivers studied and 56 percent of lakes studied are polluted from agriculture. Agriculture is also the main cause of groundwater pollution (see Box 2.1). Nitrates are the main contaminants, followed by pesticides U.S. EPA 1994, as cited in Soth 1999). A recent study in Europe concluded that agriculture is the main cause of phosphorus pollution in the coastal zones of Mediterranean countries (Ongley 1996).

Box 2.1
Some Quick Facts on Agricultural Pesticides

- The amount of all pesticides used each year on cotton: 25 percent.
- The number of pesticides presently on the shelves that were registered before being tested to determine if they caused cancer or birth defects, or were toxic to wildlife: 400.
- Amount of time it takes to ban a pesticide in the United States using present procedures: 10 years.
- Number of active ingredients in pesticides found to cause cancer in animals or humans: 107.
- Of those active ingredients, the number still in use today: 83.
- Number of pesticides that are reproductive toxins according to the California Environmental Protection Agency (EPA): 15.
- Number of pesticides found to cause reproductive problems in animals: 14.
- Most serious cause of groundwater pollution confirmed in California: agricultural chemicals.
- Number of pesticides found in drinking wells of California since 1982: 68.
- Number of California wells affected: 957.
- Number of California farming communities affected: 36.
- Percentage of the total U.S. population supplied with drinking water from groundwater: 50%.
- Number of different pesticides documented by the U.S. EPA to be present in groundwater in 1988: 74.
- Number of states affected by pesticide contamination of groundwater: 32.
- The most acutely toxic pesticide registered by the EPA: aldicarb, used frequently on cotton.
- Percentage of total aldicarb applied in California that was used on cotton: 85 to 95%.
- Number of states in which aldicarb has been found in the groundwater: 16.
- Percentage of U.S. counties containing groundwater susceptible to contamination from agricultural pesticides and fertilizers: 46%.
- Number of people in the United States routinely drinking water contaminated with carcinogenic herbicides: 14 million.
- Percentage of municipal water treatment facilities lacking equipment to remove these chemicals from the drinking water: 90%.
- Estimated total costs for U.S. groundwater monitoring: $900 million to $2.2 billion.
- Estimated costs for U.S. groundwater carbon filtration cleanup: up to $25 million per site.
- Percentage of all food samples tested by the U.S. Food and Drug Administration in 1980 that contained pesticide residues: 38%.
- Of the 496 pesticides identified as likely to leave residues in food, the percentage which FDA tests routinely detect: 40%.

Text Box 2.1, continued

- Average number of serious pesticide-related accidents between World War II and 1980: 1 every 5 years.
- Average number of serious pesticide-related accidents between 1980 and the present: 2 every year.
- Increase in cancer rates between 1950 and 1986: 37%.
- Number of Americans who will learn they have cancer this year: 1 million.
- Number who will die from it: 500,000.
- Cost of cancer to the United States in terms of lost production, income, medical expenses, and research resources: $39 billion per year.
- Highest rate of chemical-related illness of any occupational group in the United States: farm workers.
- Pesticide-related illnesses among farm workers in the United States each year: approximately 300,000.
- Number of people who die each year from cancer related to pesticides: 10,400.

Source: Monsanto 1999.

Some 135 million metric tons of fertilizer are used each year around the world. However, as the impacts of the overuse of fertilizers have become understood, the use of synthetic fertilizer over the past decade has declined per hectare in the developed world. Most fertilizer use is now in developing countries (Kimbrell 2002).

There is good evidence that delaying and reducing the rates of fertilizer application can reduce overall costs and pollution without hurting yields. The efficiency of nitrogen fertilizer use in U.S. agriculture has increased 36 percent since 1980 (Tilman et al. 2002) as a result of public expenditures on research and investments by farmers in soil testing and improved timing of fertilizer applications. In addition, the development and utilization of crops with higher nutrient-use efficiency has improved nitrogen utilization rates. In general, matching a plant's demand with the timing and location of applications has been the overall key to improvements. In some cases, the issue is the relative impact of specific production systems. For example, nitrogen runoff is thirty-five times higher from corn and soybean fields than from pasture. Feeding cattle on grass is one way to reduce overall nitrogen pollution in ecosystems (Hawken et al. 1999).

