CHAPTER 10

Food for Life

What we are undoing — Chemically dependent exhaustion — Wholly made of oil — Sustainable food and fiber — Productivity of place — When food needs passports — Rice and ducks — Dirt and climate — Unfarming — Chock-full of life

BY ONE MEASURE — THAT OF RAW OUTPUT — THE INDUSTRIALIZATION OF farming has been a triumph of technology. In the past half century, production of major crops has more than doubled; that of cereals has tripled. In the past thirty years, the number of food calories available (even if not provided) to each person on earth has risen 13 percent, despite a rapidly growing population. Almost all of the world's increase in food output has been the result of higher-yielding, faster-maturing crops, rather than from farming more land, because essentially all good land is already being cultivated. Although 1 to 4 billion more acres are potentially arable worldwide, mainly in developing countries, that land would cost more to irrigate, drain, and link to markets than crop prices now justify. Intensification is therefore conventionally considered the only feasible way to continue expanding world food production to feed the growing population.[1]

Intensive agriculture came to America in stages. It began with a mixture of brash and courageous persistence and ecological ignorance. As Wendell Berry put it, "When we came across the continent cutting the forests and plowing the prairies, we have never known what we were doing because we have never known what we were undoing." With pride and without misgivings, vast and complex native ecosystems were converted to equally vast expanses of wheat and sorghum, corn and soybeans.

People first filled and then departed the landscape. Engine-driven machines had essentially finished replacing draft-horse and human labor by the 1950s. Hybrid corn and other highly bred crops requiring synthetic fertilizers and pesticides replaced well-established varieties.

Increasingly, farmers' traditional knowledge and agrarian culture were displaced by a managerial and industrial culture — a profound shift in the foundations of society.[2] Today only one percent of Americans grow food for the rest; 87 percent of the food comes from 18 percent of the farms. Most farms have in effect become factories owned by absentee interests;[3] and ownership not only of farms but of such upstream and downstream enterprises as seed and chemical suppliers, meat-packers and grain merchants, is becoming rapidly more concentrated, leading to all the abuses that one might expect. Farmers represent about 0.9 percent of GDP, but those who sell to and buy from farmers — the entire food-supplying system, directly and indirectly — have a share about 14 times as large, and their market power tends to squeeze out small, independent, and diversified farmers.

A similar pattern of development is transforming agriculture around the world. Experts in this "Green Revolution" emphasize high-yield seeds, biocides, irrigation, and nitrogen fertilizers. Irrigation by itself accounted for more than half the increase in world food production from the mid-1960s to the mid-1980s. During the years 1961–96, nitrogen fertilizer use also rose 645 percent.[4] By 1991, the resulting level of artificial nitrogen fixation exceeded the low estimates and approximated half the midrange estimates of total natural nitrogen fixation on earth.[5]

Almost unnoticed in the figures charting the rise of agricultural output is that actual returns on agricultural intensification are diminishing. The president of the Rockefeller Foundation, among the world's leading authorities on the green revolution, warns that at least in developing countries, "Recent data on crop yields and production . . . suggest a degree of stagnation which is worrying."[6] Equally disquieting findings indicate more volatile yields and "increasing production problems in those places where yield growth has been most marked." The effects of any shortfalls in yield, and of all the increased inputs needed to sustain or increase yield, are being greatly amplified because of rapid growth in the fraction of the world's cereals (currently one-third) being fed to livestock, an inefficient use of grain. Animals turn only about 10–45 percent of grain inputs into meat — 5 percent or less in some cases.

Modern American agriculture has certain features uncomfortably similar to those of the Soviet economy. That system generated the outputs that planners considered necessary by rewarding participants for how much they manufactured (or, often, *consumed*), not how efficiently they produced. Similar distortion is caused in the United States by input subsidies, price supports, production quotas, and use-it-or-lose-it western water laws. Mechanisms like peanut permits, milk price supports (which were in force until 1999), sugar quotas, and similar schemes are attributes of overcentralized planning and unadaptive bureaucracies. Although U.S. agricultural and water systems are slowly becoming less rigid, almost all conventional sources of farm information, including Extension services and the land-grant universities, still offer the conventional party line — promoting intensive, chemically dependent production, which is profitable mainly for the input suppliers.

Industrialization, and developments like the heavily subsidized interstate highway system, enable food to be transported great distances — averaging 1,300 miles in the United States — and processed in ever more elaborate and costly ways. The food sector uses about 10–15 percent of all energy in the industrialized countries, and somewhat more in the United States. Despite improving efficiencies, about two-fifths of that energy goes to food processing, packaging, and distribution, and another two-fifths to refrigeration and cooking by final users. Only one-fifth is actually used on the farm — half of that in the form of chemicals applied to the land.[7]

American farms have doubled their direct and indirect energy efficiency since 1978. They use more efficiently manufactured fertilizer, diesel engines, bigger and multifunction farm machinery, better drying and irrigation processes and controls, and herbicides instead of plowing to control weeds. Yet U.S. farming still uses many — perhaps ten — times as much fossil-fueled energy in producing food as it returns in food energy. Our food, as ecologist Howard Odum remarked, is made wholly of oil with oil left over.

The superficial success of America's farms masks other underlying problems. A third of the original topsoil in the United States is gone, and much of the rest is degraded. Soil productivity in the semiarid Great Plains fell by 71 percent just during the 28 years after sodbusting.[8] Notwithstanding some recent progress in reviving soil conservation efforts,[9] topsoil is eroding very much faster than it is being formed. Growing a bushel of corn in conventional ways can erode two to five bushels of topsoil. In the 1980s a dumptruck-load of topsoil per second was passing New Orleans in the Mississippi River.[10] A decade later, 90 percent of American farmland was still losing topsoil faster — on average, 17 times faster — than new topsoil was being formed, incurring costs projected at $44 billion over the next 20 years.[11] In many developing countries, matters are even worse.

