require a range of small, local initiatives that are as diverse as the cultures and environments in which they take place. Promoting "small-scale on a large scale" would allow specific, on-the-ground initiatives to flourish — community supported agriculture (CSAs), community banks, local currencies and trading systems, rediscovered traditional knowledge, and more. These small-scale steps require a slow pace and a deep and intimate understanding of local contexts and will best be designed and implemented by local people themselves. Over time, such initiatives would inevitably foster a return to cultural and biological diversity and long-term sustainability.

FARMING IN NATURE'S IMAGE

Natural Systems Agriculture

WES JACKSON

FOR 10,000 YEARS TILL AGRICULTURE has been a disaster for the natural world. Topsoil and biodiversity have been agriculture's most frequent casualties. Current "techno-fixes" like fertilizers and pesticides only make things worse. As a result, nearly one-third of the world's arable land has been lost to erosion, and in the United States we have lost three-quarters of all our agricultural biodiversity over the last 100 years. To reverse our course and find a truly sustainable agriculture, we need to develop a "Natural Systems Agriculture" which features nature's wisdom over human cleverness and brings rewards to the farmer and the land.

Most people believe that there is a right way to do agriculture and that failure to do it correctly is simply a failure in character. The very nature of farming itself is seldom called into question, and the one who does question agriculture itself may be accused of wanting to return to the bow and arrow way of life.

Agriculture is seen as an essentially wholesome enterprise. The image of a well-scrubbed 4-H kid, clasping the rope on an equally well-scrubbed Holstein heifer at the country fair is always fit for the September page of the calendar put up at the local feed store. The kid's bright eyes radiate "new knowledge" and the rosy cheeks "wholesome values."

It isn't just through the kid at the country fair that the notion of the inherent wholesomeness of agriculture gets a boost. The appropriateness of till agriculture is firmly implanted in all civilized peoples. At the United Nations there is a huge statue of a man full of purpose and muscle bent to the task of beating a sword, which does
evil of course, into a plowshare, which everyone knows will do good.

The developer of a new idea is often described as having “plowed new ground.” Saul, the first king of Israel, was anointed in the field where he had been plowing with oxen, suggesting at least a left-handed endorsement of till agriculture from the Almighty himself. The concept of till agriculture is interwoven in our metaphors and symbols. Yet the plowshare may well have destroyed more of the natural world and more options for future generations than the sword.

Till agriculture, almost from the beginning, has to be questioned, not because sustainable till agriculture can’t be practiced, but because it isn’t and hasn’t been, except in small pockets scattered over the globe. So destructive has the agricultural revolution been that, geologically speaking, it surely stands as among the most significant and explosive events to appear on the face of the earth, changing the earth even faster than did the origin of life. Volcanoes erupt in small areas, and mountain ranges require so long in their uplift that adjustments to changing conditions by the life forms are smooth and easy. But agriculture has come on the global scene so rapidly that the life-support system has not had time to adjust to the changing circumstances. In this sense then, till agriculture is a global disease, which in a few places has been well managed, but overall has steadily eroded the land. Unless this disease is checked, the human race will wilt like any other crop.

As I will describe later, I think we have an opportunity to develop a cure for this disease. There is a very real chance that we can arrive at a truly sustainable agriculture. But before arriving at the remedy, it is important to describe the little-noted historical problem of till agriculture. Let us briefly review the epidemiology of the disease.

THE PROBLEM OF AGRICULTURE HISTORICALLY

Greece features a landscape famous for its cultural achievements, from classical times to the present. Here were the landscape and a people that both sponsored and still display the brilliance that has defined much of Western civilization. Here is a land where the impact of agriculture is everywhere, a land where episodes of deforestation and soil erosion have gone on for 8,000 years. History tells us that the ancient Greeks considered themselves careful stewards of the land, people who felt guided by their gods and goddesses in this endeavor. Even so, those early Greeks and their gods, like essentially all agricultural civilizations, failed to hold the topsoil. The recent archaeological evidence of soil erosion in ancient Greece due to agriculture is now well documented. The story begins with the farmers who first settled Greece when the landscape was pristine. But archaeological investigations of ancient ecosystems using soils and fossil pollen along with human relics and artifacts reveal that when hill slopes lose their soil, people move; when usable soils reform thousands of years later, people return to farm. This is no surprise, for here is where both Plato and Aristotle witnessed firsthand land degradation and its consequences. Plato, in one of his dialogues, has Critias proclaim: “What now remains of the formerly rich land is like the skeleton of a sick man, with all the fat and soft earth having wasted away and only the bare framework remaining. . . . The plains that were full of rich soil are now marshes. Hills that were once covered with forests and produced abundant pasture now produce only food for bees. Once the land was enriched by yearly rains, which were not lost, as they are now, by flowing from the bare land into the sea.”