The use of nitrogen raises other, more fundamental, environmental issues. Artificial nitrogen fertilizers and planted legume crops around the world have doubled the amount of nitrogen in terrestrial ecosystems from a background level of some 110 million metric tons (Tilman et al. 2002; Kimbrell 2002). Similarly, agricultural applications of phosphorous have doubled its availability in the environment. In addition to these applied fertilizers, runoff from intensive livestock operations (cattle, pigs, or chickens) pollutes both aboveground and underground freshwater sources with excess nutrients. The most dramatic impact of these excess nutrients is eutrophication of freshwater ecosystems. Eutrophication involves the explosive growth of algae that can kill fish and other aquatic organisms. Algal blooms are common in the Chesapeake Bay, the Gulf of California, the

Gulf of Mexico, and off the coast of China. Many of these blooms are the result of nitrogen and phosphorous from farms being carried in runoff into streams and rivers.

In addition to fertilizers, there has been a tremendous increase in the use of pesticides. The global use of pesticides is perhaps 5 million metric tons per year, having more than doubled over the past thirty years. In the United States pesticide use nearly tripled from 215 million pounds in 1964 to 588 million pounds in 1997 (Kimbrell 2002). Pesticide use has increased so dramatically because it is required for continuous monocrop production systems. Pesticides allow the reduction or even the elimination of crop rotation, so that farmers can grow large areas of the same valuable crops year after year without rotating the crops with lower-value ones.

Hewitt and Smith (1995) of the Henry Wallace Institute (an Arkansas-based, non-profit sustainable agriculture research and education organization) cite more than fifty different studies in the United States and Canada alone that document the adverse effects of agricultural pesticides on bird, mammal, and amphibian populations. David Pimentel (1999) has estimated that globally some 672 million birds are affected by pesticides each year and that some 10 percent of these die. From 1977 to 1984 half of all fish kills off the coast of South Carolina were attributed to pesticide poisoning (Kimbrell 2002).

The most toxic "dirty dozen" pesticides (which include DDT and aldrin) are banned or severely restricted in the United States, Europe, and Japan but are still commonly used in many developing countries. Recent treaties on persistent organic pollutants (POPs) will phase out the most harmful pesticides throughout the world. These pollutants, which include many pesticides, not only persist in the environment, they also concentrate within the food chain, causing reproductive, developmental, and immune-system problems in both humans and animals.

Resistance to chemical pesticides is growing among the organisms they are designed to kill. There is evidence that their effectiveness may decline as their use increases. For example, in the United States in 1948 some 50 million pounds of insecticides were used each year and about 7 percent of the preharvest crop was lost to insects. By 2001 nearly 1 billion pounds of insecticides were used, but estimates suggest that insects destroyed as much as 13 percent of the crop (Hawken et al. 1999).

Another often overlooked but important cause of land and water pollution is the improper disposal of by-products and waste generated during production and processing of agricultural crops. Agricultural waste and by-products are often heaped and left to rot where they are created. They can become breeding grounds for pests. Sometimes they are dumped into rivers, where they absorb oxygen as they decompose, which in turn can asphyxiate fish and other aquatic organisms. In other places the age-old practice of burning is used to dispose of agricultural waste, but this leads to air pollution. While agricultural wastes are still a problem in many parts of the world, they are also a potential resource. Reclamation of these wastes for commercial composting operations and creation of other uses and markets for agricultural waste and by-products could reduce pollution, increase or maintain organic matter levels and overall soil fertility, increase farmer income, and reduce spending on fertilizers and other inputs.

Finally, there is the problem of pollution generated by aquaculture. Aquaculture is, by definition, a water-based industry. All inputs, waste, etc. are found in the water. It is difficult to control pollution in land-based pond systems, and impossible to control it in open ocean systems. Depending on the form of aquaculture, the most significant effluents are wasted feed and excrement, dead animals, and molted shells (from growing shrimp). In addition, however, medications are applied directly to aquatic animals, in the feed, or in the water. A number of chemicals and fertilizers are used to condition ponds or to increase food production.

Water

Due to global increases in population and irrigated agriculture, freshwater withdrawal increased more than sixfold during the last century (from 579 to 3,750 cubic kilometers per year). Demand is expected to increase to 5,100 cubic kilometers per year by 2025 (Shiklomanov 1993, 1998). The increased demand has brought great benefits to agriculture; from the mid-1960s to the mid-1980s, irrigation was responsible for more than half of the increase in world food production (Hawken et al. 1999).