A more subtle decline than physical soil loss, but no less dangerous, is the invisible loss of the soil's organic richness. The ability of soil bacteria, fungi, and other tiny organisms to cycle nutrients, fight disease, and create the proper soil texture and composition to protect roots and hold water is essential to soil health. Texture matters: Coarse particles are needed for air spaces, fine ones for water retention and surface chemistry. So does humus: Of a good soil's 50 percent that is solid matter, the one-tenth that is organic content can hold about as much water and nutrients as the mineral nine-tenths.[12] Long-term experiments in wheat/fallow systems in the semiarid Northwest found that except when manure was applied, the soil's levels of organic carbon and nitrogen have been declining steadily since the early 1930s, even in fallow seasons.[13] Perhaps a tenth of on-farm energy use is already required to offset such soil problems as the degradation of nutrients, water-holding capacity, and hence crop productivity caused by erosion. As more soil quantity and quality are lost, that penalty — perhaps already reducing U.S. farm output by about 8 percent in the short term and 20 percent over the next 20 years[14] — will rise. Most ancient civilizations collapsed because they destroyed their topsoil,[15] but few policymakers seem mindful of that history. After a century of farming in Iowa, the place with the world's highest concentration of prime farmland, the millennia-old prairie soil, laments Evan Eisenberg, "is half gone. What is left is half dead, the roiling, crawling life burned out of it by herbicides, pesticides, and relentless monocropping. Petrochemicals feed its zombie productivity. Hospitable Iowans assure their guests that the coffee is made from 'reverse-osmosis' water, since agricultural runoff has made the tap water undrinkable."[16]

Agriculture uses about two-thirds of all the water drawn from the world's rivers, lakes, and aquifers. Irrigation waters only 16 percent of the earth's cropland, three-fourths of it in developing countries, but produces 40 percent of the world's food. In many key areas, groundwater is being overpumped and depleted — mined out just like oilfields. In the United States, about one-fourth of the groundwater pumped for irrigation (which is a third of the total withdrawal) is overdrafted. Salting and other side effects of poor irrigation and drainage management have already damaged more than a tenth of the earth's irrigated cropland, some irretrievably. Since 1945, moderate, severe, or extreme degradation of these and other kinds has already affected nearly 3 billion acres, roughly the area of China plus India. Four-fifths of those acres are in developing countries, where even governments, let alone farmers, lack capital to repair the damage, and nearly half the acres have too little water for ready restoration methods to work.[17] Of the one-ninth of the earth's land that was considered arable in 1990, little remains really healthy, most is stressed, and losses are generally accelerating.

Degradation of the natural capital that is the foundation for farming has been found to be decreasing overall farm productivity in almost all farm systems studied worldwide, including every irrigated Asian rice system. This loss continues regardless of the technological inputs that have been applied to alleviate it.[18] In many areas, tripled fertilizer use and new crop breeds have been necessary just to hold modern rice varieties' yields constant. The situation is analogous to what happened in U.S. forestry during the years 1970–94. Logging increased its labor productivity by 50 percent, but overall (total factor) productivity fell by 30 percent, because technological improvements in harvesting trees couldn't compensate for reduced accessibility and quality of the forest resources.[19]

Clear-cutting at the microscopic level of DNA may be creating the gravest problem of all. The world's farming rests on an extraordinarily narrow genetic base. Of the 200,000 species of wild plants, notes biogeographer Jared Diamond, "only a few thousands are eaten by humans, and just a few hundred of those have been more or less domesticated."[20] Three-quarters of the world's food comes from only seven crop species — wheat, rice, corn, potatoes, barley, cassava (manioc), and sorghum. Nearly half the world's calorie and protein intake eaten as food, not as feed, comes from only the first three of these crops.[21] Adding one pulse (soybeans), one tuber (sweet potato), two sugar sources (sugarcane and sugar beet), and one fruit (banana) to the list of seven would account for over 80 percent of total crop tonnage. In every one of these key crops, genetic diversity is rapidly disappearing as native habitats are destroyed. In this industrialized farming system, the most productive and narrowly specialized varieties typically become mass-produced and crowd out their diverse cousins. India, for example, is in the final process of replacing its 30,000 native varieties of rice with one super variety that will do away with centuries of botanical knowledge and breeding.[22]

Perhaps worse, seed banks that store and preserve thousands of different varieties of common and rare plants are being neglected — a consequence of government budget cuts — so their irreplaceable germ plasm is becoming nonviable.[23] Most seed companies have been bought by agrichemical companies. Not surprisingly, these companies are seeking to make themselves the sole lawful proprietors of the world's legacy of plant diversity — if not by purchase, then by manipulation of intellectual-property laws to include the traditional "free goods" of nature, or by increasingly frank grabs for legal monopoly. Such efforts to ensure that food cannot be grown without commercial control might be attractive to investors, but it may not be a good long-term strategy for anyone's survival.

Crops are becoming more specialized for other reasons, too. Prospective income from single cash crops is overwhelming local subsistence traditions, which favored varied local production to meet balanced nutritional needs. Agricultural professionals tend to encourage producers to focus on single commodities rather than pursuing a wide range of goods. Farmers, having no safety margin for experimentation, are conservative about trying new products or techniques. Land-tenure practices and complex sociological issues may create further artificial incentives for cash crops, ecological simplification, intensive production, and short-term thinking. Only the increasing need to farm in such diverse and marginal conditions as dry regions may create pressure to diversify into such promising crops as the neglected major grains (quinoa, amaranth, triticale, millet, and buckwheat) and beans (winged, rice, fava, and adzuki).[24] These are only the beginning: Subsaharan Africa alone contains over 100 such forgotten grains and more than 2,000 forgotten crops; only a handful are receiving significant research.[25] In hindsight, it will seem odd that such attractive crops were so long neglected.

