

9

FARMING, THE ENVIRONMENT, CLIMATE CHANGE, AND WATER

Does agriculture always damage the environment?

From the perspective of deep ecology, all forms of agriculture damage the natural environment. When our early ancestors went from hunting and gathering to planting crops and grazing animals, they cut forests and redirected waterways. Wild plants and animals were domesticated, then progressively modified through selective breeding. If protecting nature is the central goal, these actions must be considered damage. Using a more utilitarian and socially centered perspective, however, changes to nature caused by farming would be viewed as damage only if they brought long-term costs to human society that exceed the short-term food production gain. Even if we use this more forgiving definition, many kinds of farming today do damage the environment.

It is useful to classify the environmental damage done by farming according to where it takes place: on the farm versus off the farm. Farmers themselves will suffer most from damage on the farm, while it is mostly non-farmers who suffer if the damage is off the farm and downstream. In an important way, politics sets the balance between these two kinds of damage. Farmers in poor countries lack political power, so they will

often find themselves trapped into using practices that damage their own farm resource base, and hence their own livelihood. Farmers in rich countries have considerable organized political power, so they will find it easier both to protect their own resource base and to get away with actions that pollute air and water downstream from farms, to the disadvantage of non-farmers.

In the poorest developing countries, most of the environmental damage done by agriculture takes place on the farm itself. Prime examples include the exhaustion of soil nutrients due to shortened fallow times, waterlogging of soils due to mismanaged irrigation, or the “desertification” of rangeland caused by excessive animal grazing. By harming the agricultural resource base itself, this sort of damage lowers productivity and helps keep farmers poor. Research presented at an Africa Fertilizer Summit in 2006 revealed that the shortening of fallow times in Africa was removing nitrogen from the soil at an average annual rate of 22–26 kilograms per hectare, far too much to be offset by current rates of fertilizer application, which average only 9 kilograms per hectare. The result of this “soil mining” was a deficit in soil nutrients that causes annual crop losses estimated at between \$1 billion and \$3 billion. Nor is this the end of the problem. As cultivated soils become exhausted, farmers will extend cropping onto new lands, cutting more trees and destroying more wildlife habitat. According to the World Resources Institute, land clearing for the expansion of unsustainable low-yield farming has caused roughly 70 percent of all deforestation in Africa.

In wealthy industrial societies, by contrast, environmental damage from farming usually results from too much input use rather than too little, and those who suffer most are usually not farmers. For example, excessive nitrogen fertilizer use leads to nitrate runoff and eutrophication of streams and ponds. In Europe, excess nitrates in water are a downstream health hazard (“blue baby syndrome”). In the United States, excessive nitrogen fertilizer use on farms in the Mississippi River

watershed contributes to an environmental calamity both within that watershed and also in the Gulf of Mexico, where a 6,000-square-mile “dead zone” is no longer able to support aquatic life. In the Florida Everglades, nitrogen and phosphorous runoff from sugarcane production has produced cattail growth so thick as to replace the native sawgrass, ruining the habitat of wading birds like storks, and then sucking oxygen from the water when the cattails die and decompose, which kills the fish.

Exploitation of river water for crop irrigation can harm migratory fish species, such as salmon, which are unable to move upstream through the narrow passages and turbines of dams. Concentrated animal feeding operations (CAFOs), designed to cut livestock industry costs by fattening thousands of animals for slaughter all within one crowded facility, often pollute both the air and water with toxic effluents, creating health risks for non-farming human populations living nearby. The poultry industry in just a single county in Delaware produces 200 million birds a year, and mishandled chicken waste has been a major source of eutrophication in the Chesapeake Bay.

What kind of farming is environmentally sustainable?

