

The green revolution, fertilizer, and erosion

The “green revolution”

Two centuries ago, Rev. Thomas Malthus characterized the future as a race between a geometric (exponential) increase in human numbers and a linear increase in the means to feed that population. Malthusian thinking was that famine would inevitably come because it was not possible to increase production sufficiently to meet the need.

The 1960s proved that this thinking was wrong (at least then), that there was plenty of slack available in the agricultural system. Financed by the Rockefeller Foundation, the Ford Foundation, and other foundations, international institutes developed strains of crops that exploited enhanced knowledge of biology to increase the proportion of biomass of crops that go to producing the fruit.

Despite a population growth rate of over 1.8% per year (a doubling every 35 years), cereal production increased from 275 kg per person per year in the early 1950s to 370 kg per person per year at the end of the 1970s.⁽²⁰³⁾ The International Center for the Improvement of Maize and Wheat (known by its Spanish acronym as CIMMYT) one of the research institutes run by Consultative Group on International Agricultural Research (C.G.I.A.R.) and its director, Nobel-Prize winning Dr. Norman Borlaug, were instrumental in that growth process, which has become known as the “green revolution.” It really was revolutionary—in some cases yields increased from 0.75 t/ha to 8 t/ha.⁽¹⁵³⁾ Along the way, it was important to prevent “lodging,” or the collapse of the stem of the grain crop because the fruit was too heavy. This plagued the early advances of the CIMMYT research.⁽¹⁶⁹⁾ The identification of the dwarfism trait (see dwarf rice in Fig. 23.3 a) was important in developing high-yielding plants, because the smaller stems were

thicker and could continue to hold the grain.⁽¹⁶⁹⁾ Homologs (“lookalikes”) of dwarfing genes have been identified that operate the same way between monocots and dicots. Various dwarf sequences in various crops have been identified, and remain important.⁽¹¹⁹⁾

But that was then, and this is now. Since 1989, increases have essentially stalled; the revolution had played itself out.⁽¹⁶⁹⁾ Even record global harvests are not sufficient to meet demand;⁽²⁰⁴⁾ the Food and Agriculture Organization estimates that 800 million people are chronically hungry.^(205,206) Food security for those alive is important not only to them but to the rest of the world.^(84,207,208) Food production must rise by 1 to 2% per year just to feed the people who will be alive in 2020.⁽²⁰⁷⁾

Research funding for agriculture in the world’s (developed) temperate climates has climbed as companies rushed to patent strains of crops, but money for research in the more tropical climes where most of the world’s poor and hungry live has been at best stagnating.^(129,168,169) As the authors of Ref. 203 suggest, it may be that “increases in gross national product (GNP) per head are being realized by a depletion of natural capital; in particular, whether increases in agricultural production are being achieved by a ‘mining’ of soil, lowering of water tables, and impairment of other ecosystem services.” Such increases are clearly not sustainable in the long term. One agriculture elder statesman has characterized this situation as “running out of gas,” while another sees it as a reflection of the characteristics of the logistic curve.⁽¹⁶⁹⁾ Furthermore, the green revolution never made it to the tropics.⁽⁸⁴⁾

This group also points out that the increases we need to feed the increased population will have to come from increased harvests from the land already in production, and this will become more difficult because of destruction or withholding of genetic resources, threatened ecosystem services, deleterious consequences of fertilizer, herbicide, and

insecticide application, and the prospect of more weather disasters accompanying global warming.⁽²⁰³⁾ When farmers seize land, they may not know how to treat it to maintain productivity. Brazil has lost much soil, and in Belize, Guatemala, and Mexico, people invade forest land to practice swidden agriculture, but without the long traditional pauses that allow the land to recover.^(209,210)

In addition, many of the insights that led to green revolution crop increases are particular to the temperate zone. A record of both successes and failures has taught the temperate-zone farmers how best to sustain yields. Such longterm (over a 50 year period) assessments of the efficacy of various ways to achieve stability and sustainability have occurred up to now only for this temperate climate regime (one research station is 160 years old).⁽²¹⁰⁾ There is a clear need for equivalent tropical longterm experimental stations to identify best practices for agriculture in those climate regimes, one that includes the range of agricultural practices based on the various soils and local climates of large regions.⁽²¹¹⁾

Fertilizers

As Smil and others have pointed out, if the world were to try to feed its human inhabitants with turn-of-the-twentieth-century agriculture, it would be able to support only around half the current world population.^(212,213) The major difference is fertilizer, obtaining nitrogen by a process developed by Haber early in that century.

