How Sustainable Agriculture Can Address the Environmental and Human Health Harms of Industrial Agriculture

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The industrial agriculture system consumes fossil fuel, water, and topsoil at unsustainable rates. It contributes to numerous forms of environmental degradation, including air and water pollution, soil depletion, diminishing biodiversity, and fish die-offs. Meat production contributes disproportionately to these problems, in part because feeding grain to livestock to produce meat—instead of feeding it directly to humans—involves a large energy loss, making animal agriculture more resource intensive than other forms of food production. The proliferation of factory-style animal agriculture creates environmental and public health concerns, including pollution from the high concentration of animal wastes and the extensive use of antibiotics, which may compromise their effectiveness in medical use. At the consumption end, animal fat is implicated in many of the chronic degenerative diseases that afflict industrial and newly industrializing societies, particularly cardiovascular disease and some cancers. In terms of human health, both affluent and poor countries could benefit from policies that more equitably distribute high-protein foods. The pesticides used heavily in industrial agriculture are associated with elevated cancer risks for workers and consumers and are coming under greater scrutiny for their links to endocrine disruption and reproductive dysfunction. In this article we outline the environmental and human health problems associated with current food production practices and discuss how these systems could be made more sustainable. *Key words*: diet, environment, health, industrial agriculture, sustainability, sustainable agriculture. *Environ Health Perspect* 110:445–456 (2002). [Online 20 March 2002]
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The Union of Concerned Scientists (*1*) said that industrial agriculture

> views the farm as a factory with "inputs" (such as pesticides, feed, fertilizer, and fuel) and "outputs" (corn, chickens, and so forth). The goal is to increase yield (such as bushels per acre) and decrease costs of production, usually by exploiting economies of scale.

Industrial agriculture depends on expensive inputs from off the farm (e.g., pesticides and fertilizer), many of which generate wastes that harm the environment; it uses large quantities of nonrenewable fossil fuels; and it tends toward concentration of production, driving out small producers and undermining rural communities. The following environmental and public health concerns are associated with the prevailing production methods:

- Monocultures are eroding biodiversity among both plants and animals.
- Synthetic chemical pesticides and fertilizers are polluting soil, water, and air, harming both the environment and human health.
- Soil is eroding much faster than it can be replenished—taking with it the land's fertility and nutrients that nourish both plants and those who eat them.
- Water is consumed at unsustainable rates in many agricultural areas.

Many of the problems inherent in industrial agriculture are more acute when the output is meat. Our food supply becomes more resource intensive when we eat grain-fed animals instead of eating the grain directly, because a significant amount of energy is lost as livestock convert the grain they eat into meat. Cattle are the most inefficient in their energy conversion, requiring 7 kg of grain to produce 1 kg of beef (compared to 4:1 for pork and 2:1 for chicken) (*2*).

Despite this inefficiency, livestock diets have become higher in grains and lower in grasses. The grain raised to supply feedlots (cattle) and factory farms (chickens, hogs, veal calves) is grown in intensive monocultures that stretch over thousands of acres, leading to more chemical use and exacerbating attendant problems (e.g., pesticide resistance in insects, and pollution of surface waters and aquifers by herbicides and insecticides).

The use of growth-promoting antibiotics in animal agriculture is thought to be one of the factors driving the increase in antibiotic resistance in humans. In addition, the most prevalent foodborne pathogens are overwhelmingly associated with animal products, most of which come from factory farms and high-speed processing facilities. The crowded conditions in factory farms, as well as many of their production practices, raise ethical concerns about the inhumane treatment of animals.

Because they contain excessive amounts of fat—particularly saturated fat—and protein, animal-based diets are linked to many of the chronic degenerative diseases that are characteristic of affluent societies, such as heart disease; colon, breast, and prostate cancer; and type II diabetes. The animal-based diet that prevails in the industrialized world—and is on the rise in many developing countries—thus harms both the environment and the public's health.

High consumption of animal products in affluent countries can be placed in the context of broader global inequities between industrialized and developing countries. Since 1950, meat consumption has doubled among the world's richest 20%, whereas the world's poorest quintile has not increased its consumption of meat much at all (*3*).

Some portions of the developing world are beginning to adopt Western dietary patterns and, as a result, are experiencing an increase in the chronic diseases associated with a richer diet. China offers a sobering case in point: meat consumption nearly doubled countrywide during the 1990s (*4*), with the increase especially pronounced among urban residents. This dietary shift is considered a major reason that chronic diseases have become a more common cause of death in China, with acute diseases becoming less common because of improvements in water, sanitation, and immunizations. According to Zhao et al. (*5*), measles, tuberculosis, and senility were the three most common causes of death before 1950, but in 1985 malignant tumors, cerebrovascular disease, and ischemic heart disease were the most common. To support its "Westernizing" diet, China has also begun a shift toward more of the resource-intensive agricultural practices that predominate in richer countries.

Resource-intensive agricultural practices are considered unsustainable for two reasons: much of the consumption is of nonrenewable

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resources, in particular, fossil fuels; and consumption of some renewable resources is occurring faster than the rate of regeneration.

Developing a sustainable economy involves more than just a sustainable food system, and the food system involves more than just agriculture. However, because agriculture can have such profound effects on the environment, human health, and the social order, it is a critical part of any movement toward sustainability.

Sustainable agriculture systems are based on relatively small, profitable farms that use fewer off-farm inputs, integrate animal and plant production where appropriate, maintain a higher biotic diversity, emphasize technologies that are appropriate to the scale of production, and make the transition to renewable forms of energy. The average U.S. farm uses 3 kcal of fossil energy in producing 1 kcal of food energy (in feedlot beef production, this ratio is 35:1), and this does not include the energy used to process and transport the food. Sustainable systems involve less reliance on chemical inputs and decreased emphasis on economic efficiencies that shunt environmental costs onto society.

The health of both the environment and humans would be enhanced if more of our farms made the transition to sustainable systems of production. A more sustainable food system would involve closer connections between producer and consumer, meaning more direct marketing of foods to local consumers (through farmers markets, community-supported agriculture farms, farmer cooperatives, etc.). These localized marketing strategies mean shorter distances from the farm to the dinner plate, and therefore less energy use for food transport.

In this paper, we use examples from around the world to illustrate our points, but we place heavy emphasis on the U.S. food system because it represents one of the worst-case examples of the pitfalls of industrial agriculture. The type of agriculture that has become conventional throughout the industrialized world is, in historical terms, a new phenomenon. Humans have practiced agriculture for more than 10,000 years, but only in the past 50 years or so have farmers become heavily dependent on synthetic chemical fertilizers and pesticides and fossil fuel-powered farm machinery.

In that half-century of ascendance, industrial agriculture has substantially increased crop yields through high-yielding plant varieties, mechanization, and synthetic chemical inputs. For example, U.S. farmers were producing 30 bushels of corn per acre in 1920, whereas 1999 yields averaged about 134 bushels per acre, an increase of almost 350% (*6,7*).

The higher yields of industrial agriculture have come, however, at great cost to the environment and the social fabric—costs that are not included in the price of our food (economists would call these costs "externalities"). Low prices at the grocery store give us a false sense that our food comes cheap, but they do not include the cost of cleaning up farm pollution, for example, or the cost of vast government subsidies to agriculture. In 1996, the U.S. government spent $68.7 billion on agricultural subsidies, which translates into $259 per consumer and even more per taxpayer (*8*).

