AGRICULTURE AND ECOSYSTEMS

BACKGROUND READING

“The whole problem of health, in soil, plant, animal and man is one great subject.”
- *Sir Albert Howard*

Most of our food supply originates from **agriculture**—the production of food and goods through farming. This practice relies upon **soil**, **freshwater** and other facets of ecosystems to cradle crops from seed to harvest. Over the past century, industrialization and other trends have radically transformed U.S. agriculture, redefining farmers’ relationships with ecosystems in the process. While industrial agriculture has substantially increased food production, it has also resulted in health, environmental, social and economic harms. The organic and **sustainable** agriculture movements offer alternative approaches that are, in some respects, more ecologically sound.

Note: Raising cattle, hogs, chickens and other animals for food is an important part of agriculture; these practices are covered in greater detail in *Food Animal Production*. For more background on the history of agriculture, refer to *History of Food*.

Ecosystems: foundations of agriculture

Food and agriculture are rooted in **ecosystems**—communities of organisms interacting with each other and with their physical environment.[1] An endless number of organisms, including humans, crop plants, livestock, insects, bacteria and fungi, are essential to our food supply. Physical facets of ecosystems that affect agriculture include soil, **climate** and freshwater.

Soil

Soil is the foundation farm ecosystems; we depend on it for most of our food supply.[2] Partly because much of the American Midwest has deep, fertile soil, the region, along with parts of Europe and China, produces most of the world’s grain.[3] Although it may be mistaken for lifeless dirt, fertile soil is actually teeming with living organisms. A single teaspoon of soil can contain as many as a billion bacteria.[4] Arthropods, earthworms, fungi, nematodes and protozoa also inhabit soil, sustained by the energy and **nutrients** contained in **organic matter**, such as decaying leaves and other plant and animal materials.[4]

The interactions between living organisms and nonliving organic matter form a soil ecosystem, known as the **soil food web** because every organism becomes food for another.[4] The soil food web offers many services that promote an abundant food supply and human health. Organisms break down dead plant and animal materials, cycling nutrients into forms that crops can use. Earthworms, for example, eat decaying leaves and release valuable nutrients in their waste.[4] The soil food web stores nutrients, releasing them slowly over time.[4] It also stores water, suppresses plant diseases and, in some cases, purifies water by breaking down certain pollutants.[4]

Climate

In addition to fertile soil, a region's climate—its temperature, precipitation, humidity and other weather conditions over a long period—contributes to the suitability of the land for agriculture. The favorable climate of the American Midwest, for example, is essential to the immense productivity of agriculture in the region.[3] In contrast, Europe's climate between 1430 and 1850 shifted into a "Little Ice Age," which led to shortened growing seasons, reduced crop yields and less arable land (land that could be farmed), contributing to severe food shortages among the poor.[3] Today, a warming global climate—driven by human activities such as burning fossil fuels[5]—similarly threatens **food security** among the world's poor.[6,7]

Freshwater

Agriculture depends on a reliable supply of freshwater from streams, rivers, underground aquifers and other sources. Where rainfall is inadequate, farmers use **irrigation** to deliver water to fields, though if poorly managed, this practice can be catastrophic. The Sumerians were among the earliest human societies; they prospered for a time, but their food supply declined from 3000 to 1000 BCE—along with their civilization—largely because they mismanaged their freshwater and soil.[4] Sumerian farmers relied on groundwater to irrigate their fields of wheat, but the water contained a hidden risk: When it evaporated, it left behind deposits of dissolved salt.[3] As the growing population demanded increasingly aggressive agricultural production, continued unchecked irrigation eventually "salted the earth" to the point where crops could no longer be grown.[3] Today, in many parts of the world, irrigation depletes freshwater supplies faster than they can be replenished.[8] In the United States, 67 percent of freshwater use is for irrigation.[3]

Wild biodiversity

Biodiversity—the variety of organisms living in an ecosystem—plays a crucial role in agriculture. For example, farmers depend upon a varied assortment of bees, birds, butterflies and other pollinators that tend to 35 percent of the global food supply.[9] Greater biodiversity within soil ecosystems may enhance the beneficial services offered by soil food webs (described above).[4]

Domestic biodiversity

Diversity among the plant varieties and animal breeds we cultivate is another essential genetic resource; building our food supply upon a greater variety of species allows farmers to increase productivity and better adapt to changing conditions.[10] With a greater variety of plant and animal species to choose from, farmers are able to produce the crops and livestock that are best suited to their region.[10] Some species, for example, are more tolerant of certain weather conditions or resistant to certain **pests**.[10]

How well farmers care for soil, climate, water, biodiversity and other facets of ecosystems can greatly influence a nation's food supply. In certain parts of the world throughout every era, over-**plowing**, deforestation and other forms of soil mismanagement have turned fertile land to arid wasteland.[3] Farming practices that erode fertile soil persist to this day, even after the **Dust Bowl** caused massive crop failures, hunger and poverty across the Midwestern United States less than a century ago.[3] These sobering realities remind us that even after over 10,000 years of practicing agriculture, farmers still struggle to foster healthy ecosystems while providing a stable food supply.