Use of fertilizer and irrigation are fundamental to the “green revolution” we have encouraged poorer countries to adopt.⁽²¹⁴⁾ Fertilizer use increased from 13 Mt in 1950 to 110 Mt in 1984.⁽²¹⁵⁾ Yields would drop by a third if no fertilizer were applied to the world’s fields. Fertilizer and irrigation are the two most energy-expensive components of

the North American agricultural system. Even though farmers in India (for example) use more energy than is generally acknowledged,⁽²¹⁶⁾ most of this is human energy. It is difficult to imagine that the average farmer in South India can afford to import oil stocks to supply high-grade energy and fertilizer on scales required for wide adoption of the “green revolution” techniques, especially since it would vastly increase the number of unemployed. Farmers in Africa use on average around 20% of the fertilizer per hectare that is used by a European farmer, both because fertilizer is around four times as expensive and because there is none available.⁽²¹⁷⁾

North India, especially the Punjab, has benefited greatly. Because the revolutionary techniques are capital intensive (which means that the initial investment is high), only relatively wealthy farmers or landowners can implement them in any case.⁽²¹⁸⁾ Only the Punjab province in India, which was relatively well off beforehand, seems to have reaped real benefits from the green revolution. This feat has allowed India to triple wheat production between 1964 and 1979, and India is now self-sufficient in wheat.⁽²⁵⁾

Fertilizer application does relatively more good in India than in the United States, since the smaller the energy expenditure to begin with, the greater the incremental results. Those relatively few wealthy farmers in India have caused fertilizer use in India to skyrocket; 18 times more is used now than in 1960. The United States and India have roughly the same cropland area: The United States still uses 4 times the nitrogen (8.3 to 2), over 8 times the phosphate (5.0 to 0.6), and over 14 times the potash (4.4 to 0.3) that India does. This spectacular increase in fertilizer use is not limited to India; fertilizer use by LDCs doubled between 1972 and 1982⁽²⁰²⁾ and has grown even more since then.

About 125 billion m³ of natural gas is flared—or burned off—each year in the Persian Gulf, North Africa, Nigeria, and Venezuela, so there is a large potential fertilizer supply.⁽²¹⁹⁾ The gas flared in the Middle East is not really likely to become available any

time soon, however, because it requires expensive installations to produce fertilizer from gas, and there is no reason to expect the cost of fertilizer to decline if it did become available.

Phosphates are necessary to plant and animal growth. Energy is transferred in a living organism by the compound ATP, a phosphate. Most phosphate is mined in Morocco and in Florida (which was once part of Africa).

One consequence of fertilizer application is increased soil acidity. In temperate zones, it is known that a mixture of organic fertilizer (manure) and inorganic fertilizer gives the optimum yields.⁽²¹¹⁾ It is not clear whether this is also true of tropical soils. A clear difference between temperate and tropical soils is the ability of temperate soils to supply soil organic matter over long periods of time. On the North American Great Plains, the first half century of farming caused a loss of half the organic matter in the soils, while within 2 to 5 years tropical soils will have degraded to the point that cultivation cannot be sustained.^(43,209) In both climatic zones fertilizer application increase yields, but the fertilizers in the tropics could not restore the productivity that existed before the tract had been burned.⁽²⁰⁹⁾ According to the United nations, “[e]xcess levels of nitrogen can reduce plant diversity by enhancing the growth of plants best able to utilize it at the expense of others.”^(220,221) Species change to those that have litter that decomposes more quickly.^(88,222)

Another consequence of overfertilization is water quality degradation and nitrogen and phosphorus pollution. In my little Ohio town we suffer from high levels of fertilizer in our drinking water during planting season. The water tastes different, and measured levels of pollutants rise (even if not to “dangerous” levels). Nitrogen and phosphorus stored in ecosystems has increased substantially since agriculture has turned to chemical

fertilization.^(87,88,91-93,199,223-225) Several studies have shown phosphorus accumulation in soils of ~10 kg/ha/yr in Georgia and ~ 13 kg/ha/yr in Europe.⁽²²⁵⁾ Ref. 225 estimates preindustrial world phosphorus flux at 1 to 6 million tonnes; this grew to 10.5 to 15.5 million tonnes currently. Accumulation of fertilizer in upland soils increases environmental stress through its subsequent runoff.⁽²²⁵⁾