Industrial agriculture's tendency toward larger, more mechanized farms has also exacted a social toll. Studies have shown that farm consolidation leads to the deterioration of rural communities (*9*). According to University of California anthropologist Dean MacCannell:

> We have found depressed median family incomes, high levels of poverty, low education levels, social and economic inequality between ethnic groups, etc., … associated with land and capital concentration in agriculture (*10*).

In this paper we first outline the environmental and public health problems associated with our current agricultural system, highlighting animal agriculture as a worst-case example. We then discuss how a sustainable agriculture can address these issues.

Impact of Food Production on the Environment

Fertilizers. In 1998, the world used 137 million metric tons of chemical fertilizers, of which U.S. agriculture consumed about 20 million tons, or 15%. Between 1950 and 1998, worldwide use of fertilizers increased more than 10-fold overall and more than 4-fold per person (*11,12*). Tilman (*13*) estimated that crops actually absorb only one-third to one-half of the nitrogen applied to farmland as fertilizer.

Nitrogen that runs off croplands into the Mississippi River and its tributaries has been implicated as a major cause of a "dead zone" in the Gulf of Mexico (*14*). This zone suffers from hypoxia—a dearth of dissolved oxygen (< 2 mg/L). Excess nutrients fuel algal blooms by speeding up the algae's growth-and-decay cycle. This depletes oxygen in the water, killing off immobile bottom dwellers and driving off mobile sea life such as fish and shrimp. In 1999, the Gulf's dead zone grew to 20,000 km^2 (about the area of New Jersey), its largest recorded size (*15*).

Excess nitrogen in soil can lead to less diversity of plant species, as well as reduced production of biomass. Additionally, some ecologists contend that this decrease in diversity makes the ecosystem more susceptible to drought, although this issue has been controversial (*16*).

Chemical fertilizers can gradually increase the acidity of the soil until it begins to impede plant growth (*17*). Chemically fertilized plots also show less biologic activity in the soil food web (the microscopic organisms that make up the soil ecosystem) than do plots fertilized organically with manure or other biologic sources of fertility (*18*).

Pesticides. Each year the world uses about 3 million tons of pesticides (comprising herbicides, insecticides, and fungicides), formulated from about 1,600 different chemicals. Complete toxicity data are lacking, however, for most of these substances. In the United States, insecticide use increased 10-fold between 1945 and 1989 (*19*).

Some of the increase in pesticide use can be attributed to monocropping practices, which make crops more vulnerable to pests, but high-volume use also reflects the imprecise nature of pesticide application. Cornell entomologist David Pimentel (*19*) and colleagues stated:

> It has been estimated that only 0.1% of applied pesticides reach the target pests, leaving the bulk of the pesticides (99.9%) to impact the environment.

That environmental impact can include widespread decline in bird and beneficial insect populations. This can disrupt the balance between predator and prey because pests often recover faster from pesticide applications than do the predators that normally keep pest populations under control (*20*). Pesticide runoff and airborne pesticide "drift" pollute surface waters and groundwater.

Some of the more disturbing findings on pesticide impact are as follows:

- The number of honeybee colonies on U.S. farmland dropped from 4.4 million in 1985 to < 1.9 million in 1997, in large part due to direct and indirect effects of pesticides. Exposure to pesticides can weaken honeybees' immune systems—making them more vulnerable to natural enemies such as mites—and can also disrupt their reproduction and development (*21,22*). Honeybees are involved in the pollination of at least $10 billion worth of U.S. crops (*23*), providing farmers with an essential "natural service."
- A study in the St. Lawrence River Valley in Quebec, Canada, suggests a link between pesticides and developmental abnormalities in amphibians. Among other deformities, researchers observed frogs with extra legs growing from their abdomens and backs, stumps for hind legs, or fused hind legs (*24*). Other studies suggest that amphibian deformities may be caused by UV-B radiation (*25*) or parasites (*26*).
- Pesticide exposures have compromised

immune function in dolphins, seals, and whales (*27*).

Because of the widespread use of pesticides, many target species—whether insects or plants—develop resistance to the chemicals used against them. The number of insect species known to display pesticide resistance has increased from < 20 in 1950 to > 500 as of 1990. Meanwhile, scientists have identified 273 plant species that exhibit herbicide resistance (*28,29*).

Soil. Land degradation—and in particular, the deterioration of soils—is one of the most serious challenges facing humankind as it attempts to feed a growing population. It takes anywhere from 20 to 1,000 years for a centimeter of soil to form (*30*), yet the United Nations has estimated that wind and water erode 1% of the world's topsoil each year (*31*).

In 1990, Oldman et al. (*32*) estimated that since World War II, poor farming practices had damaged about 550 million hectares—an area equivalent to 38% of all farmland in use today.

More than 30 years ago, the U.S. Soil Conservation Service recommended that farmers reduce soil erosion to no more than 5 tons of topsoil per acre per year (*33*). Between 1982 and 1997, the average erosion rate fell from 7.3 tons per acre per year to 5 tons (*34*).

Industrial agriculture also endangers soil health because it depends on heavy machinery that compacts the soil, destroying soil structure and killing beneficial organisms in the soil food web (*35*).

Free-range cattle can have a positive influence on natural ecosystems when they graze in a sustainable fashion. The U.S. Department of Agriculture (USDA) Agricultural Research Service found that moderately grazed land (one cow per 16 acres) had more biodiversity than did ungrazed or heavily grazed land (*36*).

When animals graze land heavily they can also cause soil erosion by compacting the soil and stripping the land of vegetation that holds soil in place. Feedlot cattle (and industrial animal agriculture in general) destroy topsoil because growing grain for this industry requires so much cropland.

Land. Most of the world's arable land either is in use for agriculture or has been used up by (unsustainable) agriculture, most often because once-fertile soil has been degraded or eroded (*37*). The world's supply of arable land per person has been declining steadily (Figure 1).

An extreme example of land degradation is the phenomenon known as desertification, which the United Nations has defined as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (*38*). The annual global cost of desertification has been roughly estimated at $42.3 billion (*39*).

Desertification reduces the amount of land available for agriculture. Agriculture can contribute directly to desertification through poor agricultural practices such as overcultivation, overgrazing, and overuse of water, and indirectly when land is deforested to create new cropland or new pastures for livestock. According to the Worldwatch Institute, almost 20 million km^2, or 15% of the all land surface, may already be experiencing some degree of desertification (*40*).

In the past, increasing demand for grain has been met by two means: increasing the amount of land used to grow grain and increasing the yields per land unit. Both avenues to higher grain production have become more constrained in recent years (*41*).

The discussion of grain supplies sometimes leaves out the impact of meat production and consumption on these calculations. A reduction in meat consumption would help alleviate land scarcity because 37% of the world's grain, and 66% of U.S. grain production, is fed to livestock (*42*).

Land planted in cereal grains produces 2–10 times as much protein for human consumption as land devoted to beef production; for legumes the ratio is anywhere from 10:1 to 20:1 (*43*). Yet, in the competition for land in poorer countries, the cattle industry sometimes crowds out subsistence farmers, who are then forced to grow food on marginal land. Often, that land is steep and susceptible to erosion when cultivated (*44*).

Water. Agriculture affects water resources in two ways: irrigating fields using surface waters or aquifers diverts water from other potential uses; and when farming practices pollute surface waters and aquifers, they reduce the amount of water that is suitable for other uses.

