The Land Report

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Contents

At The Land

Land Institute Research Report

Above, Land Institute staff, Fall 1994. From left, Marty Bender, Wes Jackson, Jack Worman, John Jilka, Brian Donahue, Sally Cole, Audrey Barker, Louise Sorenson, Matt Logan, Jon Piper

Introduction

Brian Donahue

Every issue of *The Land Report* has a theme. This issue focuses on the Land Institute itself. It is a report on the progress of our research and the direction of our thinking.

This year's Prairie Festival will take place on Memorial Day weekend, Friday May 26 to Sunday May 28. The theme will be "Becoming Native to this Place." All the food will be organically grown, mostly in Kansas. Talks and workshops will revolve around the culture of place. The next issue of the *Land Report* will delve into this further. Those of you who are bringing food to the Saturday evening potluck supper are requested to make it as homegrown and organic as you can, which many of you always have.

The front cover shows '94 interns Joel Gerwin and Antonio Serrano celebrating the completion of a stretch of fence. The fenceposts are osage orange, or "hedge" as they call it around here. Osage orange hedges were planted throughout the Midwest before the invention of barbed wire over a century ago. The grown up hedges still provide a sustainable source of durable fenceposts. Old "hedge" fenceposts make terrific firewood. The picture was taken by Rebecca Geisen.

Finally, the back cover: after last spring's *Land Report* 49, we received numerous requests to show another side of farm manager Jack Worman. We are always happy to oblige. The photographer was Sally Cole.

The Land Report is published three times a year.

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THE LAND INSTITUTE IS A NON-PROFIT RESEARCH AND EDUCATION ORGANIZATION DEVOTED TO SUSTAINABLE AGRICULTURE AND GOOD STEWARDSHIP OF THE EARTH

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Photo Credits: p. 24 - 25 Christian Anders Petrovich; p. 26 right Portia Blume; p. 40 Sally Cole; all other photos by Rebecca Geisen.

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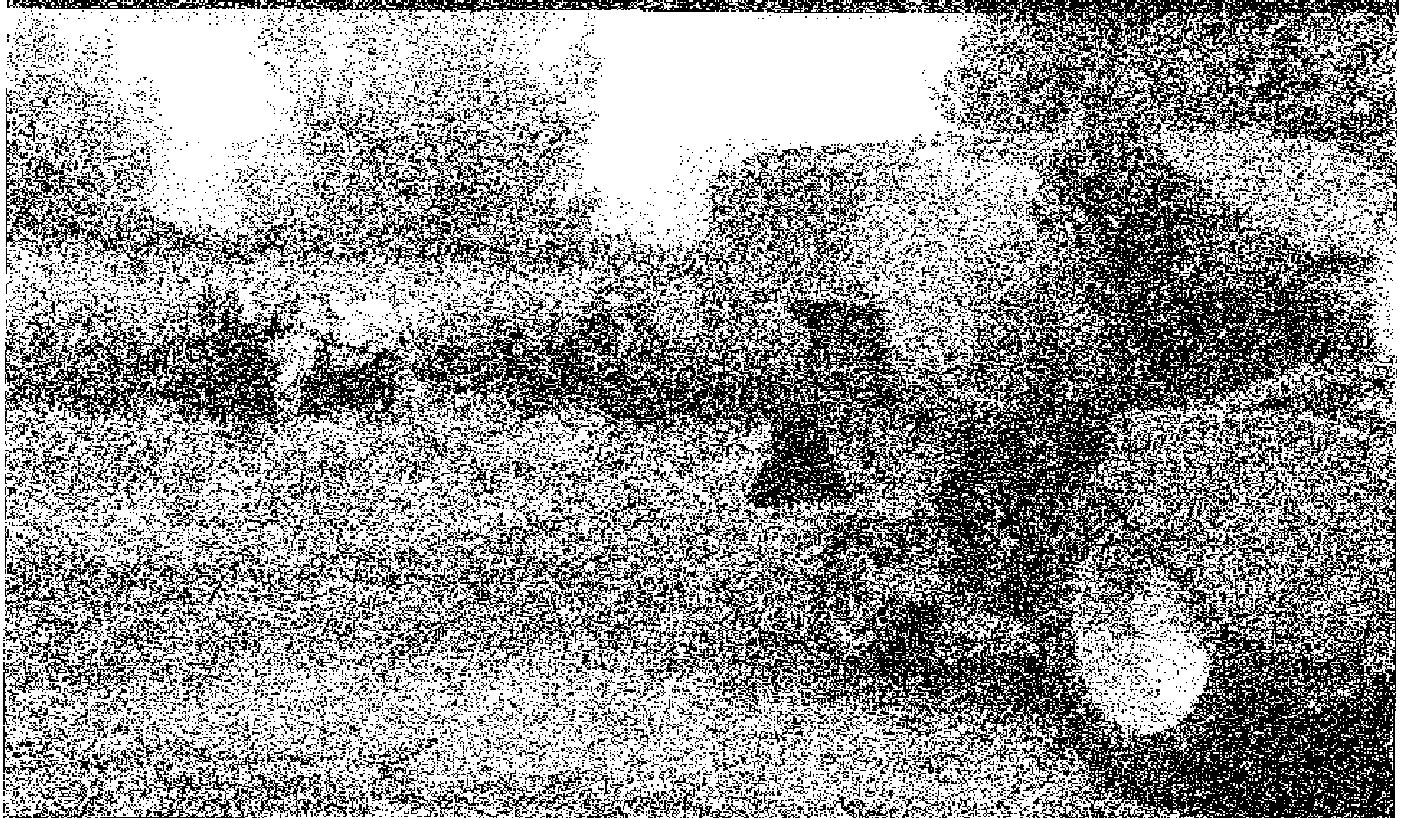
Natural Systems Agriculture: More on The Marriage of Agriculture and Ecology