As with Greece, Rome relied on the natural fertility and the benign climate of its local geography. The Romans too worshiped nature deities and called the earth “mater terra.” Their experience with erosion also mirrored the Greeks’ experience: topsoil was lost and fertility declined. The Romans had unbounded faith in human ingenuity, and many believed that intervention on a large scale would pull them through their agriculture woes. Virgil, Ovid, and Seneca were major promoters of such a view. Cicero must also have been a devotee, for he is on record as having said: “By means of our hands we endeavor to create as it were a second world within the world of nature.” As would be repeated throughout the centuries in so many cultures, the Romans’ interventions were no match for the laws of nature, and their agriculture went into a steep decline.

Egypt fared better. As Herodotus, the Greek historian, said, “Egypt is the gift of the Nile.” The Nile received silt from volcanic highlands of Ethiopia, thanks to the predictable monsoon rains arriving from the Indian Ocean each year, bringing minerals into the annual floods.
of the Nile's tributary, the Blue Nile. Egypt prospered at Ethiopia's mineral expense. The White Nile with its jungle origin and swampy places contributed its organic matter, and the best sources from two parts of the world converged at the confluence. Downstream these fresh nutrients and organic matter so combined to spill over a layer one millimeter thick each year, to be turned into crops for Egyptian farmers and Pharaohs. It seems safe to say that without the steamy jungles and volcanic ash, no pyramids would have been built.

In the New World, the story of till agriculture on sloping ground is much the same as that of the Greeks and Romans. The central Mexican highlands experienced devastating soil erosion 3,500 years before Cortez. Sarah L. O'Hara of the University of Sheffield in Britain and her colleagues took 21 cores of sediment extracted from sites in the central Mexican highlands. Radiocarbon dating of shells and charcoal in the layers determined that there were three periods of severe erosion. The first occurred when Indians began cultivating maize 3,500 years ago, the earliest appearance of maize pollen. A later erosion appeared on steep cultivated hillsides. Most recently, extensive erosion from the hillsides coincided with deforestation. Soil erosion did not increase there after Cortez arrived in 1521. "If anything," she writes, "there was a decrease in the erosion rate after the conquest." We know that not only did the population steeply decline following the conquest, but the forests regenerated.

The industrial agriculture of recent years has accelerated erosion at an almost inconceivable pace. In the last 40 years, nearly one-third of the world's arable land has been lost to erosion and continues to be lost at a rate of more than 10 million hectares per year. Ninety percent of U.S. cropland is losing soil above replacement rates. Loss is 17 times faster than formation on average. At this rate, during the next 20 years, the potential yield of good land without fertilizer or irrigation is estimated to drop 20 percent. Once all soil costs are calculated for the United States, the bottom line is $44 billion in direct damage to agricultural lands and indirect damage to waterways, infrastructure, and health in the United States, and nearly $400 billion in damage worldwide. It has been estimated that to bring soil erosion under control in the United States would require an annual outlay of $8.4 billion.

The ravages of the agricultural disease include not only topsoil loss but also the loss of biodiversity. This age-old problem has become ever more acute. Many crops now altered to conform to industrial farming have been genetically narrowed in the extreme. Nearly a third of the American maize crop comes from four inbred lines. Even in Mexico, farmers abandon the more diverse, locally adapted varieties in favor of genetically narrow, high-yielding strains. In the United States we have lost three-quarters of all our agricultural biodiversity over the past 100 years.

DIGGING THE HOLE DEEPER AS NATURAL FERTILITY DECLINES

Throughout history many have argued that the solution for saving topsoil and biodiversity is more technology. Over the last many decades they have further argued that a new revolution in farming technology will make higher production possible without sacrificing environmental quality. Even a cursory examination of two relatively recent "revolutions" in agriculture demonstrates the folly of this "quick fix" mind-set.

For example, industrial agriculture has offset much of the age-old soil erosion problem with the use of fossil fuels: fossil carbon in the form of fertilizers substituting for soil carbon. This "fossil-carbon" agriculture is startlingly inefficient in terms of materials and energy usage. U.S. agriculture requires ten fossil fuel calories to produce a single food calorie. The trend in countries worldwide is toward even greater consumption of fossil fuels by the agricultural sector. This last-gasp effort to substitute petroleum-based fertilizers for lost topsoil is doomed to failure. Energy scholars now project that global oil production will peak and begin its permanent decline around 2020 and that by the latter half of this century, it will drop to 10 percent of the present annual production. The fossil-carbon answer clearly cannot be a long-term fix for erosion.