The U.S. Environmental Protection Agency has blamed current farming practices for 70% of the pollution in the nation's rivers and streams. The agency reports that runoff of chemicals, silt, and animal waste from U.S. farmland has polluted more than 173,000 miles of waterways (*45*).

Agriculture accounts for about two-thirds of all water use worldwide, far exceeding industrial and municipal use (*46*) (Figure 2). In many parts of the world, irrigation is depleting underground aquifers faster than they can be recharged. In other cases, agriculture depends upon "fossil aquifers" that mostly contain water from the last ice age. These ancient aquifers receive little or no recharge, so any agriculture that depends upon them is inherently unsustainable.

The Ogallala Aquifer covers parts of eight states in the U.S. Midwest and is a critical resource for the region's agriculture. The aquifer receives little recharge, and its water table is dropping as much as 1 m/year (*30*). It has been estimated that in another decade or two the aquifer will be so low that its use for irrigation will become prohibitively expensive (*41*).

Irrigation has been used to turn many low-rainfall regions into agricultural wonders—at least in the short term. One-third of all the food we grow comes from the one-sixth of cropland that is irrigated (*33*). However, excessive irrigation can exact an ecologic price, through waterlogging and

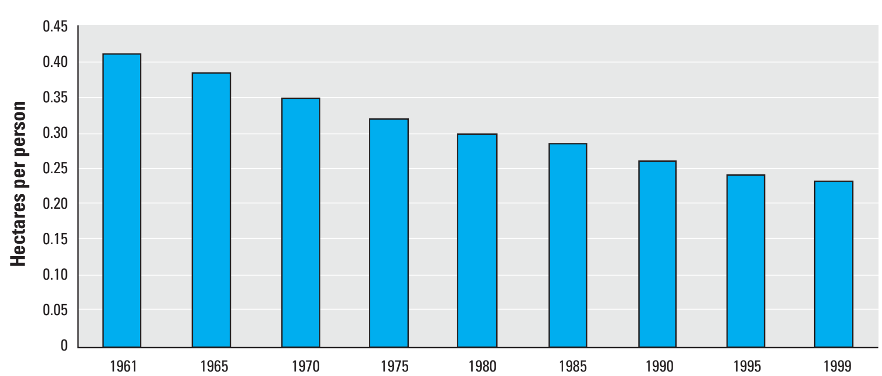

Figure 1. Average number of hectares of arable land per person, worldwide (*4*).

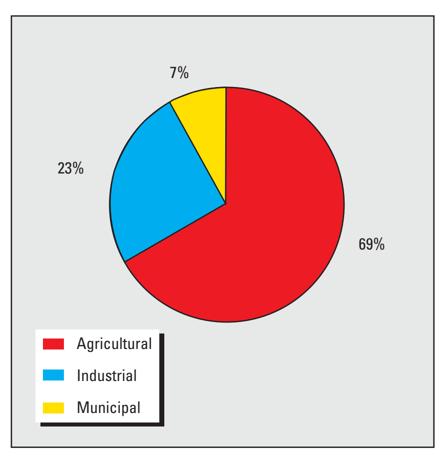

Figure 2. Global water use, by sector, based on 1990 figures. Adapted from Postel (*46*).

salinization. Irrigation water leaves behind salts that slowly diminish the soil's productivity. The Food and Agriculture Organization of the United Nations (FAO) estimates that about 13% of the world's irrigated land is either waterlogged or excessively salty, and another 33% is affected to some degree. Salinization affects 28% of the irrigated land in the United States and 23% in China, for example (*47*). According to hydrologist Daniel Hillel (*33*), many of the problems with irrigation arise from careless practices such as overwatering. He advocates modernizing the irrigation systems in developing countries, where the most acute irrigation problems exist.

Water use in irrigation is extremely inefficient: the FAO estimates that crops use only 45% of irrigation water (*47*). In the case of China's Yellow River, only 30% of the water extracted for irrigation actually reaches crops. Agriculture extracts 92% of the water taken from the river, which in 1997 failed to reach the sea for 226 days, its worst dry spell ever recorded. Since the 1950s, the amount of land irrigated with water from the Yellow River has more than tripled (*48*).

In parts of the United States, much of the water used for irrigation serves the livestock sector. For example, the beef feedlots of Colorado, Kansas, Nebraska, and the Texas panhandle get their feed grain from irrigated agriculture that relies on diminishing groundwater supplies. Beef production requires large volumes of water—as much as 100 times that required to produce equivalent amounts of protein energy from grains (*49*).

Energy. Converting grain into meat entails a large loss of food energy, particularly if cattle are doing the converting. Conservative estimates are that cattle require 7 kg of grain to create 1 kg of beef, compared with about 4 kg for pork and just over 2 kg for chicken (*50*).

Fossil fuel energy is also a major input to industrial agriculture. The food production system accounts for 17% of all fossil fuel use in the United States, and the average U.S. farm uses 3 kcal of fossil energy in producing 1 kcal of food energy. Meat production uses even more energy. In the typical feedlot system—where a little more than one-half of the cattle's feed is grain—the fossil energy input is about 35 kcal/kcal of beef protein produced (*37*).

In addition, the road from the farm to the dinner plate is an energy-intensive one because transporting, processing, and packaging our food require large amounts of fuel. For instance, before arriving at the Jessup (Maryland) Terminal Market, vegetable shipments travel, on average, about 1,600 miles and fruit shipments about 2,400 miles (*51*). Some estimated energy inputs for processing various foods are 575 kcal/kg for canned fruits and vegetables, 1,815 kcal/kg for frozen fruits and vegetables, 15,675 kcal/kg for breakfast cereals, and 18,591 kcal/kg for chocolate (*37*).

A 1969 study by the Department of Defense estimated that the average processed food item produced in the United States travels 1,300 miles before it reaches consumers (*52*). Processing accounts for about one-third of the energy use in the U.S. food system, and each calorie of processed food consumes about 1,000 calories of energy (*52*). In all likelihood, the food system has become more energy intensive since the time of this study.

Biodiversity. Agriculture is dependent on biodiversity for its existence and, at the same time, is a threat to biodiversity in its implementation. One way that agriculture depends on biodiversity is in developing new varieties of plants that keep pace with ever-evolving plant diseases. When plant breeders need to find a resistance gene to improve a domestic variety, they sometimes cross-breed the variety with a wild relative. However, because they are under pressure to bring a product to market quickly, plant breeders usually search for a single gene that confers resistance. This practice is risky, as Cary Fowler and Pat Mooney explain in *Shattering: Food, Politics, and the Loss of Genetic Diversity* (*53*):

> Frequently, resistance in a traditional landrace [wild variety] is not nearly so simple [as one gene]. Resistance may be the product of a complex of genes, literally hundreds of genes working together.… By utilizing one-gene resistance … the plant breeder gives the pest or disease an easy target. It has only to overcome or find a way around that one line of defense.… The use of one gene for resistance, one gene which is routinely overcome by pest or disease, results in that gene being "used up." It no longer provides resistance.

It may have taken thousands of years for a wild plant to develop its complex of resistance genes, but modern plant breeding methods are chipping away at this natural resource—one resistance gene at a time—and at a rate beyond nature's ability to replenish it (*54*).