Wes Jackson



"We are where the Wright Brothers were at Kitty Hawk. I don't want to trivialize agriculture by comparing it to human flight, for I really do believe that these results and implications are more profound for human civilization than the results the Wright brothers first achieved December 17, 1903."

It doesn't seem all that long ago that I outlined what is now the central idea of The Land Institute. It was 1978 that "The Search for a Sustainable Agriculture" was published, the paper which argued for the development of an agriculture featuring perennials grown in combinations which would resemble the vegetative structure of the prairie. I later expanded it into my 1980 book *New Roots for Agriculture*. I knew how radical the idea was then but did not understand the implications of my assumptions and questions. I assumed that we had to begin with asking "What was here?" and explicitly asked in the paper "What will nature require of us here?" Wendell Berry pointed out that I was also asking "What will nature help us to do here?" Since then, we have logged thousands of hours building the intellectual and research foundation around that paradigm, meaning that we have devoted more time to understanding and acting on the fact that ultimately agriculture comes out of nature. To try to understand agricultural ecosystems with no reference to natural ecosystems (which essentially all agricultural researchers do) greatly limits other agronomic possibilities.

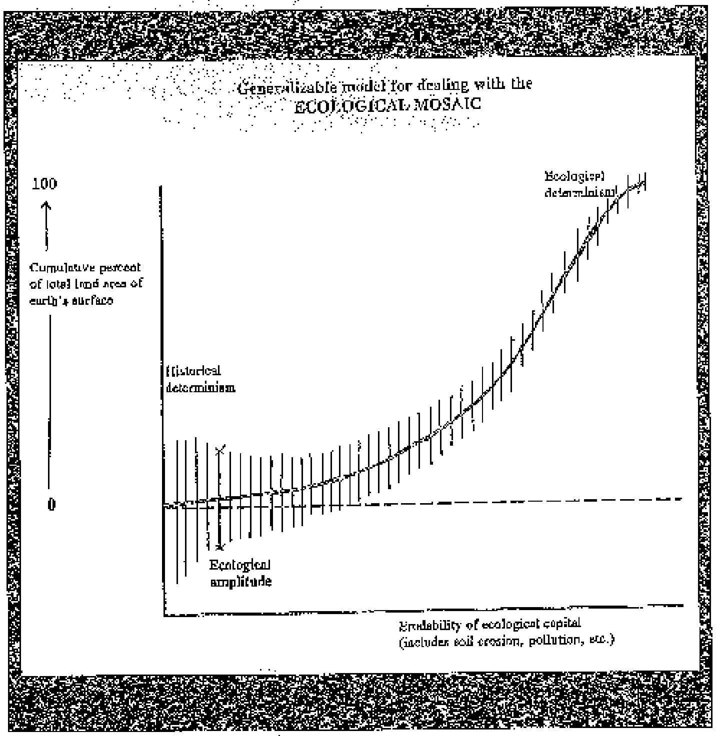
Very soon the four basic questions emerged which now guide our perennial polyculture research. They still stand as the best general questions for organizing our research agenda. The first, which asks whether perennialism and high seed yield can go together had to be answered because (a) there is some reason that the high yielding non-woody crops our agricultural ancestors gave us are annuals, and (b) most biologists in the early 1980s held to the notion that a plant was effectively a closed system. If we were to successfully select for high seed yield in a perennial, the resources devoted to the root would be robbed and we would be driving our plants toward annualism. We had to confront this trade-off idea head on.

As Jon Piper details in this *Land Report*, research now shows that there is no automatic penalty in terms of trade-off when a new gene is introduced for high seed yield. We have documented high yields in perennial monocultures which already rival those of some annual monocultures. The most important basic questions about biological possibilities for seed yield within herbaceous perennial flowering plants have been answered. But if we stop here with a high-yielding perennial, we will have missed the larger point, for in the long run it is the herbaceous perennial *polyculture* that we want to pay the ecological bills using sunlight. The next three biological questions follow from this ideal.