But fresh water supplies are running out. According to the Global Water Project based in Amherst, Massachusetts, water is being pumped out of the ground faster than it can be replenished. The annual depletion of aquifers, due mostly to irrigation, is 163.6 cubic kilometers (Kimbrell 2002). The main cause is irrigated agriculture in America, North Africa, the Arabian Peninsula, China, and India. Most of the irrigation is inefficient and so much of the water is wasted. In addition, agriculture is now in competition with other human water needs, most notably in urban areas.

Water usage can have greater impacts than the mere removal of fresh water from the ecosystem. From 1950 to 1980 more than 35,000 large dams were built. While the largest of these dams were built to generate electricity, the smaller ones were mostly built for irrigation and livestock. A dam can be as damaging to downstream ecosystems as any other impact of agricultural production.

Globally, the area of irrigated agriculture has increased steadily from 47.3 million hectares in 1930 to 254 million hectares in 1995 (Kirda 1999; Shiklomanov 1998, as cited in Soth 1999). While the total area under irrigation is still increasing, the per capita area under irrigation has declined by 5 percent since 1978 (Tilman et al. 2002). Without increased efficiency in water use, previous production gains from irrigated agriculture may well be lost as agriculture competes with other water users in a world with less per capita water available. In most of the world, the impacts of previous and current agricultural practices (e.g. the elimination of watersheds, the loss of organic matter in the soil to retain and release water slowly, and the use of finite water sources in aquifers) are responsible for per-capita and in some cases absolute declines in water available for irrigation.

About 40 percent of the world's food is produced on the 16 percent of agricultural land that is irrigated (Tilman et al. 2002). Three crops account for 58 percent of all irrigated land: rice (34 percent), wheat (17 percent), and cotton (7 percent). Globally, the agricultural sector is responsible for about 69 percent of all freshwater withdrawal, more than twice the amount of industrial, municipal, and all other users combined. Some 75 percent of all irrigated land is in developed countries. In these countries 73 percent of all fresh water is used for agricultural irrigation, but in some countries the share is as much as 98 percent. In Asia agriculture accounts for 86 percent of freshwater use and in Africa 88 percent. Much of this irrigation is inefficient. At least 60 percent of water used for irrigation is wasted. As Table 2.1 indicates, 1 kilogram of rice can be produced using as little as 1,900 liters of water, but in some regions as much as 5,000 liters are used to produce the same quantity.

Table 2.1
Freshwater Requirements for Different Agricultural Products

	Water Requirement by Area (liters/m^2)	Water Requirement per kg of Product (liters/kg)
Potatoes	350–625	500–1,500
Wheat	450–650	900–2,000
Rice	500–950	1,900–5,000
Sorghum		1,100–1,800
Soybeans	450–825	1,100–2,000
Sugarcane	1,000–1,500	1,500–3,000
Chicken		3,500–5,700
Cotton	550–950	7,000–29,000
Beef		15,000–70,000
Shrimp aquaculture	1,000–100,000*	1,000–300,000*

Sources: Soth 1999; Pimental et al. 1999; Tuong and Bhuiyan 1994; FAO 2002; Gleick 2000.
* indicates brackish water.

The efficiency of water use varies from region to region and from crop to crop (Gleick 2000). In the United States, for example, per-unit food production of the same crop requires twice as much water as in Asia because U. S. production is less efficient (Kimbrell 2002). In addition, animals require far more water than plants. For example, one kilogram of corn requires 800 to 2000 liters of water and 1 kilogram of beef up to eighty times that amount or as much as 70,800 liters of water. Daily water use by livestock in developed countries can be quite high—milk cows 154 liters per day, steers 51 liters per day, pigs 9 liters per day, sheep 3 liters per day, and chickens 0.3 liters day (Gleick 2000).

Aquatic animals can require even greater amounts of water than land-based animals. It can take as much as 300,000 liters of brackish water to produce 1 kilogram of shrimp from aquaculture. With brackish water the issue isn't so much the water use per se but all the associated costs of inefficient use—pumping, aeration, the "down" time of conditioning new water until it can be stocked with animals, and treating the nearly constant flow of effluents. Some shrimp farmers can reduce their use of brackish water to less than 500 liters per kilogram of shrimp produced, but the trade off is that they must compensate by using more energy for aeration.