The practice of monocropping or monoculture—planting the same crop over a large land area—creates greater necessity for quick-cure plant breeding. Insect pests and plant diseases are both aided by monocropping if a crop variety that may be susceptible to a plant disease or insect pest is planted contiguously and in great volume.

Industrial agriculture erodes biodiversity not only because it favors monocultures but also because those monocultures replace diverse habitats. One example is the way rice monocultures crowd out local wild varieties. In the Philippines, Indonesia, and some other developing countries, more than 80% of farmers now plant modern rice varieties. In Indonesia, this led to the recent extinction of 1,500 local rice varieties in just 15 years (*55*).

Another threat to biodiversity is the continued consolidation of the seed industry and the effect it is having on the availability of nonhybrid plant varieties. As of 1998, the 10 largest seed companies controlled 30% of the global market (*56*). Large seed companies tend to rely on first-generation hybrids because they force growers to buy new seed every year. As the industry has consolidated, traditional varieties have been removed from seed catalogs at an alarming rate. In 1981, nearly 5,000 nonhybrid vegetable varieties were being sold through mail-order catalogs; by 1998, 88% of those varieties had been dropped (*57*).

The dependence of industrial agriculture on synthetic chemicals has reduced biodiversity in the insect world, as well. Pesticides kill wild bees and other beneficial species that are nontarget victims. Managed pollination—a $10 billion a year industry in the United States and Canada—relies on just two species of bee. In contrast, North America has 5,000 wild bee species, but these have mostly disappeared from agricultural lands, due primarily to pesticides, a lack of floral diversity, destruction of habitats, and competition with managed pollinators (*58*).

Excessive fertilizer use also reduces biodiversity because of the effect that nitrogen runoff is having on ecosystem balance. A minority of species can thrive in high-nitrogen environments, and these sometimes crowd out all other species in the ecosystem (*59*).

Global warming and climate change. Agriculture is directly responsible for about 20% of human-generated emissions of greenhouse gases, according to estimates by the Intergovernmental Panel on Climate Change. Changes in land use contribute about 14% of the total human-generated emissions of greenhouse gases, and much of this land development is for agricultural purposes (*60*).

Industrial animal production. Animals have traditionally played an important role in agriculture, not only as a source of food but also as a way to recycle nutrients and build soil organic matter. Their manure deposited on croplands or rangelands helps build the fertility of the soil.

In recent decades, however, industrial agriculture has increasingly separated animals from the land. More and more meat production is occurring in concentrated operations commonly called factory farms.

The manure output from these factory farms overwhelms the capacity of local croplands to absorb it. The USDA has estimated that animals in the U.S. meat industry produced 1.4 billion tons of waste in 1997, which is 130 times the nation's volume of human waste—or 5 tons of animal waste for every U.S. citizen (*61*).

By concentrating thousands of animals into a small area, industrial animal production creates threats to both the environment and human health. Despite this, the trend in the meat industry has been toward greater concentration of livestock. Fewer and fewer farms are raising animals, and the average number of animals per farm is going up.

For example, between 1967 and 1997 the number of hog farms in the United States declined from over a million to just 157,000. The largest 3% of farms (all with at least 1,000 hogs each) now produce 60% of U.S. hogs (*61,62*).

According to Copeland and Zinn (*62*), the story is similar in poultry and beef output:

> Broiler production nearly tripled between 1969 and 1992, while the number of farms with broiler houses dropped by 35%.... Firms with more than 100,000 broilers accounted for 70% of all sales in 1975, but now account for more than 97% of sales.

In beef, more than 40% of all production comes from 2% of the feedlots (*61*).

Because the huge volume of manure from factory farms cannot be absorbed by local croplands, the industry stores it in open pits—euphemistically called "lagoons" by the industry—that are prone to spills. Animal waste is a major contributor to the excessive nutrient loading that is suspected of causing outbreaks of *Pfiesteria piscicida* and large fish kills in North Carolina waters and in the Chesapeake Bay in recent years (*61,63*).

By concentrating hundreds or thousands of animals into crowded indoor facilities, factory farms raise ethical issues about their treatment of animals. Each full-grown chicken in a factory farm has as little as 0.6 ft^2 of space. Crowded together in this way, chickens become aggressive toward each other and sometimes even eat one another. For this reason, factory farms subject them to painful debeaking (*64*).

Hogs, too, become aggressive in tight quarters and often bite each other's tails. In response, factory farmers often cut off their tails. Concrete or slatted floors allow for easy removal of manure, but because they are unnatural surfaces for pigs, they result in skeletal deformities of the legs and feet (*65*). Ammonia and other gases from the manure irritate animals' lungs, making them susceptible to pneumonia. Researchers from the University of Minnesota found pneumonia-like lesions on the lungs of 65% of 34,000 hogs they inspected (*66*).

Factory farms chain veal calves around the neck to prevent them from turning around in their narrow stalls. Movement is discouraged so that the calves' muscles will be underdeveloped and their flesh will be tender. They are kept in isolation and near or total darkness during their 4-month lives and are fed an iron-deficient diet to induce anemia so that their flesh develops the pale color prized in the marketplace (*65*).

Genetically engineered crops. Genetically engineered crops have been on the market only since 1996, but already they occupy 130 million acres worldwide, including a 19% increase in acreage in 2001. This includes 88 million acres in the United States (*67*).

Transgenic crops have been defined as genetically engineered to contain traits from unrelated organisms. In traditional plant breeding, a desired trait must be obtained from a closely related species that will breed with that plant through natural mechanisms, but genetic engineers can search for the desired trait anywhere in the plant or animal kingdom (*68*).

Introducing genes into crops in this novel way raises ethical, environmental, and health concerns. In this paper we do not discuss the ethics of transgenic crops, but we review the health issues in "Impact of Food Production and Diet on Health" below.

The environmental concerns raised by genetically engineered crops include the following:

- Gene transfer to wild relatives: Herbicide-resistance genes engineered into crops can spread to wild relatives of those crops. The FAO has said this "could create super-weeds and make weed control more difficult" (*69*).
- Increased herbicide use: The most common reason for manipulating crop genes is to confer resistance to commercial herbicides. Increased use of genetically engineered crops of this sort will likely be accompanied by increased use of the relevant herbicides (*69*). Weeds would therefore be exposed to more herbicide, helping them develop herbicide resistance more rapidly.
- Insect resistance to *Bacillus thuringiensis* (*Bt*) toxin: The second most popular reason for genetically engineering crops is to give them resistance to insects, viruses, and fungi. Genetic engineers have produced insect resistance in corn, rice, cotton, tobacco, and many other crops by introducing a gene that produces the *Bt* toxin. In other words, the plant gives off its own pesticide, so farmers do not need to apply pesticides. In nature, the soil bacterium *B. thuringiensis* produces the *Bt* toxin. The widespread use of *Bt* crops would in all likelihood hasten the development of *Bt* resistance in insects that are currently vulnerable to this natural pest control method. This would eliminate an important organic pest control method often used by organic growers as a last resort (*68*). *Bt* crops may also pose risks for nontarget species. Two recent studies reported that pollen from *Bt* corn can be deadly for monarch butterfly larvae (*70,71*).

Impact of Food Production and Diet on Health

The preceding section describes the environmental harms caused by our dominant food production system. Industrial food production methods—and some of the foods they produce—are also causing both acute and chronic disease in humans. Among the problems are the following:

- Animal-based foods contribute to chronic diseases.
- Pesticide residues enter our bodies through air, water, and food and raise risks for certain cancers as well as reproductive and endocrine system disorders.
- Concentrated, high-speed meat production leads to a greater risk from foodborne pathogens, some of them newly emerging.
- Excessive use of antibiotics in animal agriculture may create resistant strains of microbes in humans.