Health, environmental, social and economic problems

The industrialization of agriculture (refer to *History of Food*) brought enormous changes to how food is grown. Partly as a result, agriculture boomed: From 1950 to 2000, production on U.S. farms more than doubled, with a fraction of the human labor.[11] It has been said that U.S. agriculture has become the "most efficient in the world, at least in terms of the dollar and cent costs of production."[12] Many of the practices that arose from industrialization, however, negatively impact health, ecosystems and social **equity**, and may have consequences for farmers and their long-term capacities to provide a stable food supply.

Agricultural chemicals and ecosystems

Heavy reliance on agricultural chemicals is one route by which the practices associated with industrial agriculture can impact aquatic and terrestrial ecosystems.

To provide crops with nutrients, some farmers apply chemical **fertilizers**, **manure** or **treated** sewage sludge to fields.[13] When these nutrients exceed plant needs, or are applied shortly before it rains, the excess can leach down into groundwater or be carried by **runoff** into nearby waterways.[13-15] Nutrient pollution in aquatic ecosystems contributes to harmful **algal blooms** that deplete oxygen from water, creating underwater regions that are devoid of most aquatic life.[16,17] These **dead zones** are common in the Gulf of Mexico, Chesapeake Bay and other coastal regions.[16,17] Globally, synthetic nitrogen fertilizers (refer to *History of Food*) and increased intensity of meat production are among the greatest contributors to nutrient pollution.[16]

Agricultural **pesticides** can also impact surrounding ecosystems. Among other harms, pesticide use has been implicated in deformities and sex reversals in amphibians,[18-20] declining pollinator populations[21] and compromised immune systems in dolphins, seals and whales.[14]

Over time, many target species, including insects and plants, develop resistance to the pesticides used against them.[14] Chemical fertilizers can degrade soil fertility over the long term.[22] These adverse effects can create a "treadmill effect," where farmers continually need to apply more chemicals to achieve the desired result,[23,24] worsening the harms posed by their use.

Agricultural chemicals and health

People can be exposed to pesticides through inhalation, direct skin contact, contaminated drinking water or residues on or inside foods.[14] Depending on the pesticide, the potential long-term effects of exposure may include elevated risks of certain cancers and disruption of the body's reproductive, immune, endocrine and nervous systems, among other harms.[14] Agricultural workers in the United States may face health risks from occupational exposures to pesticides, including acute poisonings and in some cases death.[25,26] These occupational risks are disproportionately shouldered by minority and immigrant workers.[15]

Biodiversity loss

The heavy application of insecticides (a type of pesticide intended to control insect pests) and other agricultural chemicals can have unintended impacts on biodiversity. Insecticide use can have harmful impacts to beneficial organisms, including pollinators and predators of pests.[14,21,27] Recently, bee populations have been in dramatic decline. Scientists are uncertain as to the exact combination of causes,[28] though pesticide use is a suspected contributor.[9,14,29]

The specialized **monocultures** characteristic of U.S. industrial agriculture also contribute to the loss of wild biodiversity. Growing monocultures replaces biodiverse habitats with fields of genetically uniform organisms.[14] In places where monocultures are grown in place of a variety of flowering plants, pollinators may be left without enough forage (nectar) to survive.[29]

The extent to which agriculture specializes in producing a narrow range of crops and animals has lessened the genetic diversity of our food supply (domestic biodiversity).[30] Roughly half of U.S. cropland, for example, is dedicated solely to growing corn and soybeans.[31] Globally, 90 percent of the food supply is derived from only 15 plant and eight animal species.[32] With farmers relying on only a few crop varieties, the stability of our food supply is more susceptible to pest invasions and other shocks.[14] The Irish potato famine of the mid-1800s illustrates these dangers. Ireland's poor (one-third of its population) depended on a genetically uniform food source—potatoes—for the bulk of their sustenance.[33] This set the stage for a devastating food crisis. The plant disease *P. infestans* wiped out potato crops, crippling the food supply and causing the deaths of an estimated 1 million people.[33]