The single-crop mentality both ignores nature's tendency to foster diversity and worsens the ancient battle against pests. Monocultures are rare in nature, in part because they create paradises for plant diseases and insects — as science writer Janine Benyus puts it, they are like equipping a burglar with the keys to every house in the neighborhood; they're an all-you-can-eat restaurant for pests. Disease already damages or destroys 13 percent of the world's crops, insects 15 percent, and weeds 12 percent; in all, two-fifths of the world's harvest is lost in the fields,[26] and after some more spoils, nearly half never reaches a human mouth.[27] The conventional response of dousing infested plants and soil with biocides seemed promising at first, but using technology to combat natural processes hasn't worked. Around 1948, at the start of the era of synthetic pesticides, the United States used 50 million pounds of insecticides a year and lost 7 percent of the preharvest crop to insects. Today, with nearly 20-fold greater insecticide use — almost a billion pounds a year, two-fifths more than when Rachel Carson published *Silent Spring* in 1962 — the insects get 13 percent, and total U.S. crop losses are 20 percent higher than they were before we got on the pesticide treadmill.

To be sure, pesticides can be used more rationally. In the former East Germany, pesticide applications were reduced by about tenfold, with better results and about tenfold lower costs and risks, by nationwide installation of insect traps. Frequent inspections to see what pests were actually present replaced spraying for everything that might be. But the problem is more fundamental than one of mere measurement and management. The whole concept of pesticides has a basic flaw: In this game of "crops and robbers,"[28] the house always wins. Insects' huge gene pool, quick evolution, and very short reproductive cycles enable them to adapt and become resistant to our most powerful poisons — as more than 500 species have already done[29] — faster than we can invent new ones. Worse, by disrupting competition between species and by killing their natural predators, pesticides often transform previously innocuous insects into nasty pests.

Monocultures also leave most of the rich diversity of soil biota unemployed. Nature doesn't waste resources supporting underutilized organisms, so if they have nothing to do, they die. Treating soil like dirt — not as a living community but as a sterile medium on which to spread out leaves in the sun — makes the soil barren and unable to provide its natural services. Pathogens and insects with free habitat and no competition then flourish. California vintners have suffered phylloxera infestations on sprayed vineyards but generally not to date on organically grown ones. Some growers believe that phylloxera may not be an inevitable grapevine pest so much as a symptom of unhealthy soil.

Organic farmers, in contrast, rely on healthy soil, careful observation, and controllable levels of pests to raise their crops. In the organic, ecosystem-based view, the complete eradication of pests is a tactical blunder, because a healthy system needs enough pests to provide enough food to support predators so they can hang around and keep the pests in balance.[30] Some organic farmers also use biologically derived substances to cope with their pest problems. But the best-known of these compounds, the insect-specific family of natural *Bacillus thuringiensis* toxins, may become ineffective because agrichemical companies are putting Bt-making genes into common crops for universal use. This may appear to be a sound strategy — genes instead of pesticides, information instead of mass. But over time, and maybe sooner than expected,[31] the prevalence of Bt in the ecosystem will select for insects resistant to it and make the compound useless or, worse, begin to affect nontarget species. By 1997, eight insect pests in the United States had become resistant to Bt,[32] for the same reason that penicillin is now impotent against 90 percent of the staphylococcus infections and many of the other germs that it used to control. A coalition of organic farmers, consumers, and public-interest groups has sued the EPA to rescind all Bt-toxin transgenic crop registrations.

Monocultures' chemical dependence requires enormous amounts of fertilizers to make up for the free ecological services that the soil biota, other plants, and manure provide in natural systems. Healthy soil biota can provide about tenfold better uptake of nutrients, permitting the same or better crop yields with a tenth the application of soluble nutrients.[33] But having become dependent on ever-greater amounts of synthetic inputs, Americans consume more than 60 million metric tons a year of such agriculturally applied minerals as phosphorus and potash.[34] Alongside the average American's daily food sits the ghostly presence of nearly a half pound of synthetic nitrogen fertilizer used to grow it. Most of those chemicals are wasted, running off the soil to flow onto other land or into surface and groundwaters. Agriculture is America's largest, most diffuse, and most anonymous water polluter. In other respects as well, industrialized agriculture is increasingly presenting threats to public health.[35]

The growing volatility of weather and the potential for shifts in climate will only worsen the pressure on overspecialized crops. Finely tuned by a half century of breeding and lately by genetic engineering, they cope poorly with changes in such conditions as temperature, sun, and moisture. Genetically diverse natural populations in healthy ecosystems, in contrast, have millions of years' design experience in coping with surprises. The brittleness caused by shifting from resilient natural systems to specialized artificial ones could prove catastrophic as crops encounter conditions quite different from the stable ones assumed by their breeders and genetic engineers.

For economic, health, and environmental reasons, a major overhaul of current agricultural production methods[36] is needed to achieve adequate, acceptable, and sustainable food and fiber supplies.[37] Many practitioners in both developed and developing countries are therefore adopting new or modernizing old methods of agriculture that are more clearly based on natural models. Their overhaul doesn't involve just doing the same things differently, because the problem of agriculture cannot be solved within the mentality that created it. Rather, the new solutions are the result of whole-systems thinking and the science of ecology; they embody the principles of natural capitalism; they follow the logic not of Bacon and Descartes but of Darwin.

The innovations now emerging in agriculture are taking two complementary and interwoven paths. The less fundamental but more familiar path applies the first three principles of natural capitalism: It increases the resource and ecological efficiency of all kinds of farming, seeking new ways to wring more and better food from fewer resources, both through direct increases in resource productivity and through biomimetic, closed-loop, nontoxic practices. These are both encouraged by community-supported agriculture — an application of the third principle, whereby customers subscribe in advance to a particular farm's or cooperative's flow of food, typically organically grown. But in a deeper and even more promising break with industrial agriculture, some pioneers are also redesigning agriculture from scratch as an embodiment of the fourth principle — restoring, sustaining, and expanding natural capital. Their innovations go beyond conventional organic practices to create diverse forms of agriculture that are based, as geneticist Dr. Wes Jackson of the Land Institute in Salina, Kansas, says, "on nature's wisdom, not on people's cleverness"; that follow ecologist Aldo Leopold's dictum of tending "to preserve the integrity, stability, and beauty of the biotic community."

