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Natural systems agriculture: a truly radical alternative☆

Wes Jackson*

The Land Institute, 2440 East Water Well Road, Salina, Kansas, KS 67401, USA

Abstract

The natural systems agriculture (NSA) idea was developed at The Land Institute in 1977 and was published in 1978. Less than 20 years later, research efforts at The Land Institute and by other researchers familiar with research questions had satisfactorily answered *the difficult biological questions* launching the possibility of a new agricultural paradigm toward fruition. This new paradigm features an ecologically sound perennial food-grain-producing system where soil erosion goes to near zero, chemical contamination from agrochemicals plummets, along with agriculture's dependence on fossil fuels. NSA is predicated on an evolutionary-ecological view of the world in which the essentials for sustainable living have been sorted out and tested in nature's ecosystems over millions of years. From numerous studies, evolutionary biologists and ecologists have learned much about how ecological bills are paid by ecosystems which hold and build soil, manage insects, pathogens and weeds. A primary feature of NSA is to sufficiently *mimic the natural structure* to be *granted the function* of its components. Domesticating wild perennials and increasing seed yield and at the same time perennializing the major crops to be planted as domestic prairies is a major goal. For the first time in 10,000 years, humans can now build an agriculture based on nature's ecosystems. As a prototype this means we explore in-depth how the never-plowed native prairie works and then develop a diverse, perennial vegetative structure capable of producing desirable edible grains in abundance including perennializing the major grain crops. A paradigm shift of relatively easily manageable proportions is available to solve the *problem of agriculture* and is antithetical to solving *problems in agriculture*. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

1.1. The problem of agriculture historically

The Greek landscape has been subject to episodes of deforestation and soil erosion for 8000 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 top soil (Runnels, 1995). 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

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* Tel.: +1-785-823-5376; fax: +1-785-823-8728.
E-mail address: jackson@landinstitute.org (W. Jackson).

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(Runnels, 1997, emphasis added). This is no surprise for here is where both Plato and Aristotle witnessed first hand 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. Formerly, many of the mountains were arable. 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. The soil was deep, it absorbed and kept the water in the loamy soil, and the water that soaked into the hills fed springs and running streams everywhere. Now the abandoned shrines at spots where formerly there were springs attest that our description of the land is true".

1.2. History and soil erosion

Not all erosion is human made of course. There was erosion during the last ice age due to climate changes. The past 5000 years, however, is another story. Four episodes of erosion — at about 2500 B.C., 350–50 B.C., 950–1450 A.D. and in recent times — according to professor Curtis N. Runnels "was followed by a period of stability when substantial soil profiles formed" (1995). The researchers "place the chief blame on the activities of the local inhabitants" citing "the correlation between the periods of erosion and the periods of intense human settlement, and the formation of soil during the periods when the human impact was minimal". Runnels continues: "from these data we concluded that the clearing of land during times of intensive human settlement gave rise to soil erosion, which in turn caused the people to abandon their settlements or at least to scale back their activities. And the reduced human activity permitted erosional deposits to stabilize and soils to form . . . . Soil erosion on a similar scale has been reported from other parts of Greece — the northern provinces of Macedonia and Thessaly and the islands of Euboea in the center of the country and of Crete in the south. The episodes date from as early as the sixth millennium B.C. and continue through virtually every historical era to the present day".

1.3. History and land degradation in ancient civilizations

Civilizations of Mesopotamia — Sumer, Akkad, Babylonia, and Assyria — also rose, fell, and disappeared. Sometimes water brought salt as in Mesopotamia where wheat (*Triticum* sp.) once grew, eventually salt-tolerant barley (*Hordeum* sp.), and eventually, in some places next to nothing was grown for human food. Consequently, populations and culture moved upward in the Tigris-Euphrates valley with the salting of the soil. But soil salting, however, important is still the smaller part of the story.

After the Greeks experience of soil loss was well underway, Rome began relying on local natural fertility in the benign climate of the hilly Apennine Peninsula. Like the Greeks, they too worshipped nature deities and called the earth *mater terra*. The chapter on the Romans reads much like the chapter on the Greeks: fertility declined. Human cleverness was greatly increased under the faith that intervention on a large scale would pull them through. Virgil, Ovid, and Seneca were major promoters of such a view. Cicero must be a devotee of human cleverness 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".

Phoenicians, Greeks, Carthaginians, and Romans, each in turn, established distant colonies and empires as their own land based prosperity gave out. But subjects often rebel and the exploiting empire goes home to cope with the exhaustion accelerated by anxious quest.

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 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. Down stream these fresh nutrients and organic matter so combined to spill over a layer 1 mm thick each year to be turned into crops for Egyptian farmers and Pharaohs (Carter and Dale, 1974; Hyams, 1952).