In this section we discuss many comparison studies of the diets of various population groups and their health outcomes.These epidemiologic studies have methodologic deficiencies, in that most data sources are not sufficiently comprehensive to eliminate the effects of all possible confounding variables during multivariate analysis. However, in cases where the body of epidemiologic evidence is substantial and/or the disparities are large, these comparisons still provide results worthy of our consideration.

Diet and Disease

We have evidence that large quantities of saturated fat in the diet contribute to the chronic degenerative diseases that are the most common causes of death in affluent societies. Animal-based diets, which are high in saturated fat, dominate in the West and are on the increase in many developing countries.

Although undernutrition is still common in developing countries (affecting about 800 million people worldwide), in affluent countries the main causes of death are associated with overnutrition. In the United States, for example, the average adult male consumes 154% of the recommended daily allowance (RDA) for protein (97 g vs. an RDA of 63 g), and the average adult female consumes 127% of the RDA (63.5 g vs. an RDA of 50 g) (*72,73*). The average American derives 67% of protein from animal sources, compared to a 34%

average worldwide (*37*). Meanwhile, the World Health Organization (WHO) estimates that > 40% of children (or 230 million) in poor countries are stunted by undernutrition (*74*).

According to the U.S. Surgeon General (*75*), the "preponderance" of scientific evidence strongly suggests that

> a dietary pattern that contains excessive intake of foods high in calories, fat (especially saturated fat), cholesterol, and sodium, but that is low in complex carbohydrates and fiber, is one that contributes significantly to the high rates of major chronic diseases among Americans.

Animal products contain no fiber and almost no complex carbohydrates. Animal products are also the only source of cholesterol in the diet, and they contribute most of the saturated fat in the typical U.S. diet. On the other hand, vegetarian diets are associated with lower rates of chronic disease. According to the American Dietetic Association (*76*),

> A considerable body of scientific data suggests positive relationships between vegetarian diets and risk reduction for several chronic degenerative diseases and conditions, including obesity, coronary artery disease, hypertension, diabetes mellitus, and some types of cancer.

Cardiovascular disease. Diseases of the circulatory system account for almost one-half of all deaths in the developed world, according to the WHO (*77*). Mortality from circulatory system disease has been falling in affluent countries in recent years but it is increasing in newly industrializing countries that are adopting "Western" diet patterns (*77*). This increase in "diseases of affluence" in newly industrializing countries parallels the increasing consumption of animal-based foods (as well as higher smoking rates and greater urbanization).

In 1999, the average U.S. citizen consumed 124 kg (273 pounds) of meat. By contrast, average meat consumption for all industrialized countries is 77 kg/person, and for all nonindustrialized countries it is 27 kg. Since 1961, U.S. per capita meat consumption has increased by 40% (*4*) (Figure 3).

Cardiovascular disease is the leading cause of death in the United States, and one of the major risk factors is a high cholesterol level in the blood. The human body manufactures all the cholesterol it needs, and any cholesterol acquired through diet comes from animal foods because plant foods contain no cholesterol (*78*).

Consumption of animal foods elevates a person's cholesterol level, and this in turn elevates the person's risk for heart attack, stroke, and arterial disease. Whereas the average cholesterol level among heart attack victims is 244 mg/dL of blood serum, heart attack risk falls to virtually zero when the cholesterol level is less than 150 mg/dL (*79*). As of 1990, the average cholesterol level in the United States was 205 mg/dL (*78*).

Vegetarians who avoid meat but consume dairy products and/or eggs have lower cholesterol levels than do omnivores. Still lower are cholesterol levels in vegans, people who refrain from eating any animal products. One meta-analysis found that in nine comparison studies, vegans had an average cholesterol level of 158 mg/dL, vegetarians 182 mg/dL, and omnivores 193 mg/dL (*80*). Vegetarians also have lower-than-average mortality in general, and this is attributed mostly to their lower rates of heart disease and certain cancers (*80*).

Cancer. Diets that are high in fat and low in fiber are associated with an increased risk of colon cancer (*81*). In addition to being high in fat, meat and dairy products contain no fiber.

In contrast, many epidemiologic studies have found that high fiber intake leads to lower risk of not only colon cancer but also breast and prostate cancer (*80*). Prostate cancer has been linked to high intakes of calories, total fat, and milk, meat, and poultry (*82*).

Lung cancer is also less prevalent in vegetarians, even when one controls for the effects of smoking (*83*).

Countries with high rates of fat consumption have the highest breast and colon cancer mortality, whereas the lowest death rates from these diseases occur in populations with the lowest levels of fat consumption (*84*).

Diabetes. Seventh Day Adventists are overwhelmingly vegetarian or near-vegetarian, so researchers and others often compare their health outcomes with those of the general population. One study (*80*) found that rates of diabetes in Seventh Day Adventists were 45% of rates in all U.S. white adults, and that type II (non-insulin-dependent) diabetes correlated positively with obesity and fat and protein intake. Vegetarians have lower rates of these risk factors (*80*).

Treatment programs for diabetics now recommend drastic reductions in consumption of meat, dairy products, and oils but increased consumption of grains, legumes, and vegetables.

Medical costs of meat consumption. Barnard et al. (*85*) estimated that meat consumption costs the United States roughly $30–60 billion a year in medical costs. The authors made this calculation (which they considered a conservative one) on the basis of the estimated contribution that eating meat makes to the diseases discussed above, plus other chronic diseases common in affluent countries and foodborne illnesses linked to meat consumption.

Pesticides and Health

Pesticides produce both short- and long-term effects on human health. The United Nations has estimated that about 2 million poisonings and 10,000 deaths occur each year from pesticides, with about three-fourths of these occurring in developing countries (*86*). The long-term effects of pesticides include elevated cancer risks and disruption of the body's reproductive, immune, endocrine, and nervous systems. Population-based studies have shown associations between certain types of pesticide and certain cancers (Table 1).

Pesticides can suppress the immune system. In a 1996 report, Repetto and Baliga (*27*) cite epidemiologic evidence of an association between pesticide exposure and increased incidence of human disease, particularly those diseases to which immunocompromised individuals are especially prone (*27*).

The list of pesticides that are suspected endocrine disruptors includes atrazine and alachlor, two of the most commonly applied herbicides on corn and soybean crops in the United States. Just over one-half of the herbicides used in the United States in 1991 were applied to corn, soybeans, or cotton (*88*).

Many pesticides have not been tested for their toxicity, and testing in the past has focused on acute effects rather than long-term effects. In an inventory of commonly used chemicals in 1984, the National Research Council found that data required for

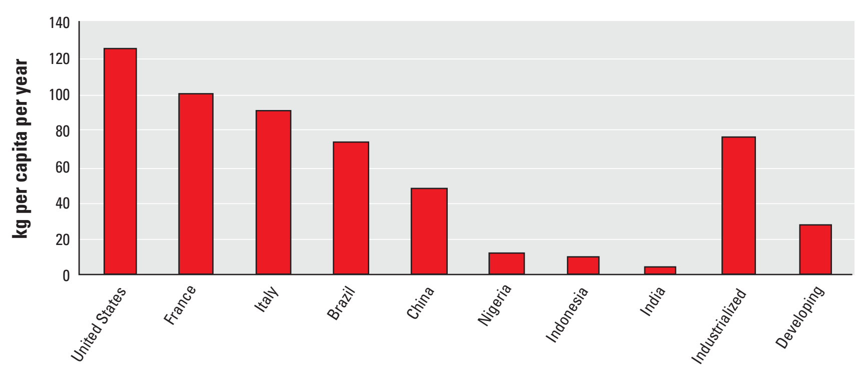

Figure 3. Average meat consumption in selected countries in 1999 and averages for all industrialized and developing countries (*4*).

complete health hazard evaluations were available for only 10% of pesticides (*89*).