Environmental activists and agricultural scientists answer this question in dramatically different ways. Environmentalists usually prefer small-scale diversified farming systems that rely on fewer inputs purchased off the farm, and on systems that imitate nature rather than trying to engineer or dominate nature. Agricultural scientists tend to assume that there will be less harm done to nature overall by moving toward specialized high-yield farming systems employing the latest technology, because increasing crop yields on lands already farmed will allow more of the remaining land to be saved for nature. While environmentalists invoke the damage done by modern farming, agricultural scientists invoke the greater damage that

would be done if the same volume of production had to come from low-yield farming systems.

The environmentalist side of this argument was most eloquently presented in 1962 in Rachel Carson's landmark book, *Silent Spring*, which exposed the damage done by chemical pesticides both to human health and to wild animal species (including songbirds, hence the title). Carson's book led to a legal ban on the agricultural use of DDT in the United States and also to the formation of a broad and powerful environmental movement, which in 1970 secured passage of the National Environmental Protection Act, creating America's Environmental Protection Agency (EPA). Carson's thinking also reinforced a continuing quest among environmentalists for an alternative to high-input, high-yield farming.

One early pioneer in this search for "alternative" models of farming was Wes Jackson, who founded a Land Institute in Kansas in 1976, to promote farming based on polycultures of perennial crops rather than monocultures of annual crops. This approach did not prove to be a commercial success, but it was Jackson, in 1980, who began employing the term "sustainable agriculture" to describe his objectives. Responding to political interest in alternative farming systems, the Department of Agriculture in 1985 finally initiated a program to promote what it called low-impact sustainable agriculture, or LISA. Conventional commercial farmers panned it as "low income sustainable agriculture," but the idea gained traction with non-farming urban populations and with a younger cohort of countercultural farmers who had links to a back-to-the-land movement from the 1960s.

High-input farming did cause environmental damage in America during the second half of the twentieth century, but the earlier style of low-input farming had also been damaging. It was an extension of low-yield wheat farming into the southern plains of Kansas, Oklahoma, and the Texas panhandle in the 1920s, before synthetic chemical fertilizers or pesticides were in wide use, that produced America's single greatest

environmental disaster until that time, a drought-induced loss of topsoil that ruined farmlands across an area as big as the state of Pennsylvania, turning it into a “dust bowl.” Roughly 400,000 farmers fled the dust bowl, many of them moving to California to work as migrants picking tomatoes and peas, a flow of environmental refugees unmatched in scale until Hurricane Katrina subsequently flooded out the population of New Orleans in 2005.

Following Carson’s book, while environmentalists were concluding that chemical use to increase crop yields was inherently dangerous, commercial farmers and agricultural scientists sought instead to develop new chemicals that were less harmful and ways to apply them with greater precision to reduce runoff. Environmental advocates were not impressed with this “technical fix” approach; they wanted a more complete move away from highly specialized, highly capitalized “industrial” farming. Their views were later supported by a 2008 International Assessment of Agricultural Science and Technology for Development (IAASTD), which warned that using still more modern science to “increase yields and productivity” might do even more environmental damage.

Growing numbers of popular writers have embraced this view. In an apocalyptic 2008 book titled *The End of Food*, journalist Paul Roberts argued that the world’s large-scale, hyper-efficient industrialized food production systems were heading toward an inevitable collapse because of the damage they had been doing to soils, water systems, and other “natural infrastructure.” Alternative food advocate Michael Pollan wrote in 2008 that “the era of cheap and abundant food appears to be drawing to a close.” In 2013, *New York Times* food columnist Mark Bittman described America’s “hyper-industrial” agricultural system as having poisoned land and water, wasted energy, and made a major contribution to climate change. “We must figure out a way to un-invent this food system,” said Bittman. Despite such popular sentiments, a preponderance of agricultural scientists and economists do not reject today’s

large-scale, specialized, and highly capitalized farming systems as unsustainable. In fact, they view these systems as the best means available to contain environmental damage from farming.

What is low-impact or “precision” farming?

Commercial farming today has moved well beyond the indiscriminate chemical use practices that Rachel Carson properly criticized in 1962. Many of the early insecticides then in use have now been banned and replaced by chemicals that are less persistent in the environment and effective when applied in lower volume. Commercial farmers are always looking for ways to cut back on unnecessary chemical and fuel use so as to reduce costs, and by the end of the twentieth century they had found a number of technical means to do so. These new methods came to be labeled “precision” farming.