Climate change

Agriculture has always been affected by, and has contributed to, a changing climate. Based on some projections, changes in temperature, rainfall and severe weather events are expected to reduce crop yields in many regions of the developing world, particularly sub-Saharan Africa and parts of Asia.[6,7,34] Many parts of these regions already struggle with a lack of food security. Recent studies suggest that rising global temperatures since 1980 have already dampened global corn and wheat yields.[35] Some of these losses may be partially offset by rising levels of atmospheric carbon dioxide, a common **greenhouse gas** (GHG) that is essential to plant growth.[6,34] It is difficult to measure the net long-term global effect of **climate change** on agricultural productivity, and the effects are expected to vary widely by region.[34] Despite these uncertainties, climate change is generally viewed as a major threat to **public health**, equity, food security, freshwater supplies and ecosystems. It is predicted to increase the frequency and severity of droughts, heat waves, flooding, hurricanes and other weather events, with far-reaching effects on human populations.[5-7,36,37] Immediate action to reduce human sources of greenhouse gas emissions may lessen some of these impacts.

Globally, agriculture contributes an estimated 14 percent of total anthropogenic (human-caused) GHG emissions.[5] Deforestation and land use, including clearing forests for crops and livestock, contribute an additional 19 percent.[5] Studies suggest that on average, GHG emissions associated with production through retail in the U.S. **supply chain** are predominantly from food production (83 percent), with smaller contributions from transporting food and food ingredients (11 percent) and food retail (5 percent).[38] Nearly half of total GHG emissions from production through retail are from red meat and dairy production.[38,39] Major sources of GHG emissions from U.S. agriculture include synthetic fertilizers, cattle belching, livestock waste and fossil fuels for farm machinery.[38,40]

Resource depletion

Natural resources, including fertile soil,[2,41] groundwater,[42,43] fossil fuels[44] and phosphate[45] (a mineral used in the manufacture of some chemical fertilizers), are being depleted at rates faster than natural processes can restore them. Many of these resources are nearing or have passed the point at which their rate of extraction begins to decline, prompting the use of terms like **peak oil**.[44] In its current form, agriculture is dependent on all of these resources and is a major contributor to their decline.[2,43-45] The possibility that they may no longer be easily acquired raises concerns about the long-term price and availability of food, which may disproportionately impact the poor.[2,43-45]

Arable land is another natural resource that calls for conservation efforts. Every minute, more than an acre of American agricultural land is lost to sprawling suburbs and other developments.[46] Paving over farmland diminishes natural ecosystems, local economies, scenic and cultural landscapes, and the nation's ability to supply ourselves and other nations with food.[47] Well-managed agricultural land can offer many ecosystem services, including providing habitats for wildlife, helping to control flooding and maintaining air quality.[47]

Loss of farmer equity

Decisions about what food is produced, how it is produced and who produces it are shifting away from farmers and into the hands of a small number of influential corporations.[48] More than half of the U.S. corn seed market, for example, is controlled by only two corporations.[49] On the **food processing** side, three corporations own more than half of the flour milling industry.[49] This trend is called industry **concentration**[50] because the majority of the sales of a product or service are concentrated under the ownership of only a few corporations. The concentration of agricultural and related industries can leave farmers with fewer choices about where to acquire supplies, such as seeds and chemicals, and where to process their products. They may be pressured into following the practices dictated by the dominant industries, potentially leading to a loss of skills and knowledge, heavier debts, greater specialization and a loss of crop and animal biodiversity.[48] The crucial point is that industrialization and market concentration can force farmers to compromise on what they believe is best for their land, animals and labor.[48] For more on market concentration, refer to *History of Food*, *Food Animal Production* and *Food Processing*.

Agriculture faces no shortage of challenges. In many cases, the problems facing agriculture are related. Climate change, for example, is expected to worsen biodiversity loss[5] and freshwater availability,[42] while the adoption of agricultural practices that conserve resources and protect health may depend on farmers having greater autonomy.[48] Addressing these problems will require a collaborative effort on the part of farmers, industries, consumers, policymakers and other participants in the **food system**.

Alternative farming systems

In recent decades, a movement toward alternative approaches to agriculture has gained momentum. These alternatives attempt to reduce the health, environmental, social and economic costs associated with the prevailing industrial model. While not an exhaustive discussion of alternative farming systems, the following briefly covers some of the more established approaches.