FARM-GROWN EFFICIENCY

Resource productivity on the farm — the first principle of natural capitalism, and the easiest to apply — comes from many small, simple applications of farmers' native inventiveness, as a few examples show. For instance, crop-drying, which is often needed to keep crops from mildewing, uses about 5 percent of direct U.S. on-farm energy. But in Kansas City, Kansas, in the 1980s the late Bill Ward invented a zero-energy way to dry grain in the silo.[38] He simply bored a hole in the top of the structure, atop which a hollow shaft connects into the hollow blades of a small windmill. As the prairie wind spins the blades, centrifugal force slings the air out the holes at the ends of them. The resulting vacuum pulls a slow, steady draft of air up through the grain from small, screened vents at the bottom of the silo. This gradually dries the grain — and evaporatively cools it, making any insects infesting it too sluggish to move and eat. This in turn means that no chemicals are needed to prevent mold or kill bugs.[39] Ward's process not only saves chemical costs but also keeps organically grown grain uncontaminated so it can fetch a premium price.

Many do-it-yourselfers have built effective solar hot-air dryers for fruits and vegetables, grains, herbs, and even lumber. But since crops are mostly water and often perishable, it may make more sense to bring the solar dryer directly to the fields. In the 1980s, Marcello Cabus, a Hispanic entrepreneur in Delta, Colorado, developed a semitrailer that unfolded into a complete fruit- and vegetable-processing and -drying plant. He'd drive it to any farm that had a distressed crop — perhaps ripe fruit that couldn't be gotten to market quite in time or couldn't command the desired price. The crop would be washed, peeled, sliced, and given any other necessary preparation. Spread on shallow racks and bathed in solar-heated rising air, the produce would dry to an exceptional quality. Backpackers, snackers, families who want to store food at home for emergencies, and people allergic to common sulfur-based preservatives — solar-air-dried food needs none — would pay high prices for such quality produce. And in countries like Korea, challenged to preserve nourishing food for the harsh winters, the method could greatly improve both farm income and public health.

The same innovations that save energy in houses can often be applied to livestock barns, too. The physical principles are the same; only the architecture and the occupants differ. Lighting chicken houses with compact fluorescent lamps instead of incandescents can increase a North Carolina chicken farmer's income by one-fourth. It even slightly increases egg production, perhaps by reducing overheating. Using big, slow fans instead of small, fast ones makes less noise, saves most of the fans' energy, and improves their reliability. Air-to-air heat exchangers can cleanly recover into fresh air 90-plus percent of the heat or coolth that would otherwise be lost in ventilation air. Insulation, weatherstripping, building orientation, and even simply making the roof the right color can greatly improve indoor comfort in a barn just as in a passive-solar house. Comfort, in turn, means healthier and more productive livestock.

Better buildings offer special advantages when crops are being grown under artificial conditions. The Netherlands uses seemingly cheap natural gas to grow about $0.7 billion worth of tomatoes per year — over 700,000 tons — in more than 3,800 acres of greenhouses.[40] Cold, cloudy Holland is not an obvious place to grow tomatoes. It takes over 100 times as much energy to produce them as the tomatoes actually contain. Over three-quarters of the fuel heats the greenhouse, and 18 percent goes toward processing, mainly canning. About two-thirds less energy would be needed to grow the tomatoes in, say, Sicily and *air-freight* them to Holland. Instead, Dutch tomatoes, most of which are not actually consumed there, are loaded into giant trucks that rumble across the continent to exploit slightly lower labor costs or laxer regulations, before being eaten or winding up in a tube of tomato paste.

If one really *did* want to grow tomatoes in Holland, it would surely make more sense to do so in passive-solar greenhouses so efficient that they burn no gas for heating. They would instead use not ordinary glass, through which heat rapidly escapes, but superwindows, like the passive-solar bananas grown at RMI's headquarters high in the Rockies. Individuals could even grow the tomatoes in a lean-to, a glorified cold-frame, or a big live-in "greenhome" like the New Alchemy Institute's "Ark" that grew crops year-round on Canada's cloudy Prince Edward Island, or, as at RMI, in their own living rooms. Some 15 percent of global food is already grown in cities. In China, urban farming in back gardens, on little plots, and on rooftops provides 85-plus percent of urban vegetables — more in Beijing and Shanghai — plus large amounts of meat and treecrops.[41]

Producing food more locally, whether indoors or outdoors, can greatly reduce the expenditures of transportation energy. A few years ago, frugal Germans were taken aback when Wuppertal Institute researcher Stephanie Böge revealed[42] that producing a cup of strawberry yogurt — a popular snack of which Germans eat 3 billion cups each year — typically entailed about 5,650 miles of transportation. The manufacturing process involved trucks crisscrossing all over the country to deliver the ingredients, glass cup, and finished product to, say, Stuttgart. Shipments from suppliers to processors to suppliers added a further 7,250 miles of transport — enough in all to bring the yogurt to Germany from New Zealand. There's nothing exotic about strawberry yogurt; it can be made in any kitchen from milk, strawberries, sugar, and a few other common ingredients. It's not obvious what advantage is gained by such extreme specialization and dispersion, which might not exist if transportation were unsubsidized. More localized production could enormously reduce transportation and probably yield a superior product.

As in industrial processes, better measurement and control systems are an inexpensive way to increase efficiency in farming. Substituting information for resources permits more intelligent management, results in more and better crops, and saves soil, time, water (as we'll see in the next chapter), and money. Instead of guessing how moist the soil is, what nutrients the crops have or need, how fast they're growing, or how many of what sorts of pests they have, farmers are beginning to use measuring devices to guide their day-to-day decisions. Some do this by remote sensing and satellite navigation equipment, monitoring and computer-controlling inputs to each part of their vast fields as they ride high in air-conditioned combines; others do it with the keen observation of a naturalist, focusing on leaves and soil from a distance of inches.