Beginning in the 1970s and 1980s, during an interlude of extremely high energy prices, farmers in the United States first learned to save diesel fuel by planting seeds in unplowed fields—a “no-till” approach to farming that also reduced erosion, conserved soil moisture, and sequestered carbon. They also switched from flood irrigation to less wasteful center-pivot sprays, or to laser-leveled fields with zero runoff, and to even more precise drip irrigation systems. Then, in the 1990s, they began using Global Positioning Systems (GPS) to auto-steer tractors in perfectly straight lines with zero overlap (saving more diesel fuel), plus soil-mapping and onboard computer systems to match chemical applications of fertilizer or lime more precisely to location-specific needs. The GPS told them exactly where they were in a field to within one square meter, and with variable rate application machinery they could deliver precisely the amount of water or fertilizer required in that part of the field. Infrared sensors can be used to detect the greenness of a crop, telling a farmer exactly how much more (or less) fertilizer might be needed. To minimize nitrogen runoff,

fertilizer can also be inserted into the soil in much smaller total quantities at exactly the depth of the plant roots, and in perfect rows exactly where the seeds will be planted. Also in the 1990s, farmers in the United States began planting genetically engineered soybean, corn, and cotton seeds that made it possible to control weeds without mechanical tillage and to control insects without as many chemical sprays.

Farmers took up these more precise methods to save money on chemicals, water, and diesel fuel, but the side result was a clear benefit to the environment. American agricultural output has increased by 40 percent since the early 1980s, but chemical fertilizer use, insecticide use, and herbicide use have all declined in absolute terms. Energy use, land use, and water use have declined most conspicuously on a per bushel of production basis. Department of Agriculture surveys reveal that between 1980 and 2011, energy use per bushel of corn production fell 43 percent. Land use per bushel fell 30 percent. Soil erosion per bushel fell 67 percent. Irrigation water use per bushel fell 53 percent. And greenhouse gas emissions per bushel fell 36 percent.

The United States has not been alone in making this technical move in commercial farming toward reduced input use per bushel of production. In 2008 the Organisation for Economic Co-operation and Development (OECD) in Paris published an important review of the “environmental performance of agriculture” in the 30 most advanced industrial countries of the world (those with the most highly capitalized farming systems). The new data showed that between 1990 and 2004, total food production in these countries increased in volume by 5 percent from an already high level, yet adverse environmental impacts had diminished in nearly every category. The area of land taken up by agriculture declined 4 percent. Soil erosion from both wind and water was reduced. Water use on irrigated lands declined by 9 percent. Energy use on the farm increased at only one-sixth the rate of energy use in the rest of the economy. Gross greenhouse gas emissions from farming

fell by 3 percent. Herbicide and insecticide spraying declined by 5 percent. Excessive nitrogen fertilizer use declined by 17 percent. Biodiversity also improved, as increased numbers of crop varieties and livestock breeds came into use.

True believers in the promise of precision farming expect there will be no end to the impact-reducing gains that can be achieved. Their long-term vision includes small solar-powered robots working farm fields in groups, hoeing weeds and picking off bugs 24 hours a day without any polluting chemicals or fossil fuels at all, then harvesting the crop with almost no human supervision required. Even if this fantasy became possible, most environmental advocates would refuse to see it as progress. They generally do not endorse modern precision farming because it favors highly capitalized industrial-scale operations, something they reject on principle. The small, diversified farms they favor cannot make use of the costly and specialized machinery that is a key component to most modern precision farming. In addition, environmental advocates instinctively reject the notion that a biological system such as a farm can be sustainably and safely precision-engineered through science. They believe, with Rachel Carson, that nature will always find a way to strike back against human arrogance of this kind.

Do fragile lands, population growth, and poverty make farming unsustainable?