Many also see the chemical industry as a panacea for our agricultural woes. But the terrible consequences of this fix become more evident every day. Nitrate from fertilizers, linked to blue baby syndrome and cancer in test animals, is increasingly a problem as it seeps...
into ground water supplies. Soils that are naturally most productive are alive with everything from earthworms to microorganisms — creatures that build, till, and nourish the soil. Herbicides and insecticides applied to crops kill huge quantities of this life that would contribute to soil health. Nitrogen fertilizers, combined with frequent tillage, "burn up" soil organic matter, thus destroying soil structure. Chemicals may also degrade soil structure, hindering water and gas relationships between the plants and the soil. Data reveal that at best one percent of applied pesticides reach their intended targets; the rest cause unintended damage both on and off site. According to the U.S. Department of Agriculture (USDA), pesticide use on major field crops, fruits, and vegetables nearly tripled from 215 million pounds in 1964 to 588 million pounds in 1997. Numerous studies have also been conducted to verify the suspected link between agricultural pesticides and diseases in humans. Direct links are often impossible to establish because they would require experimentation employing direct dosages. However, a summary of cancer risks among farmers cites "significant excesses for Hodgkin’s disease, multiple myeloma, leukemia, skin melanomas, and cancers of the lip, stomach, and prostate" due to pest control chemicals. Another study posits that the herbicide 2,4-D has been associated with two- to eightfold increases in non-Hodgkin’s lymphoma in agricultural regions. The study of farm chemicals and their clear role in disrupting the human endocrine system is a fast-growing field. Other reports reveal that numerous pesticides can reduce the immune system’s ability to deal with infectious agents.

As the Romans learned a couple of millennia ago, human technical ingenuity is no match for nature’s laws. Industrial agriculture’s temporary techno-fixes are no panacea for our agricultural woes and never will be. They only exacerbate the problem. But there is a way to escape the current crisis in topsoil and biodiversity loss, a path toward a sustainable agriculture. Once explained the answer may seem obvious, but it is one that humanity has pretty much ignored since the dawn of agriculture.

LOOKING TO NATURE AS THE STANDARD TO SOLVE THE PROBLEM OF AGRICULTURE

Thinking on the history of agriculture’s abuse of the earth, and especially the recent dependency on fossil fuels, chemicals, and the genetic narrowing of our major crops, it becomes increasingly clear that the problem of agriculture cannot be solved within our current conventions of thought and action. These agricultural practices are based on the idea that nature is to be subdued or ignored. In 1978, I published an essay entitled "Toward a Sustainable Agriculture," in which I argued against this paradigm of the subjugation of nature and for an agriculture based on the way nature works, especially nature’s prairie. I later expanded the argument for a more natural solution to the “problem of agriculture” in New Roots for Agriculture. This seemingly revolutionary idea of “nature as standard” or “nature as measure” goes back at least 2,000 years before Jesus of Nazareth. Wendell Berry, who has traced this literary and scientific history, begins with Job, who said, “ask now the beasts, and they shall teach thee; and the fowls of the air, and they shall tell thee: Or speak to the earth, and it shall teach thee; and the fishes of the sea shall declare unto thee.” Next he quoted Virgil, who advised that,

\[
\text{before we plow an unfamiliar patch}
\]

\[
\text{It is well to be informed about the winds,}
\]

\[
\text{About the variation in the sky;}
\]

\[
\text{The native traits and habits of the place,}
\]

\[
\text{What each locality permits, and what denies.}
\]

Edmund Spenser, toward the end of the 1500s, called nature “the equal mother” of all creatures, who “knittest each to each, as brother unto brother.” Spenser saw nature as the instructor of creatures and the ultimate earthly judge of their behavior. Shakespeare, in As You Like It, has the forest in the role of teacher and judge. Alexander Pope, in his Epistle to Burlington, counseled gardeners to “let Nature never be forgot” and “Consult the Genius of the Place in all.”

Berry, himself one of America’s great poets, novelists, and essayists, says that this theme departs from English poetry after Pope, with the later poets regarding nature and humans as radically divided. A practical harmony between land and people was ignored. The romantic
poets after Pope placed preeminence on the human mind to the point that nature was a mere “reservoir of symbols.” The idea that practical lessons could be learned from nature was not advanced.

When poets no longer looked to nature, agricultural writers with a scientific bent reintroduced the theme in the formal culture. The Cornell University professor Liberty Hyde Bailey's *The Outlook to Nature* appeared in 1905; in it he described nature as “the norm”: “If nature is the norm, then the necessity for correcting and amending abuses of civilization becomes badly apparent by very contrast.” He continued: “The return to nature affords the very means of acquiring the incentive and energy for ambitious and constructive work of a higher order.” Later, Bailey’s *The Holy Earth* (1915) was published. This time Bailey advanced the notion that “a good part of agriculture is to learn how to adapt one’s work to nature. To live in right relation with his natural conditions is one of the first lessons that a wise farmer or any other wise man learns.”