Because farms are (or used to be) natural systems, they offer major opportunities to combine the resource-productivity first principle of natural capitalism with the loop-closing second principle. Loop-closing design-integration strategies are the agricultural equivalent of industrial ecology or of a natural food web. The best of these systems reuse wastes in closed loops to improve the efficiency and resilience of the entire operation.

The most basic way to close loops is to reuse the wastes produced both on the farm and downstream in the food-processing industries. A typical Nebraska harvest season results in an accumulation of distressed grain — damp or otherwise below-grade. This waste could make enough ethanol to run a sixth of the state's cars for an entire year, if those vehicles were efficient enough to get 90 mpg, probably less than a first-generation Hypercar. With equally efficient cars, the straw burned in the fields of France or Denmark would run those countries' entire car fleets year-round. Similar waste exists in the form of nutshells in California, peach pits in Georgia, cotton-gin trash in Texas — that latter of a quantity adequate in the early 1980s to fuel with alcohol every vehicle in Texas. Most other organic wastes can also be usefully recovered and converted. Inedible vegetable oils can be cooked in a solar-heated catalytic device with wet or dirty ethanol or methanol to make esters that are better diesel fuels than petroleum diesel. Altogether, the diverse streams of farm and forestry wastes can probably provide enough sustainably grown liquid fuels to run an efficient U.S. transportation sector, without any further reliance on special fuel crops or fossil fuels. Across the United States today, more than 85 million tons of bio-based products and materials, valued at about $22–45 billion, are produced annually,[43] yet now most of these farm and forestry residues are wasted, benefiting neither the economy nor the soil.

When livestock wandered around in the manner for which evolution fitted them, they deposited their dung back on the land. But modern intensive raising of confined livestock turns those valuable nutrients into waste and their free redistribution into a gigantic disposal headache. Enter a Canadian building innovation — "hoop structures" within which contented pigs run around freely and nest on deep, absorbent beds of straw or cornstalks. This design is a pig shelter, not a pig jail. Unlike standard rigid barns, which cost ten times as much, the lightweight fabric cylinders are thermally passive: cooled by breezes through their open ends, heated even through northern winters by the composting bedding and the hogs' body heat. Even more important, instead of huge, foul-smelling, anaerobic lagoons of liquid manure, hoop structures yield dry manure ready to spread on the fields. The valuable nutrients are shielded from rain and runoff. In Iowa alone, more than one thousand covered "hoop houses" producing 3 percent of Iowa's hogs were successfully built just during the years 1995–98 — a little-noticed but important counterrevolution to gigantic concrete hog factories, much better both for the animals and for the farmers' bottom line.[44]

What if agricultural systems are redesigned to be even more like their wild cousins? An ecological success story rapidly influencing the course of much of the American rice industry is the California Rice Industry Association's creative response to the air pollution caused by the widespread practice of burning rice straw each winter. Silica in the straw was suspected of causing lung disease downwind. Some growers stopped burning and instead flooded their fields after harvest, turning them into habitat for millions of migrating ducks and other wild birds. The decomposing rice stubble rebuilt the soil. The ducks aerated and fertilized the fields. The ducks' favorite food animals — worms, little arthropods, minnows — came to live in the seasonal wetlands. Hunters paid to visit. Farm inputs could be reduced thanks to the natural fertilizers. Crop yields and net incomes rose. Now those farmers, with 30 percent of California's rice acreage, consider rice a coproduct of new businesses — providing water management, wildlife habitat, straw production, and other services.

The ultimate loop-closers, the basis of planetary metabolism, are the soil microorganisms that turn back into nutrient flows everything that falls on or grows within the ground. In Evan Eisenberg's metaphor:

> The soil is less a factory than a souk, a Casbah, a flea market, an economic free-for-all in which each buyer and seller pursues his or her own interest, and in which every scrap of merchandise — second-hand, seventh-hand, busted, salvaged, patched — is mined for its last ounce of value. Decay is good business because there are nutrients to be extracted and energy to be gained from the breaking of chemical bonds. If the net effect of the activity of the soil biota is overwhelmingly helpful — in fact, vital — to life on street level, it is not because nature has ordained it so, but because the various forms of life above and below ground have coevolved.[45]

Perhaps before long the companies now directing their sophisticated resources to the dubious goal of producing genetically engineered crops and their uninsurable risks[46] will use those skills instead to make soil-biota test kits. Such kits could tell the farmer what organisms are missing, whether their absence matters, and what, if anything, to do in order to restore the soil to healthy biodiversity. Farmers could then start to count their wealth in bacteria and fungi, roundworms and springtails, rather than in acres and bushels. But this will require major advances in knowledge: Soil biology is a vast and growing mystery. A recent RNA assay disclosed four thousand distinct genomes in each gram of soil, and they varied from place to place. Some appeared to represent major new taxonomic categories. Of each ten microbes observed on plant roots by microscopy, at most one could be cultured in nutrient media (the standard lab technique for determining what's living there); of each thousand in bulk soil, only one. The rest represent "a vast diversity of microbes . . . that we know nothing about."[47] Soils, in short, have recently been discovered to "harbor a complex and largely unknown microflora" implying "many unknown ecological and biochemical processes. . . ."[48] Science can't understand how plants grow until it understands the ecology of what they grow from: as Donald Worster put it,[49] "We can no more manufacture a soil with a tank of chemicals than we can invent a rain forest or produce a single bird." And understanding soil, the ultimate natural capital[50] (the Chinese call it the mother of all things), is in turn the key to turning agriculture from part of the climate problem into part of the solution.