These are popular explanations for environmental damage from farming, but institutional arrangements are usually more important.

The concept of “fragile” land can be misleading. It is true that many poor countries farm on sloping lands or irregular lands with thin and badly weathered soils, all subject to the damaging extremes of heat, flood, and drought. In many tropical countries, soil nutrients leach away immediately when trees are cut, leaving a baked and barren landscape on which only

weeds will grow. Under proper management, however, these less productive tropical lands can be improved dramatically and farmed sustainably. When farmed with adequate fallow time, or limed to the correct acidity, or terraced and mulched to capture and keep more moisture on leveled soil, or planted to several different crops at the same time (intercropped) to reduce vulnerability to pests, the productive potential of such less-favored lands can be sustainably increased.

Some argue that poverty itself is a cause of environmental damage in farming, because poor farmers who live from hand to mouth cannot afford to wait for resource-protecting investments to pay off. Yet many poor farming communities do invest to protect their resources, if the political and institutional circumstances are right. They are more than willing to build and maintain terraces, plant trees, and protect range-lands from overgrazing when effective “common property resource” (CPR) systems are allowed to operate at the local or village level. These informal systems protect local forests, streams, ponds, and grazing lands by allocating equitable use to insiders while denying access to outsiders. Such systems are good at blocking the “tragedy of the commons,” a pattern of environmental destruction that arises in systems of open access (Garrett Hardin, the influential ecologist who named this danger in 1968, should have called it the “tragedy of open access”). Within a well-managed commons systems, even poor communities can avoid environmental tragedies.

Commons systems are vulnerable to breakdown, however, if powerful outside institutions, such as colonial administrators, international companies, forestry department bureaucrats, megaproject engineers, government land-titling agencies, or centralized irrigation authorities, move in to take control away from local community leaders. Local farmers who sense that they are about to lose control of their resource base will at that point stop making investments in resource protection. They will begin using up the resource base as fast as they can—cutting the trees, plowing up terraces, over-grazing the range,

over-fishing the ponds—before the outsiders take it away. Poor farmers who have control as well as access can be conserving farmers; if control is taken away, they will use their access to exploit rather than conserve.

Well-functioning common property systems in poor countries can also break down if local leaders become corrupt, or due to excess population growth. If population density increases beyond a certain point, the value per person of protecting the resource will decline so much for insiders as to demotivate efforts at protection, just when more outsiders will be attempting to gain access. At this point, effective resource protection can require switching to an individual private property system, one that restores individual payoffs for resource-protecting actions while handing the problem of excluding outsiders over to the police. If this transition to individual land ownership is made successfully, a further increase in population density need not threaten the resource base at all. In fact, greater population density makes affordable greater labor investment in protecting the land (mulching, terracing, etc.) and increases the affordability of productivity-enhancing investments in rural roads, power, and irrigation. One example from Africa is the experience of Machakos District in Kenya, where farmers in this densely settled semi-arid area avoided serious damage to their marginal soil endowments even as population increased. This occurred thanks to clearly titled land ownership that motivated heavier labor investments in terracing systems, use of more fertilizer, and a shift to higher-value crops for sale in nearby urban markets.

Do cash crops and export crops cause environmental harm?

Shifting from food crop production to a more specialized cash crop production for export is frequently cited as a cause of both economic dependency and environmental harm. There are some cases that support this generalization, for example in Central America in the 1960s and 1970s, when landlords

introduced chemical-intensive cotton production and evicted traditional peasants growing maize and beans. Yet the cash crop versus food crop dichotomy is usually misleading, because a number of food crops in the developing world are at the same time cash crops (for example, rice in Asia), and many cash export crops (such as cocoa in West Africa) are grown by small farmers in the same fields with food crops, in an environmentally friendly intercropping system.