Sir Albert Howard published *An Agriculture Testament* in 1940. Howard thought we should farm like the forest, for nature is “the supreme farmer.” He wrote: “Mother earth never attempts to farm without livestock; she always raises mixed crops; great pains are taken to preserve the soil and to prevent erosion; the mixed vegetable and animal wastes are converted into humus; there is no waste; the processes of growth and the processes of decay balance one another; ample provision is made to maintain large reserves of fertility; the greatest care is taken to store the rainfall; both plants and animals are left to protect themselves against disease.”

At The Land Institute we have carried on this idea of agriculture in nature’s image through an effort we call Natural Systems Agriculture (NSA). We began with the goal of relying on the ecological benefits of natural ecosystems with no or minimal sacrifice in food production. We look to the never-plowed native prairie to be our teacher. Nature’s prairie features a diversity of species, nearly all of which are perennial. Because their roots do not die as annual roots do, they hold soil through all seasons, even when drenched by rain. Moreover, perennial roots build soil. This ecosystem thus maintains its own health, runs on the sun’s energy, and recycles nutrients, and at no expense to the planet or people.

Another consideration: wherever we look, from the Canadian prairies to Texas, from the state of Washington in the west to Ohio in the east, roughly 2,000 miles in both directions, wherever there is prairie, four functional groups are featured: warm-season grasses, cool-season grasses, legumes, and composites. Other species are present, but these groups are featured. Different species fill different roles. Some thrive in dry years, others in wet ones. Some provide fertility by fixing atmospheric nitrogen. Some tolerate shade, others require direct sunlight. Some repel insect predators. Some do better on poor, rocky soils while others need rich, deep soil. Diversity provides the system with built-in resilience to changes and cycles in climate, water, insects and pests, grazers, and other natural disturbances.

The challenge is to feature species diversity and perennialism. We must also try to have all four functional groups represented in our mixture or polyculture, and it must produce harvestable edible grain for direct human consumption. Our primary strategy then is to imitate the structure of the prairie ecosystem in order to be granted the functions described above. Properly designed, the system itself should virtually eliminate the ecological degradation characteristic of conventional agriculture and minimize the need for human intervention.

This sounds idyllic, but is it possible? In order to determine if a “natural systems” agriculture is feasible, we organized our research around four basic questions.

1. Can perennialism and increased seed yield go together at no trade-off cost to the plant?
2. Can a polyculture of species outyield a monoculture?
3. Can perennial species planted in mixtures adequately manage all pests?
4. Can a perennial polyculture sponsor all of its own nitrogen fertility needs?

We have published positive answers in peer-reviewed scientific journals for questions 1, 2, and 3, and have indirect evidence that supports question 4. The functions of a natural system, it is now apparent, can be achieved by replicating its structure. The implications and potential impact of this work are global. By demonstrating underlying principles along with practical applications, we have shown that the “natural systems” approach could be transferable
worldwide, as long as adequate research is devoted to developing species and mixtures of species appropriate to specific environments. With additional research, an agriculture that is resilient, productive over the long-term, economical, ecologically responsible, and socially just is within reach.

CONCLUSION: HEALTHIER AGRICULTURE

Natural Systems Agriculture research is predicated on the assumption that to be successful in agriculture we need to know what nature will require of us — a more sophisticated and desirable way of asking, “What can we get away with?”

When we put together several plant species to provide a rough structural analog of the prairie, that prairie we are imitating is a complex polyculture. In our domestic prairies, which will feature grain, we had best not treat these polycultures as wheat or corn fields have been treated. Our plots are more like a whole person that includes a heart. Some medical statisticians are still tempted to take all hearts of a certain age and gender, say, and place them under the likelihood of a heart attack. The problem with regarding hearts as existing in “hearthood,” like wheat plants in a field, is that all hearts are not interacting with other hearts in a simplifiable way as an individual wheat plant is with other wheat plants in a monoculture. The heart has to interact with all the other organs of the person’s body and respond to the pressures in his or her life, as well as to the history of those pressures, and finally with the hearts of others. The wheat field also has interactions we have chosen to ignore. It is heavily dependent on an economy that is extractive and polluting. On sloping ground it will cause soil erosion. We need ways of thinking about agriculture that are as complex as necessary, meaning an exercise in judgment as to what constitutes “good enough.”

We should commit to the journey now to solve the 10,000-year-old problem. It may be an ideal never to be achieved in an absolute sense, just as justice and sustainability are unlikely to ever be ideally achieved. Even so, to commit to this journey would put an end to ratcheting up what Sir Francis Bacon proposed four centuries ago: to torture nature to get truth out of her even as King James had tortured