SOIL AND CLIMATE

Farming, as presently practiced, contributes about one-fourth of the risk of altering the earth's climate.[51] Temperate farmland typically has about 20 to 30 times as much biomass below the surface as above-ground.[52] This hidden carbon stock, often upward of 44 tons of carbon per acre, is at risk of mobilization into the air if insensitive farming practices defeat living systems' tendency to fix carbon into soil biota. Turning land that hosted the prairie's hundreds of varieties of grasses and other plants into fields where just corn and soybeans are grown, and substituting synthetic for natural nutrient cycles, puts the huge standing biomass of soil bacteria, fungi, and other biota out of work. When they subsequently die, they oxidize or rot, releasing their carbon to the air. Breaking the sod also opens the soil not only to biological erosion via sterilizing air, heat, and ultraviolet light but also to physical erosion that strips it of its organisms and other organic constituents. The resulting "finely pulverized young coal" — carbon-bearing but ecologically destroyed — makes its way into riverbeds and deltas, where it decays into methane, a greenhouse gas twenty-one times as potent per molecule as carbon dioxide. Ever greater inputs of agri-chemicals must be used to substitute for the degraded services of the natural ecosystem. Making these chemicals, notably fertilizers, requires about 2 percent of all industrial energy.[53] None of these measures is really necessary to grow crops or make money; all are instead artifacts of an obsolete, mechanistic, abiotic practice.

Agriculture based more on natural models would feature reduced land clearance, tillage, and fertilization, higher energy efficiency, and greater reliance on renewable energy. These measures could probably eliminate most human releases of nitrous oxide, much of which is produced by the reactions of synthetic fertilizer with soil bacteria. Very large carbon-dioxide savings would undoubtedly result from building up organic matter in soil humus by accumulating a richly diverse soil biota. Soil loss — especially the physical loss or biological impoverishment, hence carbon depletion, of humus — is currently far outpacing soil and humus formation and enrichment worldwide. This net loss of soil carbon has contributed about 7 percent of the carbon now in the atmosphere.[54] Yet successful conversions to organic or low-input practices, chiefly in the United States and Germany, have demonstrated that after a few years' reequilibration, these carbon losses can actually be *reversed* — protecting the earth's climate and the farmer's soil simultaneously. U.S. cropland alone (8 percent of the cropland on earth) could thereby offset about 8–17 percent of U.S. carbon emissions.[55] If the carbon removed from the air could be traded for, say, $25 per metric ton — manyfold less than climate skeptics expect — it could earn $9–20 per acre per year[56] for the average U.S. farmer. Net farm income in 1996 was only $55 per acre and falling. Moreover, the organic content's extra nutrient- and water-holding power could have a natural-capital value of about $200 per metric ton of carbon, to say nothing of its other ecological functions.[57]

Worldwide, the potential is far greater. The world's cultivated soils contain about twice as much carbon as the atmosphere, whose carbon content is rising by half a percent per year. The earth's 5 billion acres of degraded soils are particularly low in carbon and in need of carbon-absorbing vegetative cover. Increasing degraded soil's carbon content at plausible rates[58] could absorb about as much carbon as all human activity emits.[59] This would also improve soil, water and air quality, agricultural productivity, and human prosperity. Especially important is the opportunity to use modern grazing management techniques, described below, and to refrain from plowing and burning in "brittle" environments, so as to diversify and densify the grasses that cover much of the earth. This can often reverse desertification, restore soils and water tables, increase livestock-carrying capacity, and put large amounts of carbon back into the grassland and savanna soils. It may seem farfetched to rebuild the deep black soils and abundant water that Herodotus noted around Libya, or restore the hippos that aboriginal peoples painted in what is now the interior of the Sahara Desert, but it may well be possible for the processes that built these flexible ecosystems over the ages to be set back into motion by applying today's understanding of how grasslands coevolved with grazers.

There are also many techniques for reducing the use of nitrogen fertilizer[60] in conventional farming practice: Overapplication is so common that in the early 1990s, U.S. farmers were applying 56 percent more nitrogen than their harvested crops removed.[61] Most reductions are cost-effective because they lower chemical and application costs and nitrate-runoff pollution without cutting yields. Better nitrogen management also decreases climate-altering emissions. In many developing countries, additional measures to cut methane emissions are available and desirable.

Changes in farming that have the highest potential climatic leverage involve livestock. Six billion people keep nearly 1.3 billion cattle, 900 million pigs, and 1.3 billion chickens. These animals' metabolisms are substantially larger than those of the people.[62] Just as saving electricity reduces carbon-dioxide emissions severalfold more than saving other forms of energy, because it takes several units of fuel to make one unit of electricity, so changing the numbers and rearing methods of livestock offers similar but even greater climatic (and food-supply) benefits. As mentioned earlier, under conventional practice, livestock converts from 2.2 to more than 20 pounds of grain into just one pound of meat. Beef averages 7 but can reach the least efficient end of that range in the later stages of grain-finishing, while fish, poultry, and pork are at or near the most efficient end.

High-priority actions for reconfiguring livestock raising include:[63]

- Desubsidizing livestock production, especially for cattle, which emit approximately 72 percent of all livestock methane:[64] Dairy and beef cattle would be grown differently and probably in considerably smaller numbers without their various subsidies, especially in rich countries;[65]
- Reducing the rich countries' dairy output to match demand rather than propping up demand with subsidies. Dairy cows emit extra methane because they're fed at about three times maintenance level to make them produce more milk;
- Improving livestock breeding, especially in developing countries, to increase meat or milk output per animal, consistent with humane practices;
- Regulating or taxing methane emissions from manure to encourage manure-to-biogas conversion for useful combustion;
- Reforming U.S. beef grading standards to reduce the inefficient conversion of costly, topsoil-intensive grains into feedlot fat that's then largely discarded;[66]

- Encouraging ultralean, organic range beef as a replacement for feedlot beef. The organically raised cattle then feed only on natural grass, need no antibiotics, taste better, can be just as tender, are more healthful, can cost less, and may produce less methane than equivalent feedlot beef;[67] and
- To the extent that cattle are still to be grown in feedlots, shifting some meat consumption to less feed- and methane-intensive animals and to aquaculture, preferably integrated with agriculture — a highly flexible and productive approach that may also help cut rice-paddy methane.