Human exposure to pesticides can come through residues in food—either on or within fruits and vegetables, or in the tissues of fish and animals we eat—through contaminated drinking water, and through the air we breathe (because of "pesticide drift" from the spraying of fields or lawns).

Some pesticides accumulate up the food chain, or "bioaccumulate." A 1967 study found that DDT levels were 20,000 times higher in one fish species than they were in the surrounding sea water, and 520,000 times higher in fish-eating cormorants (*90*). So, when humans eat foods higher on the food chain (more meat, milk, cheese, and eggs and fewer plant foods), they increase their exposure to bioaccumulated pesticides.

Industrial Food System and Public Health

The production and processing of food are increasingly concentrated (fewer owners and larger operations), automated, and fast-paced, which has implications for public health. Among the major problems:

- Pollution from factory farms is harming the health of both workers and residents living downstream or downwind from these operations.
- New strains of foodborne pathogens (e.g., *Listeria* and toxigenic *Escherichia coli*) have emerged in recent years, and long recognized pathogens have been causing more widespread harm.
- The nonmedical use of antibiotics in animal agriculture may be threatening the effectiveness of antibiotics in treating human disease by creating selective pressure for the emergence of antibiotic-resistant bacteria.
- Genetically engineered foods present risks of new allergens in the food supply and may be harmful to immune systems and vital organs.
- These phenomena are due, in part, to production and processing methods that emphasize economic efficiency but do not give sufficient priority to public health or the environment.

Factory farming and human health. Gases from animal manure at factory farms create potential human health risks for workers and residents living downwind, and manure runoff can damage local water quality by overloading it with nutrients, particularly phosphates.

Factory farms store manure from animal confinement buildings either in pits underneath the buildings or in nearby open-air pits, often extending over several acres. Farmers and farm workers have died from asphyxiation after entering underground pits used for storing animal manure (*91*).

The prevalence of occupational respiratory diseases (occupational asthma, acute and chronic bronchitis, organic dust toxic syndrome) in factory farm workers can be as high as 30% (*92*). A University of Iowa study found that people living near large-scale hog facilities reported elevated incidence of headaches, respiratory problems, eye irritation, nausea, weakness, and chest tightness (*93*).

Manure runoff from factory farms is among the suspected causes of outbreaks of *Pfiesteria piscicida* in Maryland, Virginia, and North Carolina. The human health effects have included acute short-term memory loss, cognitive impairment, asthmalike symptoms, liver and kidney dysfunction, blurred vision, and vomiting (*94*).

Water polluted with manure runoff has other health implications. A Senate report (*61*) noted that

> Manure contains pathogens to which humans are vulnerable, including *Salmonella* and *Cryptosporidium*, and can pollute drinking water with nitrates, potentially fatal to infants. More indirectly, microbes that are toxic to animals and people are thought to thrive in waters that have excessively high levels of nutrients from sources including animal waste pollution.

Foodborne pathogens. The U.S. Centers for Disease Control and Prevention (CDC) have estimated that foodborne diseases cause approximately 76 million illnesses, 325,000 hospitalizations, and 5,000 deaths in the United States each year. Of the approximately 1,800 deaths attributed to known pathogens, more than 75% are blamed on *Salmonella, Listeria,* and *Toxoplasma* (*95*). All three pathogens are transmitted to humans primarily through meat.

Two bacteria commonly found on meat—*Campylobacter* and *Salmonella*—cause more than 3 million foodborne illnesses in the United States each year (*95*). These bacteria occur naturally on chickens and are not always harmful to them, but in humans they can cause severe diarrhea and nausea and occasionally produce fatal disease. The crowded conditions of factory farms increase the level of contamination, and the high-speed, automated methods of slaughtering and processing the animals make it difficult to detect that contamination.

Much less common but more deadly than the bacteria mentioned above are the newly emerging strains of toxigenic *E. coli* and *Listeria*. The CDC puts the annual disease burden for *E. coli* at about 62,000 illnesses and 50 deaths, and blames *Listeria* for about 2,500 illnesses and 500 deaths (*95*).

Infection with the enterohemorrhagic strain of *E. coli* (O157:H7) was first discovered in 1975. The pathogen causes bloody diarrhea and acute renal failure and is sometimes fatal; children and the elderly are at greatest risk. *E. coli* O157:H7 is most often spread by undercooked ground beef or raw milk (*96*).

Listeria monocytogenes is referred to as an emerging pathogen because only recently has food been recognized to play a role in its spread. According to the U.S. Food and Drug Administration, infections with *Listeria* can cause abortion and stillbirth, and blood poisoning or meningitis in infants and immune-deficient persons. *Listeria* is most often associated with consumption of certain dairy products and processed meats (*97*).

Another newly emerging concern about the food supply is a neurologic disease in cattle known as bovine spongiform encephalopathy (BSE). According to the WHO (*98*), a new variant of Creutzfeldt-Jakob disease, a degenerative neurologic disease in humans, has a strong link to exposure to BSE, probably through the food supply. BSE was first recognized in cattle in 1986, and epidemiologic studies suggest that cattle feed prepared from carcasses of dead ruminants was the source of the disease (*98*).

Antibiotics in animal agriculture. Seventy percent of U.S.-produced antibiotics are fed to animals to promote growth (*99*). Excessive use of such drugs in animals can enhance the development of drug-resistant strains of disease, which can then be transmitted to humans through the food supply.

The National Research Council and Institute of Medicine (*100*) have noted that there is

> a link between the use of antibiotics in food animals, the development of bacterial resistance to these drugs, and human diseases—although the incidence of such disease is very low.

The WHO has called for reduced use of antibiotics in animal agriculture, noting that resistant strains of *Salmonella, Campylobacter,*

Table 1. Associations between various classes of pesticide and various forms of cancer.

Class of pesticide	Cancer
Phenoxyacetic acid herbicides	Non-Hodgkin's lymphoma, soft-tissue sarcoma, prostate
Organochlorine insecticides	Leukemia, non-Hodgkin's lymphoma, soft-tissue sarcoma, pancreas, lung, breast
Organophosphate insecticides	Non-Hodgkin's lymphoma, leukemia
Arsenical insecticides	Lung, skin
Triazine herbicides	Ovary

Data from Blair and Zahm (*87*).

Enterococci, and *E. coli* have been transmitted from animals to humans (*101*).

Genetically engineered foods. Only recently have genetically engineered foods been introduced into the human food supply. One of the concerns surrounding genetic engineering of foods is that new allergens could be introduced into the food supply because the sources for genetically engineered material may include organisms not previously eaten by humans (*102*). In addition, it will be harder for people with food allergies to avoid consuming an offending food if proteins from that food are integrated into a food to which they are not allergic. For example, soybeans that were genetically engineered to contain proteins from Brazil nuts caused reactions in individuals who were allergic to Brazil nuts (*103*).