Cash crops for export are not inherently less rewarding for small farmers to grow, or more damaging to the environment. Exported cash crops are often tree crops or perennials that provide better land cover and more stable root structures than annual food crops. In Africa, some kinds of perennial export crops—such as tea or coffee, planted along the contour of sloping lands, or oil palm planted in low-lying areas—can protect the soil much better than food crops requiring annual tillage, such as maize. At least a partial switch to higher-value cash crops helps farm families with limited land and labor earn the income they need to pay for their children's school expenses. Farmers will typically switch part of their land to cash crop production, then use some of the income to purchase improved seeds and fertilizer, allowing a simultaneous boost in food crop production on the rest of their land.

Do farm subsidies promote environmental damage in agriculture?

Yes. Most subsidy policies work by giving farmers artificially high prices for their products, which induces them to use excessive fertilizers, pesticides, and irrigation water in an effort to boost crop yields as high as possible. In Korea, where rice farmers are heavily protected (with a guaranteed price roughly five times the world market price) pesticide use is extremely high, at 12.8 kilograms per hectare. In France, where farmers have less price protection, pesticide use is less than half as high, at 4.5 kilograms per hectare. In the United States, where there is even less protection, pesticide use is only 2.3 kilograms per

hectare. And in Senegal, where farmers get almost no protection at all, pesticide use averages only 0.1 kilograms per hectare. In most of Africa, farmers are often taxed rather than subsidized (a symptom of their political weakness), which frequently results in too little chemical use rather than too much. Fertilizer use in most of Africa is insufficient for replacing the soil nutrients taken up by crops.

When subsidies to farmers go up, input use often goes up in lock-step. Between 1970 and 1990 in Thailand, as income protections for farmers increased, fertilizer use per hectare increased nearly sevenfold. In Indonesia in the 1980s, where the government subsidized fertilizer purchases directly by as much as 68 percent, chemical use increased 77 percent over one five-year period. In India, when the government began to subsidize 86 percent of the electric bill for pumping irrigation water in the Punjab, groundwater tables began dropping at an unsustainable rate of about 0.8 meters a year.

In rich countries, farmers are not only powerful enough politically to demand the subsidies that encourage excessive input use, they are also powerful enough to avoid being held accountable for the resulting downstream environmental damage. Because of farm lobby strength, the air and water pollution that emanates from farms in rich countries is regulated far less than pollution from other industries. In the United States, the agricultural sector is significantly exempt from the regulatory structures of both the original Clean Air Act and Clean Water Act, because pollution from farms does not come from a "point source."

Despite the dead zone in the Gulf of Mexico, Congress does not regulate excess nitrogen runoff from farms and does not tax farm fertilizer use. Instead, it has created voluntary programs that pay farmers to take land (temporarily) out of production, or to cultivate their land in ways that reduce runoff. In 2010, these incentive-based, voluntary conservation programs operated by the U.S. Department of Agriculture (USDA) cost taxpayers \$5.5 billion. Instead of using a "polluter pays"

principle, the government actually pays the polluter. Even in extreme cases such as chemical pollution in the Florida Everglades from heavily subsidized sugar farming, strong regulations are routinely blocked by industry. In 1996, when Vice President Al Gore proposed taxing sugar growers to finance an Everglades clean-up project, a direct phone call from a Florida sugar baron to President Bill Clinton resulted in the tax proposal being set aside.

A more recent example of the power of U.S. agriculture to resist environmental regulation can be seen in the case of climate change policy. In 2009, when the House of Representatives passed the Waxman-Markey bill to create a cap-and-trade system to limit greenhouse gas emissions, the entire agricultural sector was left “uncapped.” Instead of being subject to caps under this bill, farmers would have been entitled to profit by selling “offsets” to industries in sectors that were capped. The offset would be based on a voluntary reduction in emissions, or an increased sequestering of carbon—things a farmer might be doing anyway.

One of the few environmental policy instruments strong enough to resist the farm lobby in the United States has been the 1973 Endangered Species Act. For example, in 2008, a lawsuit filed under that act by the Natural Resources Defense Council forced the Bush administration’s Fish and Wildlife Service to divert more than 150 billion gallons of water away from irrigated farming in the San Joaquin Valley, in California, so as to protect the delta smelt, an endangered 3-inch bait fish. Environmentalists know that their best chance, in a battle against farmers, is usually to move the action out of Congress and into the courts.