Our second question, then, is whether a polyculture of perennials can stay even with or, better still, outyield a monoculture. The third question is can a polyculture adequately manage insects, pathogens, and weeds? Again, Jon's article will give you the results of our work on these questions, and the news is mostly good. By imitating the structure of the native prairie ecosystem, we *are* granted some of the function of internal nutrient cycling and "pest" control. Finally, the fourth question is can a domestic polyculture analog of the native prairie sponsor enough of its own nitrogen fertility? Though three of our four questions have been answered to our satisfaction, we still have to worry about this question for nitrogen is a major limiting factor in crop production and comes at a large cost of nonrenewable energy. Natural gas is the feed stock for commercial nitrogen.

These are the highlights of our recent work on perennial polyculture. We are where the Wright brothers were at Kitty Hawk. I don't want to trivialize agriculture by comparing it to human flight, for I really do believe that these results and implications are more profound for human civilization than the results the Wright brothers first achieved December 17, 1903. We have been some sixteen years getting to this point. Whether there is some utility in the comparison for where this work will go from here, we can't say. But neither the Wright Brothers nor the five spectators standing on those sands at Kitty Hawk could have foreseen how that awkward contraption would become the prototype of a craft which would one day cross the Atlantic with 300 people or travel, as the SST does, as fast as a .22 bullet (that one is especially impressive to us farm boys who hunted rabbits with a .22).

We didn't need another form of transportation when airplanes were invented and developed. But a study of the history of earth abuse through till agriculture should convince anyone that we do need to solve the problem *of* agriculture, rather than focusing only on problems *in* agriculture. The problem of agriculture still features *soil erosion*, as it has since agriculture was invented. That alone justifies a new form of agriculture for grain production. But that age-old problem now includes *fossil fuel dependency* for fertility and traction and the introduction of human-made *chemical killers* of life forms to get at our traditional competitors which we call pests. Since pests are made of the same DNA and amino acids as we, should we be surprised to know that we are being killed too, at an increasing rate? A major failure of evolutionary biologists is their lack of warning to regard alien chemicals as guilty until proven innocent.