Ecosystems buffer the amount of fertilizer released, and the history of particular sites dictates how much nitrogen is released into groundwater.⁽²²⁶⁾ It does seem that, overall, the greater the amount of nitrogen applied to the soil, the correspondingly greater amount of nitrogen shuffled into nearby rivers.^(43,227-229) The smallest streams were most efficient at removing nitrogen.⁽²²⁵⁾ The huge amounts of nitrogen and phosphorus carried off soils eventually cause eutrophication (excessive production of algae, with consequent dieoff, oxygen depletion, and noisome smells in lakes caused by phosphorus) and decrease in marine production on the coast (the Gulf of Mexico's "dead zone" near the mouth of the Mississippi caused by nitrogen).^(43,225) Nitrogen has loomed larger as a source of acidity in surface waters, as measured at Hubbard Brook Experimental Forest, for example, since the Clean Air Act helped reduce sulfur emissions.⁽⁸⁸⁾

Also, as mentioned in Ch. 13, nitrogen oxides cause forest soil degradation.^(87,223) (It should be mentioned that about 20 Tg [20 thousand tonnes] of nitrogen comes from fossil fuel emissions; it is not all caused by agriculture.⁽²³⁰⁾) The collapse of the Baltic Sea cod resource is seen as a consequence of excess nitrogen release.⁽²²⁷⁾ An experiment on a Minnesota grassland found that addition of nitrogen fertilizer decreased the grassland's diversity. Plants that stored the most nitrogen and carbon in the soils were most vulnerable. So prairie is most vulnerable to ecosystem disruption due to fertilization.⁽²²⁹⁾ And as we have mentioned above, soils are used up by most agricultural methods. One special problem is the "pulse" nature of nitrogen fertilizer application, and its

asynchronization with plants' needs. It is estimated that because of this lack of synchrony, 40 to 60% of the applied fertilizer is unused or lost.⁽⁴³⁾ Overall, only one-eighth of the fertilizer applied by farmers "entered human mouths," in Galloway et al.'s apt turn of phrase.⁽⁸⁷⁾

Socolow points out the disadvantages of this massive fertilizer release by farmers: "Excess fixed nitrogen, in various guises, augments the greenhouse effect, diminishes stratospheric ozone, promotes smog, contaminates drinking water, acidifies rain, eutrophies bays and estuaries, and stresses ecosystems." Socolow does not even mention the health effects outlined in Ch. 14 as consequences of nitrogen emission through combustion. According to Socolow it may be possible, on the other hand, that the increase in the amounts of nitrogen fixed into soils could result in "transferring significant amounts of carbon from the atmosphere to the biosphere, and mitigating global warming."⁽²³¹⁾ Others are skeptical.

It has only recently been recognized that disruption of the nitrogen cycle is a big, and "growing" problem.⁽²³²⁾ "There is a growing consensus among researchers that the scale of disruption to the nitrogen cycle may have global implications comparable to those caused by disruption to the carbon cycle," says a United Nations environment report.⁽²¹⁹⁾ Some 60% of streams in America have nitrate levels (from fertilizer runoff) above the "background" level of 1 mg/L (1 g/m³).⁽²³²⁾ About three-quarters of the nitrogen that is problematic comes from agricultural practices (NO_x, which is also a problem, comes from combustion). Nitrogen found in rivers as dissolved inorganic nitrogen has increased by a factor of 2 to 4.⁽²³³⁾ Each piece of the nitrogen problem has been considered in isolation, rather than as part of a larger phenomenon. It appears that an international body on the issue might be set up (patterned after the IPCC) to deal with the global problem as a global problem, rather than a series of isolated problems.⁽²³²⁾

One possible source of reduction in nitrogen emissions is in the mismatch between the one-eighth of fertilizer that ends up being eaten and the other seven-eighths.⁽⁸⁷⁾ While some nitrogen inevitably escapes to the atmosphere and water, and crops typically have 30 to 40% of the nitrogen applied as part of their structure,⁽²³⁴⁾ much is used in animal husbandry. Animals are roughly 25 to 40% efficient at utilizing the nitrogen they are fed (on top of the losses of raising grain to feed them).⁽²³⁵⁾

Eliminating or reducing dependence on animal meat would greatly reduce the emission of nitrogen by agriculture.^(87,230) In fact, if the developed world adopted the Mediterranean diet, much energy and fertilizer would be saved.⁽²¹²⁾ Galloway et al.⁽⁸⁷⁾ quantify this: “if the US population adopted a Mediterranean diet of approximately 6.3 kg meat per capita per year (about one-seventh of the supply in the United States), total inorganic N fertilizer consumption would decrease to about 6.9 Tg N per year by 2030—a 65% decrease.”