How will climate change affect food production?

Climate change will affect food production in complex ways, and in different ways at different latitudes. In the tropics higher temperatures will damage farming, since some crops

are already being grown near the upper range of their biological heat tolerance, but in some higher temperate zone regions warmer weather will mean longer growing seasons, and perhaps the chance to add a second seasonal crop. Average rainfall and rainfall variability will change as well, in ways far more difficult to predict. A warming earth will be, on average, a wetter earth, due to accelerated ocean evaporation leading to increased cloud formation, and this can be good for farming. Other things being equal, increased carbon dioxide (CO_2) in the atmosphere will also help farming, since plants need to take in CO_2 . This is known as the carbon fertilization effect. But increased atmospheric ozone, another greenhouse gas, can slow plant growth.

In North America, longer growing seasons at upper latitudes, more rainfall overall, and greater carbon fertilization may actually provide net benefits to farming. According to the Intergovernmental Panel on Climate Change (IPCC), crop yields in North America are expected to increase by 5–20 percent during the first several decades of the twenty-first century, due to climate change. At the same time, these gains will be uneven across the region, and weather variations are likely to be more extreme. Experts disagree on whether the 2012 summer drought in the United States was linked to long-term climate change or to short-term factors such as a cyclical La Niña effect.

The impacts of climate change on farming in the developing world are likely to be more damaging. One 2009 projection done by the International Food Policy Research Institute (IFPRI) was based on a linked computer model that incorporated both a food supply-and-demand component and a biological crop growth component, one that captured yield changes driven by temperature changes within 281 different spatial regions around the world. The temperature changes expected within these spatial regions, out to the year 2050, were calculated based on modeled scenarios generated from the IPCC's 2007 4th Assessment Report. The results of this

exercise were alarming. Rice production in the developing world in 2050 was expected to be 14 percent lower with climate change compared to without, and wheat production in the developing world was expected to be 34 percent lower due to climate change. In South Asia, specifically, wheat production was projected to be 49 percent lower in a 2050 world with climate change, compared to a world without climate change. When IFPRI then put these projected production impacts into its economic model, it estimated the higher food prices these climate effects would generate and concluded that there would be a 23 percent increase in the numbers of malnourished children expected in 2050 in a world with climate change, compared to a world without.

Two kinds of policy response are available to this threat. One would be “prevention,” in the form of a redoubled effort to slow climate change, limiting any further temperature rise to no more than 2 degrees Centigrade, by somehow keeping atmospheric concentrations of CO₂ from exceeding 450 parts per million. This, however, would require a sharp downward adjustment in current fossil fuel consumption trends for countries such as China and India, as well as the United States and Europe. Such a response is politically unlikely, because it would imply much slower economic growth, at least until the costs of wind and solar power come down. A second option, favored by IFPRI, is to recognize the high probability of future climate change and to help developing countries adapt their farming systems by making larger investments in irrigation expansion and efficiency, rural roads, and agricultural research. If an added \$7 billion were properly spent every year for such purposes, the adverse impacts of climate change on food production might be offset. This is a small amount of money relative to the budgets of today’s major governments (the United States spends 100 times this amount on the Defense Department every year), yet political support for spending this money in the developing world is difficult to mobilize.

Does agriculture contribute to climate change?