Intern Debbie Crockett

It is time to move the Darwinian evolutionary ecological world view to front and center for agricultural research. Agricultural researchers have routinely stiff-armed ecologists who have wanted to get involved, while other ecologists have been so anxiety-ridden due to physics-envy that they have not wanted to lower themselves to work on agricultural problems. That is changing now, but the merger of agriculture and ecology could be greatly accelerated. This should provide the new paradigm for agricultural research everywhere.

This does not mean perennial polyculture everywhere. Friends of the Land will forgive me, I hope, for the second time in these pages showing the accompanying graph which describes the agricultural situation on the American landscape. At the lower left are the forgiving environments like flood plains, environments not subject to erosion or salting or whatever. Maybe they have deeper soils or soils recharged by periodic flooding. These are what we might call resilient environments. History teaches us that they are few and far between.

As agriculture spread over large parts of the landscape, disaster struck in the form of loss of ecological capital — soil. Look to the upper right on the graph and imagine there a sloping hillside or some other fragile environment. Here we had better rather precisely imitate the natural vegetative structure or leave it alone. If we don't, there will be an erosion of ecological capital. Imagine a steep southwest facing slope in Kansas, or the southern end of the San Joaquin Valley where irrigation brings salt to the surface. This is what brought ancient Mesopotamia down. The vertical lines along the slope represent the ecological amplitude or the range of departure "permissible" from the original vegetative structure. Even in the more resilient environments, some sort of crop rotation must be maintained to insure adequate nitrogen fertility and management of pests.

Now look between these two extremes at the American landscape. In the early 1980s, before the Conservation Reserve Program we had 400 million till ag acres in the US. Of that acreage, only 48 million is considered non-erodable. That leaves at least 350 million acres susceptible to erosion, which is the place for perennial polycultures. They should not be the same ensemble of species everywhere, of course. We are dealing with the reality of the ecological mosaic. As John Todd once put it, in reference to architecture but applicable to agriculture, we seek "elegant solutions predicated on the uniqueness of place." Or, as Alexander Pope said in the "Epistle to Burlington," "consult the genius of the place in all."

But just as the idea of Darwinian evolution through natural selection holds from the poles to the tropics, so would the principles of an ecological agriculture hold worldwide. This would mean the end of agricultural methods and technology being transferred from the fossil fuel-intensive industrialized societies into the Third World. Rather than the current division between industrial and Third World agriculture, the new paradigm would unite agricultural workers everywhere for the evolutionary and ecological principles are common. Across the ecological mosaic a coherent community of Papago Indians would be understood and honored by a coherent community of farmers from Massachusetts or Thailand. Agricultural researchers in Austria could talk the same language as agricultural researchers in Chad. The vegetative structure would differ but the principles would be common.

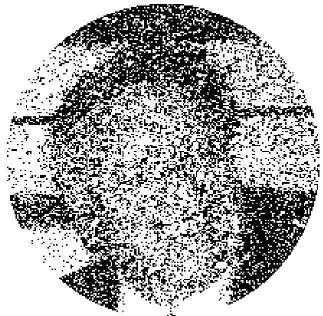
Now for the second major area of our agricultural research and how it fits with perennial polyculture. Back in 1979, Marty Bender and I recognized the need to compare our perennial polyculture yields and their ecological costs against a sun-powered standard. We needed an even playing field for comparative purposes. Imagine a sunshine farm using traditional annual grain crops in optimum rotations. When Marty Bender returned after finishing a Ph.D., we had the man back who I knew could get our Sunshine Farm project moving. The first year, Marty lived in Lawrence where he took advantage of daily access to the University of Kansas libraries to generate a paper study. We are now in the third year, the second year of implementation for a ten-year project. This experiment is unlike any that has ever been done, not so much because it combines the use of draft animals and a diesel tractor to be run on vegetable oil produced by crops that we grow, but because it includes a detailed computer accounting of nutrients, energy, and labor. We want to know how much of the bill can be paid from the farm itself, including even the embodied energy in all equipment (i.e., the cost to mine, process, fabricate, and assemble the likes of shovels, batteries, and everything else used on the farm). Two important outcomes are likely to come from the Sunshine Farm. First, we will have a standard against which we can eventually compare traditional and conventional grain agriculture (featuring human cleverness) with herbaceous perennial grain polyculture which mimics the prairie's structure (featuring nature's wisdom). Second, we will be closer to knowing the true ecological cost of our food, which is now the product of a cheap food policy.