There are other steps that could decrease reliance on chemical fertilizers. One example is to make crops more efficient at using nitrogen. Maize crops in the U.S. are 36% more efficient than they were a mere two decades ago.⁽²²³⁾ Better monitoring of individual soils can allow better matching of nutrient supply and demand, both on the ground and at the right time.⁽²²³⁾ Roy et al. suggest several measures, the most important being more utilization of biological nitrogen fixation (a no-cost measure, very important in many regions of the world).⁽²³⁶⁾

Better use of manure is also important, for two reasons. First, there is substantial “natural” nitrogen in wastes, and about 100 million tonnes are excreted every year (three-quarters from domesticated animals).⁽⁸⁷⁾ Second, the human waste, if not treated, can

adversely affect water quality both because of the spread of fecal bacteria and because it adds so much nitrogen to the watershed. Only about 9 million tonnes of human waste is treated.⁽⁸⁷⁾

Irrigation

The ancients used systems of canals underground (“qanats,” “qarezes,” or “foggaras” in various languages) to distribute water in arid regions; qanats originated in Persia.⁽²³⁷⁾

Some of the consequences of irrigation are waterlogging (too much water in the root zone) and increased salinity in the soil.^(43,238,239) Many of the productive croplands in the Fertile Crescent were ruined by salt that is brought up by capillary action (see Ch. 13) due to ancient farming practices. Even those longterm experimental stations in temperate climates have not been able to give good advice on the best methods of irrigation there, as was also pointed out in Ch. 9. Salinity affects perhaps 19% to 24% of all irrigated cropland.^(238,240,241) It is estimated that an area of Australia the size of Ireland, 17 million hectares, will have been lost to salinization by 2050 because of farming customs unsuited to the land.⁽²⁴²⁾ Global irrigated land area affected by secondary salinization is estimated at 47.7 million hectares.⁽²⁴¹⁾

Water is necessary for plant growth; every liter of water transpired produces about 2 g of biomass (that is, the more water, the greater the production).^(238,239) In semidry areas, irrigation is needed for plant growth. The total amount of irrigated land is estimated at about 250 million hectares worldwide.⁽²³⁸⁾ Only 17% of the world’s cropland is irrigated, but because it allows double cropping, irrigated land produces about 40% of the world food supply.⁽²³⁸⁾ About 2500 km³ of water is used for irrigation each year.

The growth of irrigated land appears now to be on the upper part of the logistic curve, as the amount gained each year has steadily decreased over the past few years. There is a question as to whether irrigation can be sustainable, particularly if the water comes from aquifers in dry areas (the Ogallala Aquifer, for example, could have sustained small amounts of pumping over long periods of time, but the exponential growth in pumping resulted in plummeting water table, that is, exhaustion, in some parts of the aquifer system). And, if the water requirements of plants do not change much, to feed the world of the future will require about doubling the volume of water used each year, to 5000 km³ (already agriculture uses well over half the fresh water withdrawn from freshwater lakes and rivers).^(238,239)

Erosion

There's nothing new about erosion, or fighting its effects. The Greeks did it first (just kidding—partly).⁽²⁴³⁾ They did cut down their forests, just as the early Italians did, and they did suffer from erosion. Small checkdams were built over two thousand years ago to trap soil that otherwise would have washed down gullies. Mexican erosion has been documented. The Incas were master engineers who overcame erosion as they took over areas by conquest, for example by planting and maintaining *Alnus acuminata* in the Patacancha Valley to reduce erosion and constructing terraces.⁽²⁴⁴⁾ They used the sediment from canals they dug for irrigation to raise and fertilize fields in Peru.⁽⁷⁾ Modern Peruvians have in some cases rebuilt the irrigation system, with salutary results.⁽²⁴⁵⁾

Europe has suffered extreme deforestation over the ages. Plato blamed the barrenness of his native Greece on ruthless deforestation.⁽²⁴⁶⁾ The water storage capacity of denuded hills is much smaller than that of the same hills when they were covered with forest. Soil erosion consequently increases, as does the frequency and severity of floods. The story

of more and more serious floods in Florence over the past half millennium seems to rest with the denudation of the once-timbered hills.⁽²⁴⁷⁾ In Algeria, the rainy season now washes some 80,000 acres of land cover out to sea.⁽²⁴⁸⁾