Antibiotic resistance genes are used as markers in the genetic engineering of foods. This practice raises two possible concerns: eating such foods soon after taking antibiotics could reduce or eliminate the drugs' effectiveness because enzymes produced by the resistance genes can break down antibiotics; and resistance could be transferred to disease organisms in the digestive tract, making it harder to treat them with antibiotics. But there is disagreement over these issues within the scientific community, and more research is under way (*104,105*).

Sustainable Agriculture

Unsustainability in agriculture is not a new issue. Large civilizations have risen on the strength of their agriculture and subsequently collapsed because their farming methods had eroded the natural resource base (*106*). Today's conventional or industrial agriculture is considered unsustainable because it is similarly eroding natural resources faster than the environment can regenerate them and because it depends heavily on resources that are nonrenewable (e.g., fossil fuels and fossil aquifers).

One of the goals of the sustainable agriculture movement is to create farming systems that mitigate or eliminate environmental harms associated with industrial agriculture. Sustainable agriculture is part of a larger movement toward sustainable development, which recognizes that natural resources are finite, acknowledges limits on economic growth, and encourages equity in resource allocation.

Sustainable agriculture gives due consideration to long-term interests (e.g., preserving topsoil, biodiversity, and rural communities) rather than only short-term interests such as profit. Sustainable agriculture is also place specific. For example, a farming system that is sustainable in a high-rainfall area may not be sustainable in an arid climate. Sustainable agriculture is dynamic, meaning that it must evolve to respond to changes in its physical environment or its social or economic context. Sustainable agriculture is holistic in that it takes a systemwide approach to solving farm management problems, and also because it places farming within a social context and within the context of the entire food system.

Sustainable agriculture has been defined in several ways, for example:

> • Sustainable agriculture integrates three main goals—environmental health, economic profitability, and social and economic equity.... Sustainability rests on the principle that we must meet the needs of the present without compromising the ability of future generations to meet their own needs (*107*).

> • Sustainable agriculture is a model of social and economic organization based on an equitable and participatory vision of development which recognizes the environment and natural resources as the foundation of economic activity. Agriculture is sustainable when it is ecologically sound, economically viable, socially just, culturally appropriate, and based on a holistic scientific approach (*108*).

> • Sustainable agriculture does not refer to a prescribed set of practices. Instead, it challenges producers to think about the long-term implications of practices and the broad interactions and dynamics of agricultural systems. It also invites consumers to get more involved in agriculture by learning more about and becoming active participants in their food systems. A key goal is to understand agriculture from an ecological perspective—in terms of nutrient and energy dynamics, and interactions among plants, animals, insects and other organisms in agroecosystems—then balance it with profit, community and consumer needs (*109*).

Sustainable methods. Although no one set of farming practices constitutes sustainable agriculture, we briefly describe here certain methods that enhance sustainability.

- **Crop rotation.** By rotating two or more crops in a field, farmers interrupt pests' reproductive cycles and reduce the need for pest control (*110*). Rotations sometimes reduce the need for added fertilizer because one crop provides nutrients for the next crop.
- **Cover crops.** Cover crops are planted to improve soil quality, prevent soil erosion, and minimize weed growth. Some cover crops can also generate income.
- **No-till and low-till farming.** These farming systems are based on the premise that minimizing disturbances to the soil will increase the retention of water, nutrients, and the topsoil itself. Between 1980 and 1993, the amount of land under conservation tillage increased from < 15% to about 35% of all U.S. farmland (*111*).
- **Soil management.** Good stewardship of the soil involves managing its chemical, biologic, and physical properties. Industrial agriculture has tended to emphasize the chemical properties of soil, to the detriment of the other two. An acre of healthy soil can contain 4 tons of organisms, which make up the soil's ecosystem (*112*). Organic matter and compost are food for beneficial bacteria, fungi, nematodes, and protozoa. If managed properly, these soil organisms perform vital functions that aid in plant growth (*113*). Healthy soil produces plants that are more vigorous and therefore less susceptible to pests.
- **Diversity.** Growing a variety of crops provides a buffer against both ecologic and economic problems. Monocultures are more vulnerable to pests as well as to fluctuations in market price. Crop variety can also create more niches for beneficial insects (*107*).
- **Nutrient management.** After monitoring the soil content of nitrogen and other nutrients, farmers can prevent runoff into adjacent waters—and also save money on purchased fertilizers—by applying only what the plants and soil can absorb, with no excess.
- **Integrated pest management.** An integrated pest management (IPM) system prefers biologic methods and uses (least-toxic) chemical pesticides only as a last resort. To keep destructive insects under control, an IPM emphasizes crop rotations, intercropping, and other methods of disrupting pest cycles, as well as plant varieties that have high resistance to pests. IPM also uses insect predators, as well as biopesticides such as *Bt* (*114*). As of 1994, coordinators of the federal IPM program were reporting that

  > more than 40,000 farmers in 32 states have made significant reductions in their use of synthetic chemical pesticides by implementing practices associated with sustainable agriculture (*115*).

- **Rotational grazing.** By continually moving animals to different grazing areas, rotational grazing prevents soil erosion by maintaining sufficient vegetative cover. It also saves on feed costs, averts the manure buildup of concentrated animal feeding operations, and contributes to soil fertility.

Barriers to sustainability. If our current agricultural system is so harmful and unsustainable, why is it being perpetuated? Most important, powerful economic interests benefit from the status quo in agriculture. Industrial agriculture relies heavily on external inputs (e.g., synthetic chemical fertilizers and pesticides, machinery, fossil fuels), which mean costs for farmers but profits for farm input industries.

Farmers use such inputs because they promise greater yields from their crops, but greater yields have been a mixed blessing, according to agricultural economist John E. Ikerd (*116*):

> Over most of the past century, profits from farming have gone primarily to those who found ways to reduce costs first and expand production the

> fastest. However, each new round of cost cutting technology has resulted in increased production and lower prices, erasing initial profitability.

Thus, the quest for greater yields has landed farmers on a technologic treadmill of increasing inputs and decreasing profit margins.

Increasing dependence on off-farm resources and distant markets has caused much of the profitability of agriculture to shift from the farmer to the industries that supply the inputs and market the outputs. Madden and Chaplowe (*108*) estimate that between 1910 and 1990, the share of the U.S. agricultural economy going to farmers declined from 41% to 9%, while the marketing and farm input industries' shares increased by similar amounts (*108*).

As farmers' profit margins shrink, some farmers choose to enlarge their operations to compensate. Invariably, this means some farmers get pushed out of business. For example, in the hog industry, about one-fourth of all U.S. producers went out of business between 1998 and 2000 (*117*), leaving only 50 producers controlling one-half of all hog production (*118*).

The trend toward large-scale farming has implications for the economic health of rural communities. Studies have shown that independent hog farmers produce more jobs, more local retail spending, and more local per capita income than do larger corporate operations (*62*). Profits generated by small-scale producers (of hogs or any other commodity) are more likely to remain in the community and create multiplier effects in the local economy.

Despite these benefits of small farms, U.S. agricultural subsidies flow disproportionately to large farms. The International Institute for Sustainable Development (*8*), based in Winnipeg, Canada, reports that

> Almost 30% of subsidies go to the top 2% and over four-fifths to the top 30%. Ironically, if the United States government were to shift its target from the top 30% to the bottom 70% of farmers, it could save at least $8 billion a year while supplying a competitive boost to lower-income farms.