One of the main reasons that water is used so inefficiently for agriculture is that the real cost of water is much higher than most farmers pay. Other water users tend to pay much higher prices than agricultural users for water from the same sources. An open market for water through auctions or transparent, competitive bidding would increase the price of water to farmers and increase the efficiency with which they use it.

There are known technical solutions to reduce water use through conservation. Some new hybrids require less water than previous ones. For example, some rice varieties can reduce water needs by 20 to 30 percent. If combined with improved irrigation and management systems, water use for rice and other agricultural products can be reduced by as much as 50 percent (Gleick 2000). Sprinkler nozzles are 95 percent efficient. Drip irrigation and improved water management (e.g. demand-driven water supplies) are two effective ways to reduce water use by 30 to 70 percent over conventional flooding systems, and they can increase yields by as much as 20 to 90 percent (Kimbrell 2002). Israel has developed drip-irrigation systems that take advantage of both brackish water (focussing on halophytes that prefer brackish water) and wastewater that has been kept separate from sewage. However, only 0.7 percent of worldwide irrigated areas use drip irrigation because given the current value of water, it is cheaper to use it inefficiently than it is to buy all the necessary equipment to deliver and use it more efficiently. The main issue will be to find incentives that encourage other producers to adopt the same techniques before they waste too much more fresh water.

Very little is done to capture and use rainfall in agriculture. Great gains could be made by learning to use rainfall more efficiently by directing its on-land flow so that more can be absorbed into the soil or stored. For example, more water runs off bare soil; soil that is protected by mulch or crop residues slows the rate of runoff. Many small-scale producers use cisterns that catch water draining off roofs, plus other forms of ponds and embankments to catch and store rainwater for use another time. Similarly, water-absorbing substances are available that can be mixed into the soil to hold water and release it gradually. While agriculture, even truck gardening, makes little use of these at present, they can reduce watering needs by 50 percent or more. Though these are expensive inputs for the extensive production of low-valued crops, they would be viable for most horticulture and even perennial crops, particularly where water is more scarce or more expensive.

Climate Change

Agriculture is an important contributor to climate change through the release of carbon dioxide and other so-called greenhouse gases into the atmosphere. According to some sources, agriculture contributes about a quarter of the total risk of altering the Earth's climate (Hawken et al. 1999). One estimate suggests that soil microbes produce 85 percent of atmospheric greenhouse gases (Kimbrell 2002). The production of such gases increases when soils are disturbed and when nutrients are added (in short, when modern agriculture is practiced). Soil conservation measures can reduce the production of greenhouse gases by 16 to 42 percent (Kimbrell 2002).

Temperate farmland can have as much as twenty to thirty times the biomass below the surface as above it. Soil carbon can exceed 110 metric tons per hectare. Bad agricultural practices tend to mobilize this carbon by converting it to carbon dioxide, which escapes into the atmosphere. At this time some 2 billion hectares of agricultural lands are low in carbon as a result of current agricultural practices. Globally, the net loss of soil carbon from agriculture from these lands is estimated to have contributed 7 percent of all atmospheric carbon (Hawken et al. 1999). Carbon emissions are also caused by production of agricultural chemicals such as fertilizers and pesticides. Other greenhouse gases also have their origin in agriculture. For example, most nitrous oxide (N_2O)—a greenhouse gas hundreds of times more potent than carbon dioxide—is produced from the interaction of synthetic fertilizers and soil bacteria (Hawken et al. 1999).

Much of the planet's methane (CH_4) emissions come from the production of livestock and continuously flooded rice paddies (Wassman et al. 2000). One estimate places total methane emissions from rice at some 10 to 15 percent of total global methane emissions (Wang et al. 2000). Other sources suggest that the total methane emissions from rice represent 5 to 30 percent of global emissions. An estimated 1.3 billion cattle produce some 72 percent of all livestock-generated methane (Crutzen et al. 1986, as cited in Hawken et al. 1999).

Ozone depletion is another factor in global climate change. One pesticide alone, methyl bromide, is generally considered responsible for 5 to 10 percent of the Earth's total ozone depletion (Kimbrell 2002). In California a third of the 15 million pounds of methyl bromide used each year is for strawberry production. In other states it is used primarily on tomatoes or potatoes.