It seems safe to say that without the steamy jungles and volcanic ash, no pyramids would have been built. The story of the Orient differs only in detail (King, 1911).

1.4. History of land degradation in the Americas

In the new world, the story of arable agriculture on sloping ground is much the same. The central Mexican highlands experienced significant soil erosion 3500 years before Cortez. O'Hara et al. (1993) 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 (*Zea mays* L.) 3500 years ago (this is 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. O'Hara et al. (1993) write, "if anything there was a decrease in the erosion rate after the conquest". Historical records indicate that not only did the population steeply decline following the conquest, but the forests regenerated (O'Hara et al., 1993).

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 ha per year. With the addition of a quarter of a million people each day, the world population's food demand is increasing when per capita food productivity is beginning to decline (Pimentel et al., 1995). Ninety percent of US 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%. Once all soil costs are calculated for the US, the bottom line is $ 44 billion in direct damage to agricultural lands and "indirect damage to waterways, infrastructure and health in the US and nearly $ 400 billion in damage worldwide". Pimentel et al. (1995) argue that to bring soil erosion under control in the US would require an annual outlay of $ 8.4 billion.

2. Digging the hole deeper as natural fertility declines

2.1. Fossil fuel dependence — less than two centuries old

Much of the soil erosion problem has been offset with the coming of the fossil fuel epoch: fossil carbon substituting for soil carbon. Conventional agriculture is startlingly *inefficient* in terms of materials and energy usage. US agriculture requires 10 fossil fuel calories to produce a single food calorie (Cox and Atkins, 1979). The trend in countries worldwide is toward even greater consumption of fossil fuels by the agricultural sector. These are brittle agricultural economies some industrialized societies are putting in place. Energy scholars now project that global oil production will peak and begin its permanent decline around 2020 and that by the latter half of the next century, it will drop to 10% of the present annual production (Hatfield and Karlen, 1994; Hall et al., 1986).

2.2. The chemical industry — decades old

Data reveal that at best 1% of applied pesticides reach their intended targets; the rest cause unintended damage both on and off site (Pimentel, 1991). Since 1950, insecticide usage in the US has increased from 15 million pounds to more than 125 million pounds (8–57 million kg). Yet over this same period, crops lost to insects nearly doubled from 7% of total harvest to 13%. Numerous studies have 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. Epidemiological evidence is required. A summary of cancer risks among farmers states that "significant excesses occurred for Hodgkin's disease, multiple myeloma, leukemia, skin melanomas, and cancers of the lip, stomach, and prostate" due to pest control chemicals (Blair et al., 1992). Another study posits that the herbicide 2,4-D has been associated with 2–8-fold increases in non-Hodgkin's lymphoma in agricultural regions (Zahm and Blair, 1992). The study of farm chemicals and their clear role in disrupting the human endocrine system is a fast growing field.

One report reveals that numerous pesticides can reduce the immune system's ability to deal with infectious agents (Repetto and Baliga, 1996). Formerly acute poisonings and cancer risks dominated risk assessment. Now direct evidence from clinical and epidemiological studies show that those exposed to pesticides experience alteration of their immune system structure and function.

2.3. *The loss of biological diversity — an age-old problem has become acute*

Many crops conform to industrial farming and are narrowed genetically. Nearly, one-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.

2.4. *Technological fixes — an extension of the 10,000-year-old paradigm*

Some have argued that the solution for saving the biodiversity of species-rich tropical rainforests, which are under pressure from farmers and ranchers intent on acquiring more land, is to intensify production on current farmland (Evans, 1998). A new revolution in farming technology, the advocates say, will make higher production possible without sacrificing environmental quality (Avery, 1995). Caution is in order here since many recent technological fixes either cut into the farmers' profit or leave unforeseen consequences behind.

3. Looking to nature as the standard to solve the problem of agriculture

The history of earth abuse, the recent dependency on fossil fuels, chemicals, and the genetic narrowing of major crops, underline that the problem of agriculture cannot be solved on the basis that nature is to be subdued or ignored. In 1978, the author published an essay entitled "Toward a Sustainable Agriculture" which argued for an agriculture based on the way nature works, especially, nature's prairie (Jackson, 1978). That was later expanded as the argument for a more natural solution to the "problem of agriculture" in *New Roots for Agriculture* (Jackson, 1985).

3.1. *Literary and scientific history*

Wendell Berry (1990), who has traced the literary and scientific history of the "nature as standard" paradigm, begins with the book of *Job*, which states, "... 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, at the beginning of *The Georgics* (36–29 B.C.) advised that, "... before we plow an unfamiliar patch/It is well to be informed about the winds,/about the variation in the sky,/the native traits and habits of the place,/what each locale 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. The poet Alexander Pope, in his *Epistle to Burlington*, counseled gardeners to "let Nature never be forgot" and "Consult the Genius of the Place in all".