Organic agriculture

As defined by the U.S. Department of Agriculture (USDA), organic farming practices generally prohibit the use of petroleum-based fertilizers, synthetic pesticides, sewage sludge and genetic engineering.[51] Animals raised under organic practices must be given organic feed and allowed access to the outdoors, and cannot be given hormones or other growth-promoting drugs (refer to *Food Animal Production*).[51] Since 1990, organic production in the United States has more than doubled (sales have increased over fivefold).[52] Despite these gains, only 1 percent of U.S. farmland was certified organic in 2005.[52]

USDA organic practices can offer many ecological and health benefits, including reduced chemical contamination of air, water and soil, as well as the absence of pesticide residues in food.[53] Despite these benefits, the USDA organic certification program has come under some criticism since it was first introduced in the 1990s.[53,54] The originally proposed standards allowed for the use of debated practices such as irradiation, use of sewage sludge as fertilizer and genetically engineered crops.[53] The public responded in outrage. After receiving an unprecedented volume of negative comments, the USDA revised the standards to resemble their current form.[53] Today, parts of the organic food industry are characterized by large, industrial-scale farms and global product distribution to distant supermarkets,[53,54] while many organic brands have come under the ownership of some of the world's largest corporate food manufacturers.[53-57] The industrial nature of the current organic food industry has been criticized for moving away from the movement's original ideals of small-scale production, **local** distribution and community engagement.[53,54] In defense of "big organic," the C.E.O of a large-scale organic dairy producer argues that globalization is not inherently harmful, and that large-scale capitalism can be leveraged to create sustainable change.[58] Refer to *Marketing and Labeling* for more on the *USDA Organic* label.

Sustainable agriculture

Sustainability has been described as "meeting the needs of the present generation without compromising the ability of future generations to meet their needs."[59] Literally, "to sustain" means "to maintain," "to keep in existence" or "to keep going."[60] Unlike the set of required and prohibited practices for USDA organic agriculture, a prescription for sustainable agriculture remains elusive. Some argue that this is rightly so because each farm is unique, not standardized like a factory; what is sustainable on a farm in North Dakota may be dysfunctional in California.[61] Sustainable agriculture has also been described as a "moving target"; one must continually anticipate change and adapt accordingly.[61]

Although lacking a set of definitive rules, sustainable agriculture does have several themes that describe it. It has been argued that it must be ecologically sound,[61,62] practiced in ways that minimize harms to the natural environment; economically viable, allowing farmers to make an adequate living and produce sufficient food supplies; and socially just.[62]

In practice, sustainable agriculture gives due consideration to the importance of long-term interests, such as preserving fertile soil, biodiversity, freshwater and other resources.[14] **Soil erosion**, for example, can be minimized by protecting soil from wind and rain.[2] Crop rotations, cover crops, mulching, no-till farming and **rotational grazing** are farming practices that can reduce erosion.[2,14]

When appropriate, sustainable agriculture mimics natural processes. Among these core principles is "waste equals food."[63,64] In nature, the concept of waste does not exist; organic matter and the nutrients within it are continually recycled. On a farm, manure, food waste and other forms of organic matter enhance fertility when they are **composted** and put back into the soil, where plants incorporate them back into the food supply.[63]

One way to promote the efficient cycling of organic matter is to combine crops and animals on a farm.[61] In the words of agriculturalist Sir Albert Howard, "Mother Earth never attempts to farm without livestock."[65] The specialized industrial model separates the two, creating enormous quantities of animal waste on the one hand and a need for fertility on the other (refer to *Food Animal Production*). Farmer and poet Wendell Berry describes the irony of this approach: "Once plants and animals were raised together on the same farm—which therefore neither produced unmanageable surpluses of manure, to be wasted and to pollute the water supply, nor depended on such quantities of commercial fertilizer. The genius of American farm experts is very well demonstrated here: They can take a solution and divide it neatly into two problems."[66]

In the predominant industrial model of agriculture, technological "quick fix" solutions are often designed to solve a problem by attempting to exert control over nature.[67] This short-term, reductionist approach often solves one problem while creating several others.[67] The heavy reliance on chemical pesticides is an example.[67] In contrast, more sustainable approaches attempt to work with nature by leveraging existing relationships in an ecosystem,[67] for instance, managing pests by growing a diversity of crops and rotating them over time,[14] a practice that capitalizes on natural defenses.

Although *some* pre-industrial cultures farmed in relatively sustainable ways, sustainable agriculture is not a throwback to earlier times. It neither shuns nor embraces modern technology, nor does it necessarily reject all of the principles associated with industrialization. Rather, it is informed by the latest knowledge among farmers, researchers and policymakers.

Finally, because sustainable agriculture is place-specific, farmers must look to the unique biological, physical, social and economic qualities of their region.[14] Underscoring this point, author and farmer Wes Jackson has said that farmers must "become native" to the places where they grow food,[14] connecting with local ecosystems as though they were lifelong residents of them.

Conclusion

The prevailing industrial approach to agriculture, though highly productive in some respects, presents a number of health, environmental, social and economic problems. Ecosystem degradation, as history teaches us, poses particular concerns for the long term viability of the food supply and the health of populations.

Some alternative farming systems, though not always easily defined, tend to favor practices that work in concert with natural ecosystems. Most farms share some qualities of both industrial and alternative models. A shift toward more sustainable alternatives may offer a way forward that is more ecologically sound, economically viable and socially just.

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