Besides contributing to global climate change, agriculture will also be affected by it. Weather extremes and climate variability caused by climate change will tend to limit production. In addition, land use and land-use change affect climate change, and it will affect them as well.

Current crop production is taking place within an atmosphere of increasing concentration of carbon dioxide. If all other production variables remained constant, increasing carbon dioxide levels would increase crop yields. Unfortunately, all other variables will not remain the same. Increasing carbon dioxide levels cause global warming. In addition, increasing the concentration of carbon dioxide causes partial closure of plant stomata (the small openings in plant leaves that control the flow of air), which in turn decreases evaporative cooling and can cause leaf temperatures to exceed air temperature (Shafer 2002).

Soybeans provide a good example of how complicated it is to predict the agricultural impact of global warming. Doubling of carbon dioxide in the atmosphere at a constant temperature could increase plant mass by 50 percent and seed yield by 30 percent. However, this increased level of carbon dioxide brings global warming. Soybean seed yields decrease about 10 percent for each Celsius degree above 30 degrees. Declining yields result from fewer and smaller seeds, reduced stores of carbohydrates within seeds, different ratios of fatty acids, and increased vitamin E (Shafer 2002).

Increases in atmospheric carbon dioxide will cause all plants—crops and weeds alike—to increase pollen production (Shafer 2002). For example, experimental carbon dioxide enrichment from 280 parts per million to 600 parts per million increases ragweed reproduction nearly 4.5 times. It is likely that some weeds and other pests may be able to outperform crops under increased carbon dioxide conditions. This could have significant implications for sustainable agriculture with reference to the use of herbicides and insecticides.

Another major impact of climate change will be uncertainty (Shafer 2002). The distribution of crop pathogens and pests depends on climate, as outbreaks are influenced by weather. Variability will most likely increase due to climate change. In addition, host/parasite interactions are known to depend on the concentrations of sugars and other chemicals in plants, and these, too, will be affected by climate change.

It is clear from the evidence to date that the impact of climate change on agricultural production will not be spread evenly around the world. For example, by 2025 if global carbon dioxide increases to 405–460 parts per million and global mean temperature increases by 0.4–1.1 degrees Celsius, then cereal crop yields will likely increase in many mid- and high-latitude regions but will decrease in most tropical and subtropical regions. By 2050 if carbon dioxide increases to 445–640 parts per million and temperature increases by 0.8–2.6 degrees Celsius, then there will be mixed impacts on cereal yields in mid-latitude regions and more pronounced cereal yield decreases in tropical and subtropical regions. However, if by 2100 carbon dioxide increases to 540–970 parts per million and global mean temperature increases by 1.4–5.8 degrees Celsius, then there will be reduced production throughout the world (Shafer 2002).

Proposed solutions for global climate change could affect agriculture. For example, increasing overall soil carbon could have broad environmental benefits on and off the farm while increasing overall agricultural production. By contrast, calls to produce more biomass on farms to substitute for as much as 10 percent of total petroleum needs will take land from crop and animal production and, unless performance is better than the current norm, degrade the land and require the use of agrochemical inputs to maintain production.

Soil is an excellent source of sequestered carbon, and many see a potential to use improved farming practices as a way to take atmospheric carbon and store it in the soil. Globally, there is about 1,500 gigatons of carbon in soils and about 770 gigatons in the atmosphere. Carbon sequestration programs on agricultural lands could have a triple benefit. First, they would help offset global warming. If properly designed, sequestration programs could also provide additional income for farmers. Finally, by enriching the soil with carbon they would increase the productivity of existing farmland, thereby reducing the pressure to expand into other areas. Most agricultural areas, however, are not net carbon sinks (areas that gain more carbon than they lose each year), so if carbon sequestration programs are to provide income for farmers, improved practices are needed or land will have to be taken out of agricultural production and dedicated to carbon sequestration. This could happen either because the price of sequestered carbon warrants it or because governments decide it is important enough to pay for.

Energy

Globally, the food sector uses some 10 to 15 percent of all energy consumed in developed countries, and even more in the United States (Hawken et al. 1999). If that energy is derived from fossil fuels, it also contributes to increased atmospheric carbon dioxide and therefore to global climate change.