Several of these options would have important side benefits. For example, many cattle herds in the industrialized countries are fed at conversion ratios of 8:1 or worse, with grain grown in developing countries. The Western European herd consumes two-thirds of Europe's grain crop, and that continent imports over 40 percent of its feed grain from developing countries,[68] which need grain for human food. More grain nutrients are consumed by American livestock than by Americans or by people in other countries.[69] If the rich countries replaced part of their feedlot beef consumption with range beef and lamb, white meats, aquaculture, marine fish, or vegetable proteins, then Central and South America might feel less pressure to convert rainforest to pasture. Many developing countries could free up arable land. There could be less displacement of the rural poor onto marginal land, less soil erosion, and renewed emphasis on traditional food crops rather than on export cash crops. This one action could save enough grain, if properly distributed, to feed the world's half billion hungry people.[70]

NATURE AS MODEL AND MENTOR

An important alternative to intensive feedlot production of livestock, especially cattle, is to let them graze as their forebears were designed to do. Grazing has often been carried out in such a destructive way that growing crops for feeding confined animals is widely considered a normal and preferable alternative (and an even more profitable one if sufficiently subsidized). But pioneers of ecologically based grazing are showing that it is far better to restore and maintain grazing by cattle and other animals on grasslands that typically coevolved with grazing animals and cannot remain healthy without them.

When Allan Savory was a Zimbabwean wildlife biologist,[71] he became curious about why the huge herds of native ungulates grazing Africa's grasslands seemed to do no harm to the land, while cattle herded by tribal people did moderate damage to the grass and cattle herded by white ranchers destroyed it. He observed that the grazing of the native animals, hemmed in and agitated by prowling predators, is very concentrated in time and space. The herd quickly moves on, leaving in the churned-up ground deep hoofprints that catch dung, water, and seed to make next year's grass crop. The animals don't return until the following year, when the grass has regrown. Savory mimicked these patterns by establishing analogous grazing patterns with cattle in dry climates, notably in the western United States. He proved that much of the rangeland commonly considered overgrazed is actually *under*-grazed but grazed the wrong way. Range management based on an understanding of the ecology of each piece of land, often using more cattle, *more* intensely resident for shorter and less frequent periods, can improve carrying capacity for both livestock and wild grazers, while producing a premium product — the ultralean, organic range beef mentioned above. Though ecosystem-specific, and not a panacea, this approach has reportedly been successfully applied by thousands of ranchers in dry regions where beef is the traditional product. Criticized by some, Savory's approach clearly merits greater attention.

More recently, such management-intensive rotational grazing (MIRG) has spread through beef, pork, and especially dairy farming in the humid American Midwest, where it is now "the most innovative and fastest growing farming practice."[72] Just between 1993 and 1997, as Wisconsin lost 18 percent of its dairy farms, MIRG operations grew by three-fifths to about 15 percent of all the dairies in the state.[73] The grazing cows yield slightly less milk than confined animals but at far lower capital and operating cost, hence higher income per cow. The technique is simple in principle. The cows walk around fetching their own food (grass) and depositing their own manure within a paddock, moving on to another area about every day, so the grass can recover. But this practice isn't simplistic. It draws on attentive management and new knowledge of forage ecology to harvest the grass at its nutritional peak and then let it recover for the optimal period. It also ensures adequate time for the manure to return to the soil, closing the nutrient loop without producing toxic runoff. (About thirty-five times less nitrogen runs off perennial grass pastures than the corn-and-bean fields otherwise used to make cattle feed[74] — the main source of the nitrogen runoff that's asphyxiating that New Jersey–sized patch in the Gulf of Mexico.)[75] If MIRG's economic logic keeps driving its rapid expansion, it could displace enormous quantities of expensive feed grains. It could return soil to its original erosion-resistant grassland structure and restore groundwater. It could improve the habitat and wildlife (such as insect-eating songbirds),[76] the health of the cattle, the purity of the milk, and the waters now contaminated by sediments, agrichemicals, and manures (equivalent to the waste output of twenty-four people per cow). Careful rotational grazing can even heal and improve highly erosive soils in hill country: As veteran grazier Charles Opitz put it, "Your land is the canvas, the grass the paint and the cattle the brush."[77]

The naturalist's keen eye can reshape farming and gardening as well as ranching. In both the North and the South, ordinary organic farming practices modeled on complex ecosystems generally produce comparable or only slightly lower yields than chemical farming but at even lower costs. They therefore earn comparable or higher farm incomes[78] — without taking into consideration the premium many buyers are willing to pay for food free of unwelcome biocide, hormone, and antibiotic residues. The organic practices' economic advantage has been demonstrated in large commercial operations over a wide range of crops, climates, and soil types.[79] That advantage tends to increase at family-farm scale, which brings further social benefits.[80] It can also be successfully facilitated worldwide by a "farmer first" model that honors, empowers, learns from, and supplements local knowledge to achieve complex, individually tailored results, rather than trying to impose a uniform set of simplified techniques by top-down "technology transfer."[81]

Organic farming goes a long way toward providing better food from far smaller and more sustainable inputs. It is gaining market access, customers, and practitioners: In Vermont in 1995–98 alone, the number of certified organic farms doubled and their total acreage tripled. But conventional organic farming isn't the last word in the evolution of modern agriculture. Biointensive minifarming, for example, is a newer technique that combines four commonsense gardening principles: deep cultivation to aid root growth, compost crops, closely spaced plants in wide beds to optimize microclimates, and interplanting of mixed species to foil pests. Since nature does most of the work after the initial bed preparation, the upkeep is quite small and the yield can be high for crops and much higher for nutrients — the true measure of yield, as "bioneer" Kenny Ausubel rightly notes. The results are startling.

Standard U.S. agricultural practice today requires at least 45,000 square feet of land to feed a person on a high-meat diet, or about 10,000 for a vegetarian. Developing nations aspiring to similar diets have only about 9,000 square feet of land per person available for cultivation, and that amount will probably shrink with further urbanization, desertification, erosion, soil salinization, and other stresses. However, biointensive gardening can provide for a vegetarian's entire diet, plus the compost crops needed to sustain the system indefinitely, on only 2,000 to 4,000 square feet, even starting with low-quality land. Compared with conventional farming, water used per unit of food produced decreases by up to 88 percent. Off-farm energy inputs are reduced by up to 99 percent, land per unit of food produced by 60–80 percent, and land per dollar of net farm income by half. Except for the land and a few locally manufacturable hand tools, essentially no capital or any chemical inputs are required.[82] This works so well that biointensive agriculture is being practiced in 107 countries worldwide.