Government subsidies often help perpetuate unsustainable practices. For example, one of the largest beneficiaries of federal agricultural subsidies are the cattle ranchers whose animals graze on federal lands for less than one-third the price they would pay on private land. Total subsidies in the federal grazing program cost taxpayers at least $500 million a year, not counting the cost of the environmental degradation caused by overgrazing (*8*).

Subsidies often stimulate greater use of chemical inputs, despite their environmental and public health harms. Rice farmers in Japan, Taiwan, and Korea use just over one-half of all insecticides applied to rice worldwide yet produce only 2% of the world's crops. The reason is that large government price supports ($13 billion worth in Japan) make it profitable to increase insecticide use even when the resulting production gains are small (*119*).

Besides encouraging harmful practices, farm subsidy programs often fail to reward good stewardship. They tend to emphasize a handful of major crops and "put resource-conserving crop rotations at a financial disadvantage" (*120*). Farmers receive no government incentives for sustainable practices such as growing clover or alfalfa to enhance soil fertility (*120*).

Governments also help perpetuate chemical-intensive agriculture by funding research on chemical fixes for agricultural problems, to the exclusion of research on more sustainable options. Of 30,000 agricultural research projects on the USDA's Current Research Information System for 1995, only 34 had a strong organic focus (*121*).

Adopting sustainable methods. Government programs, research, and other factors can influence moves toward sustainability in agriculture, but ultimately this shift also involves decisions by individual farmers. Some farmers will be motivated to change because of environmental concerns, but we also need to reassure farmers that sustainable methods are economically viable. Comparisons between conventional (industrial) and sustainable agriculture systems can be complicated, but those that exist describe sustainable practices as "highly productive and economically competitive" (*110*).

In the early 1990s, the Gallo Wine Company (Sonoma County, CA) shifted 6,000 acres of wine grapes from conventional to organic methods. After a transition phase during which production was more expensive, Gallo was producing yields equivalent to those produced by its previous chemical methods but at a lower cost per acre (*115*).

Sustainable systems are especially apt to compare favorably with conventional systems when the comparison includes a full-cost accounting of the environmental and public health harms and benefits of each system. For example, if a conventional system were to produce higher yields per acre than a sustainable one but also degrade local water supplies because of pesticide or fertilizer runoff, the benefits of the higher yield may be offset by the cost of environmental cleanup (costs that are usually "externalized," meaning they are paid by society rather than the polluter).

Other factors that influence adoption of sustainable practices are land ownership and the age of the farmer. According to an FAO report (*122*),

> Land tenure is … critical to the adoption of organic [free of synthetic chemicals] agriculture. It is highly unlikely that tenant farmers would invest the necessary labour and sustain the difficult conversion period without some guarantee of access to the land in later years when the benefits of organic production are attainable.

Urban agriculture. The world is becoming increasingly urbanized. The United Nations has estimated that world population will increase by about 2 billion people in the next 30 years, and all of that growth is expected to occur in urban areas (population growth plus continued migration to cities) (*123*). This makes urban agriculture an increasingly important component of agricultural sustainability.

Because it produces closer to consumers, urban agriculture reduces energy costs and pollution from transport and storage and reduces packaging and spoilage. It also offers a viable use for urban waste (such as wastewater for irrigation), creates economic development, and improves food security in poor communities (*124*).

Alternative marketing. Farmers can capture more of the profitability of agriculture through value-added products or direct marketing strategies such as farmers markets and community-supported agriculture (CSA). In the CSA model, consumers purchase a "share" in a farm and receive a portion of its harvest. This gives farmers more working capital at the beginning of the growing season and a guaranteed market at the end. Consumers develop a direct link to their food supply and have input into production decisions. CSAs have helped keep many small farms in business (*125*). Meanwhile, farmers markets have enjoyed rapid growth in the United States. Between 1994 and 2000, the number of U.S. farmers markets increased by 63%, from 1,755 to 2,863 (*126*).

Conclusion

Hunger and food insecurity are currently problems not of resource scarcity but of insufficient political will or moral imperative to change the way food is allocated—Pinstrup-Anderson et al. have estimated that the developing world alone is producing enough food to provide every person with > 2,500 calories/day (*127*). If unsustainable agriculture remains the norm, however, scarcity of resources could soon become a major factor in food insecurity.

Coupled with energy- and resource-intensive food production methods, rising population and rising per capita consumption are bringing us closer to the limits of the planet's ability to produce food and fiber for everyone. The world's fisheries may be putting out a warning signal about nature's limits. The FAO reported that "11 of the world's 15 most important fishing areas and 70% of the major fish species are either fully or overexploited" (*128*).

The United Nations' most recent midrange projection is that the world population will increase to 9.3 billion by 2050 (*129*). The world's population is rapidly becoming more urbanized. In 1975, about one-third of the world's people lived in cities (*130*); by 2030, that figure is expected to rise to > 60% (*131*). Both population growth and urbanization bode ill for the environment and the social order that it upholds. To meet their need for food and other goods, the additional people will make further demands upon finite resources such as arable land, fertile soil, and freshwater.

When people move from rural to urban areas, they characteristically increase their consumption, including the amount of animal products they consume. Thus, the combination of more people and greater consumption per capita are creating a threat of future scarcity in vital resources.

These problems are complex and have no single solution, which leaves many people feeling powerless to affect them.

One personal act that can have a profound impact on these issues is reducing meat consumption. To produce 1 pound of feedlot beef requires about 2,400 gallons of water and 7 pounds of grain (*42*). Considering that the average American consumes 97 pounds of beef (and 273 pounds of meat in all) each year, even modest reductions in meat consumption in such a culture would substantially reduce the burden on our natural resources.

For the United States and other industrialized nations, lowered meat consumption would yield significant public health benefits, particularly a reduction in heart disease, several cancers, and other chronic diseases. These diseases are largely associated with the excessive fat and protein intakes that are characteristic of animal-based diets. Coupled with sedentary lifestyles, excess meat consumption also contributes to the epidemic of obesity.

Public policies that encourage a shift toward a more plant-based diet could bolster individual actions in this area. These policies should include preventing factory farms from polluting and requiring them to pay cleanup costs when they do pollute. Without such policies, the products of factory farms will continue to be artificially cheap, in that prices will not reflect their impact on the environment, human health, animal welfare, or the economic and social stability of rural communities.

Both the individual and collective actions described above would hasten the shift toward a more sustainable agriculture, which is an important component in the larger transition to a sustainable economy.

Sustainable agriculture is not merely a package of prescribed methods. More important, it is a change in mindset whereby agriculture acknowledges its dependence on a finite natural resource base—including the finite quality of fossil fuel energy that is now a critical component of conventional farming systems. It also recognizes that farm management problems (weeds, insects, etc.) cannot be dealt with in isolation but must be seen as part of a whole ecosystem whose balance must be maintained.

In this paper we have introduced some of the environmental and human health problems inherent in industrial agriculture. In many respects, industrial-style meat production provides a worst-case example of these problems. It also provides an opportunity for dramatic improvements in environmental stewardship and public health. Because meat consumption is such a major component in the broader issues described here, its reduction—through both individual and collective action—can have profound effects on the health of humans, animals, and the environment.

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