Much of the energy use in agriculture is in the processing, manufacturing, and food distribution systems. For example, it can take 40 calories of energy to ship 1 calorie of lettuce from California to the East Coast, or 240 calories of energy to ship 40 calories of strawberries from Chile to the United States.

A recent study in Germany suggests that the production of .24 liters (a typical cup) of strawberry yogurt entails 9,093 kilometers (5,650 miles) of transportation. The amount of transportation is more than doubled if one includes distribution. Germans eat .7 billion liters (3 billion cups) a year (Hawken et al. 1999). In the United States, the food for a typical meal has traveled nearly 2,092 kilometers (1,300 miles) (Kimbrell 2002), but if that meal contains off-season fruits or vegetables the total distance is many times higher.

Production of agricultural chemicals accounts for 2 percent of all industrial energy use, and synthesis of nitrogen fertilizers alone is thought to require half of all energy used for high-yield crops in developed countries. One estimate suggests that a ton of coal is required to create every 2.27 kilograms (5 pounds) of synthetic nitrogen fertilizer (Kimbrell 2002). Between 1910 and 1983 corn yields in the United States increased 346 percent. During the same period, however, energy consumption for agriculture increased 810 percent (Kimbrell 2002).

Other sources of energy consumption in agriculture typically include tilling, planting, applying fertilizers and pesticides, harvesting, and drying. In the United States, for example, crop drying accounts for 5 percent of total on-farm energy use.

Many opportunities exist for improving energy efficiency in agricultural production. While U.S. farms have doubled their direct and indirect energy efficiency since the 1970s, it still can take up to ten times as much energy to produce food as the energy value of the food itself (Hawken et al. 1999). In the Netherlands it requires 100 times as much energy to produce hothouse tomatoes as the energy contained in those tomatoes. Some 75 percent of the energy is used to heat the greenhouses and another 18 percent to process and can the tomatoes. It would require only a third the amount of energy to produce the tomatoes in Sicily and ship them by air to the Netherlands (Hawken et al. 1999). The margins for producers are so small in some agriculture industries that small changes can have a surprisingly large impact. One study found that North Carolina chicken farmers could increase net farmer income by 25 percent simply by switching from incandescent lighting to compact fluorescent lamps (Hawken et al. 1999).

Genetically Modified Organisms

The commercial planting of genetically modified or transgenic crops began in 1996 with around 2 million hectares. In 1997 the area planted to genetically modified organisms (GMOs) increased to more than 10 million hectares. In 1999 about 40 million hectares of genetically modified crops were grown in a dozen countries. By 2001 more than 52 million hectares were planted to GMOs globally. The prediction is that more than 74 million hectares will be planted to genetically modified crops by 2006 (Freedonia, as cited in *The World in 2003* 2003). While soybeans, corn, cotton, and canola have dominated the area of crops planted to date, the first genetically modified rice will be planted in China in 2003. Transgenic wheat is just around the corner, possibly as early as 2004.

The production of genetically modified crops has been dominated by the United States (71.9%), Argentina (16.8%), Canada (10%), and China (0.75%), primarily because U.S. corporations dominate the technology. Between 1996 and 2001, sales of transgenic soybeans increased from $11 million to $1,090 million; of corn from $15 million to $544 million; and of cotton from $35 million to $480 million (Verdia 2003). Most of the crops were bred to resist herbicides (e.g. Roundup-ready soybeans) or to produce their own insecticidal proteins (e.g. corn and cotton bred to produce their own *Bacillus thuringiensis*, or Bt). Increasingly, however, varieties are being developed for other purposes, including some that require less fertilizer, fewer pesticides, and less water. This latter factor is particularly important for producers in arid environments.

The implications of GMOs for people and the environment are much debated, as they are neither black nor white. As described in Chapter 1, consumers in several countries have made it clear that they do not want such products, despite any possible benefits. Herbicide application per hectare appears to have fallen on genetically modified crops compared to conventional ones, but overall more herbicide is being used because more marginal land has been brought into production and is being planted to genetically modified crops. In addition, resistance appears to be building to some pesticides commonly associated with genetically modified crops, so GMOs may not entirely fulfill their promise of freeing the agricultural sector from the treadmill of developing new varieties before the old ones lose their effectiveness. While this may be good for seed companies, it will not be good for farmers who will find that an even higher percentage of their income goes to pay for research and development.