Agriculture globally is a major contributor to climate change. The expansion of crop farming releases CO_2 into the atmosphere when trees are cut to clear land, and also when the soil is disturbed. Heat-trapping gases are also released when fuel is burned to manufacture fertilizer, or to power farm machinery, and when rice is grown in flooded paddy fields, which give off methane gas, more than 20 times as powerful in trapping heat as CO_2 . Livestock production is an even more potent source of greenhouse gas emissions, because of the clearing of lands for pasture, and also because so much crop farming today goes for animal feed purposes. Moreover, the animals themselves are a source of greenhouse gas emissions, principally in the form of methane released from the digestive processes of ruminant animals (cattle, goats, sheep) that depend on microbial fermentation of fibrous grasses and feeds, and also from animal manure, which emits gases such as methane, nitrous oxide, ammonia, and carbon dioxide. The Intergovernmental Panel on Climate Change (IPCC) reported in 2007 that the agricultural sector overall was the source of 10–12 percent of total global anthropogenic emissions of greenhouse gases. If we add emissions from fertilizer production, food transport, refrigeration, consumer practices, and waste management, somewhere between one-fifth and one-third of all greenhouse gases emitted by people come from the food and farming sector, according to a 2012 analysis from the CGIAR Research Program on Climate Change, Agriculture, and Food Security. In the United States specifically, if only on-farm emissions are considered, agriculture accounts for somewhere between 7 and 8 percent of all greenhouse gas emissions.

Calculations of this sort are contentious and sometimes flawed. For example, in 2006, the United Nations Food and Agriculture Organization (FAO) released a report titled *Livestock's Long Shadow: Environmental Issues and Options*, which estimated that livestock production worldwide was responsible all by itself for 18 percent of all human-induced

greenhouse gas emissions, “a bigger share than that of transport.” In generating this high percentage, the FAO followed a life cycle analysis approach that considered not just greenhouse gases from the animals themselves—including methane and nitrous oxide from the digestive systems and manure of the animals—but also emissions from a large number of associated activities such as land-use changes (converting forest to pasture), the burning of fossil fuels to produce animal feed, plus emissions from animal processing and transport. The surprising findings of the report prompted an animal welfare organization, PETA, to chide former vice president Al Gore for having failed to mention reduced meat consumption as one powerful way to prevent climate change.

It later came to light that this 2006 study was an exaggerated estimate, because it had compared a full life cycle analysis of the livestock industry to only a partial life cycle analysis of other sectors. For example, in the transport sector it counted greenhouse gas emissions from the gasoline burned by cars, but not the CO₂ emitted from factories that assembled the cars, or from the factories that manufactured the steel, glass, plastic, and rubber from which the cars were made. Authors of the FAO report conceded this flaw, but livestock industry critics continued to reference the study, and they even produced a dubious study of their own claiming that livestock were actually responsible for 51 percent of global greenhouse gas emissions.

One useful message from the original FAO study was that livestock systems based on extensive grazing are just as prone to produce greenhouse gas emissions as systems based on confined feeding. Cattle raised exclusively on grass take far longer to reach a market weight than cattle finished in a confined system, meaning more months or years of digestive methane and nitrous oxide emissions per pound of meat. As for confined systems (concentrated animal feeding operations, or CAFOs), they generate less methane and nitrous oxide per pound of meat, but usually much more CO₂, because of the diesel fuel burned in growing the feed grain.

Returning to a more traditional farm production system may seem a tempting way to reduce greenhouse gas emissions, but given today's much greater market demand for food, including animal products like meat, traditional systems would actually result in an increase in emissions. In 2010, a team of scientists at Stanford estimated that if world food consumption in 2005 had to be satisfied with the average crop yields of 1961, the total area of cropland under production worldwide would have to more than double, a damaging change in land use that would release sequestered carbon from forests and soils and increase global greenhouse gas emissions from agriculture roughly fivefold. This same study then asked how actual greenhouse gas emissions in 2005 would have changed if the world returned not only to 1961 crop yields, but also to 1961 per capita consumption levels. Moving back to a 1961 diet (one that depended far less on meat consumption) would reduce greenhouse gas emissions, but only enough to offset about half the damage done by moving back to the lower 1961 crop yields. The lesson from this study was that the worst possible situation for climate change would be a world that retains the current level of meat consumption but moves back to 1961 (pre-green revolution) crop yields.

Is the world running out of water to irrigate crops?