Wendell Berry, himself one of America's great poets, novelists and essayists, says that this theme departs from English poetry after Pope, when the later poets regarded nature and humans as radically divided. A *practical* harmony between land and people was ignored. The romantic poets, after Pope, placed pre-eminence 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.

After poets who looked to nature, agricultural writers with a scientific bent reintroduced the theme. Cornell University professor Liberty Hyde Bailey's *The Outlook to Nature* appeared in 1905 in which he described nature as "the norm": "if nature is the norm, then the necessity for correcting and amending abuses of civilization becomes baldly 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 high order". Later, Bailey's *The Holy Earth* was published in 1915. 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".

3.2. The role of the land institute

The literary and scientific examples, quoted above, have *emerged out of* the common culture. The writers did not build on other writers who had gone before. Their understanding probably comes out of the familial and communal handing down of the *agrarian common culture* rather than any succession in the literary culture or in the schools. Therefore, they form a *series*, not a *succession* (Berry, 1990).

NSA is The Land Institute's response in a research way to the problem of agriculture. The goal is to rely on the ecological benefits of natural ecosystems with no or minimal sacrifice in food production. The never-plowed native prairie serves as our teacher. Nature's prairie features a diversity of species nearly all of whom are perennial. The perennial root system is the underlying strength of the prairie ecosystem. This ecosystem, thus, maintains its own health, runs on the sun's energy, 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 2000 miles in both directions, wherever there's 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.

3.2.1. The challenge of species diversity and perennialism

The challenge is to feature species diversity and perennialism and maintain all four functional groups represented in the mixture or polyculture — and to produce harvestable edible grain for direct human consumption. The primary strategy then is to imitate the *structure* of the prairie ecosystem in order to achieve 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, The Land Institute organized its 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 out-yield 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?

Several peer-reviewed scientific journals have addressed questions 1–3, and, depending on yield expectations, indirect evidence is available that supports question 4 (Jackson and Dewald, 1994; Piper, 1992, 1993a,b; Piper and Kulakow, 1994). The functions of a natural system can be achieved by replicating its structure. The implications and potential impact of this work are global. By demonstrating underlying *principles* rather than practical applications only, the research has 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 is well within reach (and productive over the long-term), economical (the need for costly inputs would be diminished), ecologically responsible, and socially just and acceptable (the entreé for social and economic justice is heightened with the ecological paradigm. Nature's services are free).

3.2.2. Current natural systems agriculture research at the land institute

1. Hypothesis testing experiments:
   - 1.1. Polycultures of perennial grain candidates can out-yield monocultures of same species.
     - 1.1.1. Quadracultures versus monocultures (third field season, 1998)
     - 1.1.2. Bicultures versus monocultures (second field season, 1998)
   - 1.2. High plant diversity alone can rapidly reduce the population of weedy species.
     - 1.2.1. Plant Community Experiment (sixth field season, 1998)
     - 1.2.2. Soil Community Experiment (new)
   - 1.3. Degraded soils of cropland can be improved by planting perennial polyculture-like vegetation.
     - 1.3.1. Comparative study of cropland, restored prairie and original prairie soils
     - 1.3.2. Mycorrhizal fungal species characterization
2. Developing perennial grain crops and cropping systems by
   - 2.1. perennializing annual crops, and
   - 2.2. domesticating wild perennial species
3. Mechanical planting and harvesting methods for establishing and managing perennial polycultures on the field scale.
   - 3.1. Maximillian sunflower (*Helianthus maximilianii* Schrad.) as a short-lived perennial grain crop and weed-suppresser
   - 3.2. Polyculture of four annuals: two warm-season grasses [dwarf maize (*Zea mays* L.) and milo sorghum (*Sorghum bicolor* (L.) Moench)], Legume [soybean (*Glycine max* L.)], Sunflower [annual sunflower (*Helianthus annuus* L.)]. These comprise three of the four functional groups of the native prairie. The purpose of the study is to evaluate weed, insect and pathogen problems and polyculture harvest all at once, and to attempt to perennialize the farm annuals.

4. Conclusions

NSA research is paradigmatically different from the work of others. The world needs a Center for NSA. Research staff could include ecologists (landscape, plant, soil, insect and microbial), ecological or environmental historians, plant breeders (domesticating and breeding wild perennials and perennializing the major grain crops). Biotechnologists would assist the breeder under the ecological imperative. A modeler and data manager would work together around other scientists. Such a center could be imagined any place on earth, pertaining not only to local agriculture, but could be devoted to forestry or fisheries as well.

The final product is a domestic grain producing prairie with the four functional groups represented (warm-season and cool-season grasses, legumes, sunflower family). These mixtures could comprise domesticated wild species and/or domestic annuals made perennials. Here is the prototypical ecosystem toward solving the 10,000-year-old problem of agriculture.

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