The net benefit to farmers generated by GMOs is difficult to calculate. In many areas, GMOs allow the use of no-till cultivation practices, in which existing vegetation is killed with herbicides and a new crop is sown through the dead vegetation and the previous year's crop residues. No-till techniques reduce soil erosion and also allow marginal land to be cultivated that would otherwise be susceptible to high erosion rates. Yields across the board have not increased, but yields for specific crops such as Bt corn appear to have increased on average. Where productivity increases, prices may decline and offset most of the potential gains. What will happen, of course, is that this will be another factor that will affect farmers' overall cost of production. To the extent that this allows some producers to lower their overall costs, higher-cost producers will go out of business without government subsidies.

Research supported by the FAO in China suggests that cotton farmers who adopt and use better practices in general improve their yields and reduce their use of inputs by comparison to conventional producers. Similarly, those planting Bt cotton reduce their use of inputs by comparison to conventional producers. However, the use of pesticides and other inputs is decreased most (and net profits are increased most) when producers use improved practices such as integrated pest management (IPM) in conjunction with planting Bt cotton (Peter Kenmore, personal communication).

Aside from the health concerns that some consumers have about GMOs, there are other concerns as well. The GMOs that allow the use of broad-spectrum herbicides will tend to reduce most biodiversity in the field. However, some pests will develop resistance and, over time, this will pose the same problem of generating "superbugs" or "superweeds" as broad-spectrum antibiotics do for human health. By 1997, for example, eight insect pests in the United States had already developed resistance to Bt (Hawken et al. 1999).

There are also concerns that genetically modified crops might interbreed with wild relatives in the field, neighboring fields or even in nearby unfarmed areas and that the added genetic material might contribute to the formation of new pests. In addition, Bt products actually kill neutral or beneficial insects. Bt corn can stunt or kill Monarch butterfly caterpillars. Perhaps more important, but less symbolic, Bt corn can be lethal to green lacewings—important natural predators of the corn borer that Bt corn was developed to combat.

While the impact of "escaped" plant varieties of GMOs can be debated, the impact of genetically modified animals, particularly aquatic ones, is of far more concern. The recent development of transgenic salmon for aquaculture production has brought this issue into sharp focus. It is known that salmon escape from net-pen aquaculture no matter how many protocols have been put in place. So far, the industry has not been allowed to culture such salmon on a commercial scale because of concerns of how escapes might affect wild populations. But hearings are currently under way in several countries that would allow the use of such animals.

It is clear that some genetically modified crops can be produced in such a way as to reduce the aggregate environmental damage from agriculture, at least in the short term. This means that more food and fiber can be produced with genetically modified crops than with other varieties with less damage to the soil (either in terms of erosion or fertility) or to downstream freshwater and marine environments. It appears, however, that producers will be required to support the ongoing research necessary to ensure the development of new varieties in a timely way. Fortunately, the technology allows for the development of new varieties relatively easily by comparison to traditional plant and animal breeding programs. However, the biggest issue is what the genetic modification technology will do to the soil environment and the web of organisms that depend upon it. It is very difficult to predict such impacts when most soil organisms have not yet been named, much less studied. For this reason alone, caution is suggested. More importantly, though, agricultural producers need to develop the capacity to monitor the health of the soil in order to truly understand the impact of GMOs on the environment.

Box 2.2
GMO Issues in Europe in May 2000

- A series of recent events in Europe will continue to constrain the ability of farmers to sell GMO products (and consequently their willingness to plant GMOs) throughout the world.
- The United Kingdom, Germany, Sweden, and France saw the accidental introduction of GM canola in seed that was labeled as non-GMO. This introduction by AVANTA, partially owned by AstraZeneca, has affected thousands of farmers.
- Traces of GM pollen have been found in honey produced in the United Kingdom. It is difficult if not impossible to sell tainted honey in the United Kingdom. The issue of who is liable is now being determined.
- The Welsh Assembly voted unanimously to ban the sale of all GMO products, or manufactured products that contain them, throughout Wales.
- A three-year study by the University of Jena in Germany found that genes from GMO crops could spread from plants into other forms of life. This will raise health and environmental questions about the safety of GMO products.
- These events reflect the increasing intensity of the GMO debate in Europe. Even before these issues became widely known, corn exports from the United States to Europe decreased from 2 million metric tons in 1997–98 to 137,000 metric tons in 1998–99. Soybean sales declined from 11 million metric tons in 1997–98 to 6 million metric tons in 1999. Japan has also refused to purchase grain if it cannot be guaranteed to be from non-GMO sources.