Agriculture in the temperate regions involves using up the organic matter in the soil itself. Prairie farming in the Midwest reduced the soil's organic content by half over 25 to 50 years; a comparable loss in the tropics is 5 years, as we mentioned above.^(43,209) In India, the intensive rice and wheat characteristic of "green revolution" success led to rapid loss of soil quality and increased plant health consequences.⁽⁴³⁾

Recent agricultural practices maximize the likelihood of wind erosion. Lubbock, Texas, the worst place for dust in the United States, averages 150 hours of blowing dust per year.⁽²⁴⁹⁾ According to Pimentel et al., "soil erosion is a self-degrading process—as erosion removes topsoil and organic matter, runoff intensifies and erosion worsens, only to be repeated with more intensity during subsequent rains."⁽²³⁹⁾ As much as 85% of U.S. rangeland, 685 million acres, is said according to a United Nations Environmental Program report to be becoming desert because of overgrazing and consequent salinization.⁽²⁵⁰⁾

In many cases, because green revolutionary techniques favor the large-scale landowners who are concerned with immediate profit rather than the welfare of the land, poor farming practices result as small-scale landholders are bought out or tenants are evicted. This is partly responsible for the worldwide problems of erosion. It is estimated that in the Third World, an average of about 16 tonnes per hectare (43 tons per acre) of soil is being lost.⁽²⁵¹⁾ Overall, half a billion hectares of cropland have been affected in some way by wind erosion, and a billion by water erosion, with 400 million hectares of cropland physically degraded.⁽²⁵²⁾

Of course, poor agricultural practices antedate the green revolution. For example, huge amounts of African dust come westward each year. Some dust contains the fungus *Aspergillus sydowii*, which has killed tropical corals in the Caribbean.⁽²⁵³⁾ It is estimated that crop losses in Africa from the history of erosion total 18 Mt,⁽²⁴¹⁾ and Africa has experienced significantly higher soil erosion rates than other areas.⁽²⁵⁴⁾

Even in the United States, erosion is a problem. Erosion under normal tillage can exceed 100 t/ha (and in the Palouse region of the Pacific Northwest, 225 t/ha).⁽²⁵⁵⁾ Often, application of large amounts of fertilizer can compensate to some extent for loss of soil. It is estimated that about 3 Gt of sediment runs off the land each year worldwide, 60% from agricultural land.⁽³⁵⁾

Agriculture is the prime cause of this land degradation. There is an estimated 10-100 t/ha/yr loss on cultivated land around the world, about 10-fold soil formation rates, which is about 0.3 t/ha/yr.⁽³⁵⁾ In the United States, the average rate of soil loss is 16.5 t/ha/yr; in the U.S. Midwest, it is higher, 35.6 t/ha/yr; and in the southern high plains, it is 51.5 t/ha/yr.⁽³⁵⁾ The 1982 National Resources Inventory found 44% of the nation's cropland losing topsoil in excess of its tolerance level; perhaps a third of cropland topsoil has been lost already.⁽²³⁾ Our rivers carry about 22 Gt of topsoil into the oceans each year (an estimated 8 Gt was lost from soil in preagricultural America).⁽²⁵⁶⁾ If such erosion continues, U.S. agriculture could experience a 10% decrease in productivity over the next century.⁽²⁵⁷⁾ World crop losses total perhaps 270 Mt, about 9% of world production.⁽²⁴¹⁾

The average soil loss in China is gauged at 40 t/ha/yr.⁽³⁵⁾ As a result, the Huang He (Yellow River) is depositing 11 Gt of soil each year into the ocean.⁽²⁵⁸⁾ Elsewhere, 1 Gt of Ethiopian soil per year washes down from the highlands.⁽²⁵⁸⁾ The problem of soil

degradation is clearly worldwide. Soil chemical degradation is estimated to total 239 million hectares (43 million hectares strongly or extremely degraded).⁽²⁵²⁾

There are two main avenues for erosion—from water, and from wind. It is known that erosion was much higher in the dust bowl era. There is some controversy about the current size of the effect, at least in the United States (the estimates given above are deemed overstated).^(259,260) At Coon Creek, Wisconsin, yearly erosion rates for the period 1975-93 were found to be only about 6% of what occurred in the period stretching from the 1850s to the 1930s. Sediment is stored and released in such a way as to keep the amount released roughly constant from year to year.⁽²⁵⁹⁾ The lesson from Refs. 256 and 258 is that sediment yields are relatively unchanging, no matter that erosion changed by dramatic amounts.