One of the models for biointensive techniques, yet an even less labor-intensive one in the right conditions, is Masanobu Fukuoka's "do-nothing" system of organic farming. On some of the highest-altitude fields in Japan, his system of "crops that look after themselves" reportedly yields 22 bushels of rice and 22 bushels of winter grains on a quarter acre. That's impressively productive, enough to feed 5 to 10 individuals, but it takes only one or two people a few days of work to hand-sow and harvest a crop, because an elegantly conceived sequence of plantings provides the weed control, composting, and other services automatically, just by doing the right few things at the right time and in the right sequence.[83] Science writer Janine Benyus states that Fukuoka-sensei's method has spread widely in Japan and to about a million acres in China.

Some of the most productive kinds of biofarming integrate livestock with crops, and garden and tree crops with field crops. They involve often tens and sometimes hundreds of cultivars instead of just one or a few. A typical Javanese kitchen garden, for example, looks like a miniature forest, growing over fifty cultivars in four layers on scarcely more than an acre. Its intricate diversity renders it highly and stably productive, providing food both equitably and sustainably.[84] In Asia, there is also a rich tradition of integrating many kinds of food production — vegetables, fish, rice, pigs, ducks, et cetera — in a sophisticated quasi-ecosystem that efficiently recycles its own nutrients through plant-animal interactions. A recent Bangladeshi adaptation stopped applying pesticides to rice in order to grow fish in the wet paddy fields — whereupon the fish flourished and the rice yields increased by one-fourth, because without interference, both crops could benefit each other.[85]

Biological farming principles can also be adapted to the vast areas now planted to grains. Its many variants can simultaneously reduce farmland's emissions of methane and nitrous oxide, and can reverse agricultural CO_2 emissions. These techniques can and often do use standard farm machinery but require it less often. They can work well on any scale but do not inherently disadvantage the small-scale farmer. They substitute natural for synthetic nutrients (for example, legumes, composted manure, or certain microorganisms[86] for synthetic nitrogen), mulches, compost, and cover crops for bare ground, and natural predators and rotations for biocides. Dr. Christine Jones's team at New South Wales's Land and Water Conservation Agency are even developing a new "pasture cropping" technique with controlled grazing on perennial grass cover but also annual grains sown into the grass in its dormant season. This yields the grain crop and livestock while protecting the soil and holding water.

High-yielding seeds developed for the green revolution and artificial fertilizers have often been assumed to be essential to growing enough food in land-short developing countries. Yet diverse African field studies have demonstrated that "ecoagriculture," by substituting good husbandry and local seed for otherwise purchased inputs, yields nearly as much of crops like corn and sorghum even in the short term. The small yield difference probably narrows with time, given the accelerated degradation of soils that is usually the result of chemical agriculture. Such results suggest that restorative and biological farming, often organized on the traditional family or village scale, could increase both in industrialized and developing countries without jeopardizing the goal of increasing Third World agricultural yields. Without this conversion, current trends suggest that arable land will continue to disappear, especially the thin soils of the tropics.[87] Research is revealing an even more far-reaching potential for what geneticist Wes Jackson, Janine Benyus, and others call Natural Systems Agriculture. This approach is based on the endurance, efficiency, and self-reliance of wildness. Reflecting on how much worse Minnesota cropland is damaged by a severe hailstorm than a natural grassland would be, Benyus notes that, in the prairie,

> Some of the grasses suffer, but most survive quite well, thanks to a perennial root system that ensures next year's resurrection. There's a hardiness about the plants in a wild setting. When you look at a prairie, you don't see complete losses from anything — you don't see net soil erosion or devastating pest epidemics. You don't see the need for fertilizers or pesticides. You see a system that runs on sun and rain, year after year, with no one to cultivate the soil or plant the seeds. It drinks in no excess inputs and excretes no damaging wastes. It recycles all its nutrients, it conserves water, it produces abundantly, and because it's chock-full of genetic information and local know-how, it adapts.
>
> What if we were to remake agriculture using crops that had that same kind of self-sufficiency, that ability to live amiably with their fieldmates, stay in sync with their surroundings, build soil beneath them, and handle pests with aplomb? What would agriculture look like?[88]

Experiments in rethinking agriculture are under way in biomes ranging from tropical forests to deserts, from temperate hardwood forests to prairies.[89] For example, Dr. Wes Jackson and his colleagues at the Land Institute in Salina, Kansas, are now seeking one long-term answer. They believe that, in the Great Plains of North America, it may be feasible to replace annual monocultures with perennial polycultures to form a diverse ecosystem that looks rather like native prairie, is closely modeled on it, doesn't erode (prairie soaks up rain eight times as well as a wheatfield does),[90] builds topsoil (a prairie contains about as much living matter per acre as a forest, mostly underground), and requires virtually no inputs.[91] Its efficiencies come from natural integration. Its rewards, as Jackson puts it, go "to the farmer and the landscape, not to the suppliers of inputs."

Such a replacement of annual grains with perennial cereals that do not require annual tilling and replanting could eliminate up to half the soil erosion in the United States, saving nearly $20 billion worth of U.S. soil and $9 billion worth of fuel for farm equipment every year.[92] If Jackson's ambitious research goal can be widely commercialized, a bigger and more daunting step, then at least in the earth's great grasslands, farming may ultimately come to look as if nothing at all is happening. The domestic prairie will occasionally be harvested by combines, or indirectly by harvesting various grazing animals. Such a system would require attention, but no chemicals, no cultivation, no irrigation. The efficiency of this method in turning sunlight into food will by its very nature be the highest possible, because if there were a more efficient way to do it, nature would have found it.