Toward More Sustainable Agriculture

There is no doubt that agriculture has had a greater environmental impact on Earth than any other single human activity. The question is whether new kinds of agriculture can be developed that will produce the food needed to feed an increasing population and still accommodate all the other life forms on the planet.

It is also clear that business as usual in agriculture is not the solution. Conventional agricultural production technologies will not provide the food and fiber needed by populations in the future. Under most systems of agricultural production at this time, it is not a question of if, but rather when, virtually all of the natural habitat on the planet will become degraded to the point that it is no longer productive and then abandoned for future generations to find ways to rehabilitate and repair. Not only is it unfair to pass these costs on to future generations, it is unnecessary. In fact, it is cheaper to farm sustainably now than it ever will be to correct the problems created through unsustainable farming.

There is no single "right" way to practice more sustainable agriculture. Many farmers have found ways to reduce environmental damage, improve production, and increase profitability. How the farmers do this depends tremendously on where they live, what they produce, and where they sell their product. Broadly speaking, though, farmers are beginning to invent, adapt, and adopt a wide range of approaches that are usefully seen as "better management practices." Such practices involve maintaining and building soils, maintaining the natural ecosystem functions on farms, working with nature and not against it to produce products, reducing total input use and using inputs more efficiently, and reducing waste or creating marketable by-products from materials that were previously considered waste.

The ways in which farmers can improve their lots are not limited to production; they also involve market initiatives. Some farmers are experimenting with organic or other ecological labels to differentiate their products and enable them to charge more for them. Some are adding value to their production (e.g. bagging potatoes rather than selling in bulk, processing fruit into juice, selling meat directly to consumers; others are trying to become more vertically integrated (e.g. by buying equity in processing plants or distribution companies) into the market. Some specialize their production while others diversify to reduce risks. A number of specific examples of these new strategies are given in the different commodity chapters.

Likewise, producers around the world can benefit from appropriate government actions. These can include appropriate zoning and siting of operations in areas that are most suited to agriculture or aquaculture expansion, or it can include linking permits and operating licenses to the adoption of specific practices. The governments that help producers most in the future, however, are likely to be those that require certain performance levels but leave it up to the farmer to find the way that is best to achieve these on the specific property in question.

Similarly, buyers, retailers, investors, insurers, and consumers can all support producers who adopt better practices to reduce their environmental and social costs to more acceptable levels. This is not only good for the producer, it also reduces the risks and increases the profits of everyone else who is part of this system. And, of course, the consumer is the biggest winner of all by getting a reliable source of products that are grown with less damage to the environment and that contain fewer substances that may be harmful to human health.

Farmers have learned a lot about sustainable production. Unfortunately, farmers' business is farming, not teaching others to farm better. This book is an attempt to glean examples of lessons that farmers and others have learned around the world while trying to survive in an increasingly competitive business. The focus here is on commodities, because they are what virtually all farmers sell and would like to sell more of at higher prices. This is not to deny that farmers' strategies are complex and involve systems both of their own and others' making. Nor is the goal to provide blueprints for what should be done and how it should be done. The goal here is to help people understand how to think, not what to think. To paraphrase an old adage—give a person a solution and they will solve a problem, teach them to think and they will be able to solve problems that do not yet exist.

Resources

Web Resources

Multi-commodity web sites:
www.fao.org
www.wisard.org
www.agrifor.ac.uk
www.intracen.org
www.ifpri.org
www.worldbank.org
www.worldfarming.org
www.unescap.org/esd/main.asp
www.growingforthefuture.com
www.africancrops.net/
www.ers.usda.gov
www.fas.usda.gov
www.iita.org
www.unctad.org
www.agjournal.com
www.wri.org
www.eldis.org/agriculture/index.htm
www.iisd.org/
www.indiancommodity.com
www.globalexchange.org/
www.environmentaldefense.org/
www.gpgnet.net

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