Erosion has certainly plummeted as frequent plowing of the soil has lessened and no-till agriculture has taken greater hold. This happened over 50 years ago, but became especially widespread in America in the 1980s.⁽²⁵¹⁾ An example is those vastly smaller erosion rates measured at Coon Creek, Wisconsin, cited in the preceding paragraph, where agricultural advances were made starting in the 1930s as a result of the dust bowl experience. Another advantage of no-till agriculture for the farmer is in savings in time spent and for fuel and wear and tear on farm vehicles.^(261,262) In Ohio, for another example, the land area of farms using conservation tillage in the Maumee and Sandusky River watersheds feeding into Lake Erie leaped tenfold (to half) between 1985 and 1995.⁽²⁶²⁾ Since less soil was disturbed, apparently less fertilizer ran off: riverine nitrogen levels decreased by ~ 15% and phosphorus levels decreased by ~ 48% (but nitrate levels went up ~10%).⁽²⁶³⁾ In addition, there is less need for farmers using conservation tillage to hire help, so the farmer saves in decreases in wages paid, too. A similar increase was

seen in Iowa; over half the planted land is subject to conservation tillage.⁽²⁶²⁾ About one-third of all American farmland is currently conservation tilled.

Part of the American success with no-till farming is that farmers leave substantial organic material on their fields, typically 35%. Crop residue lessens weed invasion and helps conserve topsoil by lessening the effects of rain (it shields the soil and also absorbs some of the water and releases it over long periods).^(43,250) Soil that isn't tilled experiences 90% lower erosion than equivalent tilled fields.^(43,264) In addition, there is less interference with soil biota with no-till, less destruction of the decomposers, and enhanced availability of soil nutrients.⁽⁴³⁾

It is difficult to export this change, however, to countries that are undeveloped. Where animals are used for tilling, the technological hurdle to seeding by drilling is enormous. There is more of a chance in Europe (where it has made headway) and in more developed (and mechanized) parts of the world. Farmers in Argentina have found their water use much lower when they were persuaded to switch to no-till agriculture.⁽²⁵¹⁾ Even so, zero-tillage—combined with the use of green manures, herbicides, or both—has spread to 20 million hectares in southern Brazil and Argentina.⁽²⁶⁵⁾ Possibly by chance, Argentina and Brazil have registered solid growth rates in cereal production in the 1990s, much greater than the other countries in Latin America.⁽²⁵⁴⁾ It is also spreading in the rice-wheat zone of South Asia.⁽²⁶⁶⁾

While government support may be helpful in increasing conservation tillage and other sustainable measures,⁽²⁶³⁾ it has not been the main driver. The Dutch tried a scheme to protect diversity in the face of its intensive agriculture using EU monetary subsidies. The project was a great disappointment: “Management agreements were not effective in protecting the species richness of the investigated species groups: no positive effects on

plant and bird species diversity were found.”⁽²⁶⁷⁾ The EU does support the idea of sustainability, though in this case, ineffectively. Only Cuba and Switzerland have *national* policies for sustainable agriculture.⁽²⁶⁵⁾

Lessons to be learned

The mission of exporting North American agricultural techniques ought to be considered carefully in light of these adverse ramifications. Will “smart farms” work elsewhere?⁽²⁶⁸⁾ The “intelligent systems” are computers that do much work without continuous supervision. In the developed countries cheap sensors and microchips have made costs reasonable. Robotic “hoes” and milkers are under development.⁽²⁶⁸⁾ The future farmyard may look very different from the past.

We must consider which sort of research results are suitable for export to underdeveloped countries. Can irrigation be expanded? At what price? Can soil be preserved? At what price? Can local customs be addressed? At what price?

Also, although it is economically advantageous for developed countries to use fossil fuel in the agricultural system to free human labor for other purposes, this is probably not true in developing countries. LDCs would need to find new jobs for the large numbers of newly landless, untrained laborers put out of work by mechanization.

Further, as discussed in **Extension 24.3, *Genetic modification and biotechnology in agriculture***, we need to make certain that the changes in the genome be made in such a way as to complement the practices and needs of poor farmers throughout the part of the world where people continue to go to bed hungry.