For farmers everywhere, water is destiny. Producing one kilogram of wheat requires the use of about 1,000 liters of water, and paddy rice requires twice this amount. The earth's freshwater supply is not diminishing overall, since it is renewed every time it rains, and about 60 percent of farm production in the developing world is still based on rainfall alone. Yet in regions where rainfall is uncertain or inadequate, irrigation techniques that bring freshwater from surface streams or from underground aquifers to the roots of crops are essential. Irrigated farming is the most reliable and often the most productive kind of farming; irrigated land makes up about

one-fifth of total arable area in the developing world, yet it provides two-fifths of all crops harvested and close to three-fifths of cereal production.

Total irrigated land area has doubled over the past 50 years, and globally today about 20 percent of all cultivated land is under irrigation. Roughly 70 percent of all the water we take from aquifers, streams, and lakes now goes into agriculture. Because the most promising sites for irrigation were developed long ago, the United Nations FAO expects irrigated area to grow more slowly in the years ahead, by only 6 percent between 2009 and 2050. This may not be enough to keep pace with future production requirements.

Expanding the use of irrigation water for agriculture will be difficult for several reasons. First will be an unavoidable increase in competition for freshwater from urban users, but second will be the needless degradation of some past irrigation sites. Poor drainage of irrigated lands has left some lands waterlogged or saline. Basins of dams have silted up, reducing capacity. In many large rivers, excessive withdrawals have left as little as 5 percent of the former water volume in-stream, and some rivers no longer reach the sea year-round. Nearly 40 percent of irrigated area now depends primarily on groundwater, yet aquifer depletion is a growing threat because rates of pumping have proved nearly impossible to regulate. According to one 2012 estimate published in *Nature*, roughly 1.7 billion people now live in areas where groundwater resources or groundwater-dependent ecosystems are under threat.

What can be done to improve water management in farming?

The first and most important step is to reduce water waste. The technical means available include shifting from flood irrigation to more precise spray-and-drip systems, leveling fields to eliminate runoff, and lining irrigation canals to reduce seepage. The policy steps needed include ending subsidies for

cheap electricity that encourage excessive pumping (in India, for example), establishing water users' associations to regulate access, and creating water markets based on tradeable water rights.

Private water markets have saved farming in some dry parts of Australia. One example is the Murray-Darling Basin, where the Australian government in the 1990s shifted from building dams and subsidizing water to a policy that separated water rights from land rights. This allowed farmers with less need for water to sell their rights to farmers who needed more. Total water availability was falling in this basin, yet the income of farmers remained high, thanks to the operation of this water market. As water availability went down, the price of water went up, which encouraged growers of thirsty low-value crops such as rice to sell some of their water rights to growers of higher-value crops such as vegetables or grapes. The system allows willing buyers and willing sellers to make deals, which in the end allocate scarce water to its highest value use. Water trading systems for farmers also operate at the state level in the western part of the United States, in Arizona, New Mexico, Colorado, and California.

While reducing water waste in currently irrigated regions, it will be equally important in the years ahead to extend irrigation coverage to regions where rainfall alone does not allow crop farmers to prosper. In Africa today, only 4 percent of cultivated land is irrigated, and 41 percent of annual farm production comes from lands that are both hot and dry. Farmers on these dry lands are pushed back into poverty every time the rains fail. The irregular topography of much of Africa, plus poor rural road and power infrastructures, have discouraged investments in irrigation. Building dams also encounters opposition from environmental groups. Because so many non-governmental organizations (NGOs) are now opposed to dams, the World Bank has virtually stopped financing such projects in the developing world. NGOs tend to favor small-scale irrigation alternatives such as rainwater harvesting,

bucket irrigation, treadle and pedal pumps, and small earthen dams, yet these options are hard to scale up and they carry excessive labor costs in much of rural Africa.

Citizens in today's rich countries, who gained prosperity in part by building dams to develop 70 percent or more of their own hydroelectric potential, might wish to think twice about telling Africa—where only 3 percent of potential has so far been developed—that dams are a bad idea.