Under the extractive economy and monoculture mindset, little attention has been given to the social costs of industrialized agriculture, and still less to honoring and enlivening the culture that would know how to farm according to the ecological mosaic. Fossil-fuel-powered economic forces have caused people to be forced off the land and out of the small towns and rural communities. Main Street silently closes. Schools close. Churches close. Rural baseball stops, and the cultural seed stock ends up in the likes of Silicon Valley. People who have the cultural information necessary to raise food and families and build lasting communities vanish. Perennial polyculture and Sunshine Farms aren't enough. We can't simply design a new agriculture and expect it to be implemented automatically by the market economy.

It seems worthwhile, therefore, to extend the "nature as measure" paradigm all the way to the structure of human communities. Natural ecosystems run on sunlight and feature material recycling. This is what humans will have to do, so should we not learn from nature as well for human communities? It may seem outrageous to presume that the ecological world view could penetrate all sectors of society, but consider the power of the world view which informs our everyday thinking now. It is unconscious, "comes with the milk," so to speak. George Bernard Shaw once said that "perfect memory is perfect forgetfulness." If the current industrial paradigm can build dendrites all of the way into the inner recesses of our thinking and affect and be affected by the social structures, be they governmental, religious, economic, whatever, how about a little dendritic growth from the ecological paradigm reaching way beyond agriculture into society? Human communities must be part of natural systems agriculture.

Matfield Green, in the Flint Hills of Kansas, has a population of 50, within a township which has a total of about 150. All of Chase County now has only 3,000 people left, down from around 8,500 a century ago. Accounting for changes in human populations is an ecological problem. Our project is about "setting up the books for ecological community accounting." We take our cues from the way ecologists have studied natural ecosystems such as prairies, forests, fens, and alpine meadows, only include the human community. We establish a series of boundaries in order to determine what goes in and out and look at the dynamics between the community and the surrounding ecosystems. We want to know whether the system is gaining or running down, and what happens to communities as a result.

Extending the "nature as measure" idea into the design of human communities introduces a different sort of complexity than that which attends our perennial polyculture research. We hope that the methodologies developed here will increase the imagination about possibilities for others interested in rural community development. There are thousands of such declining small towns throughout the Midwest and Great Plains. Here is a great opportunity for a new generation of homecomers to reinhabit the countryside, not as a matter of mere nostalgia but as a practical necessity. We need people who will defend their community fired by an inner flame of affection. It is from life in the little places connected to the sources for food, clothing, and shelter that much of the important cultural seed stock developed in earlier sun-powered economies. The war against biotic diversity is the same war being waged against cultural diversity. In short, there are sound cultural and ecological reasons to resettle these places, but we dare not settle them with the same set of assumptions that we settled in the first place — infinite resources, infinite substitutability, control nature. We need settlers whose offspring will come to take the idea of the ecological mosaic with the milk.



I think embedded in all of this is the possibility of the beginning of a moral philosophy, for within "nature as measure" the reward runs to the farmer and the landscape. The system pays the bills. With the human cleverness approach, the reward runs to the suppliers of inputs, the seed houses, the chemical companies, the farm machinery companies. The farmer has been a victim of a system more designed to exploit his subordinate and vulnerable position than to alleviate it. With nature as measure the farmer of the future might have a psychology more like that of a nineteenth century British naturalist. When it comes to trying to plant and maintain the correct arrangements across the ecological mosaic, he or she will be a naturalist with a utilitarian bent.

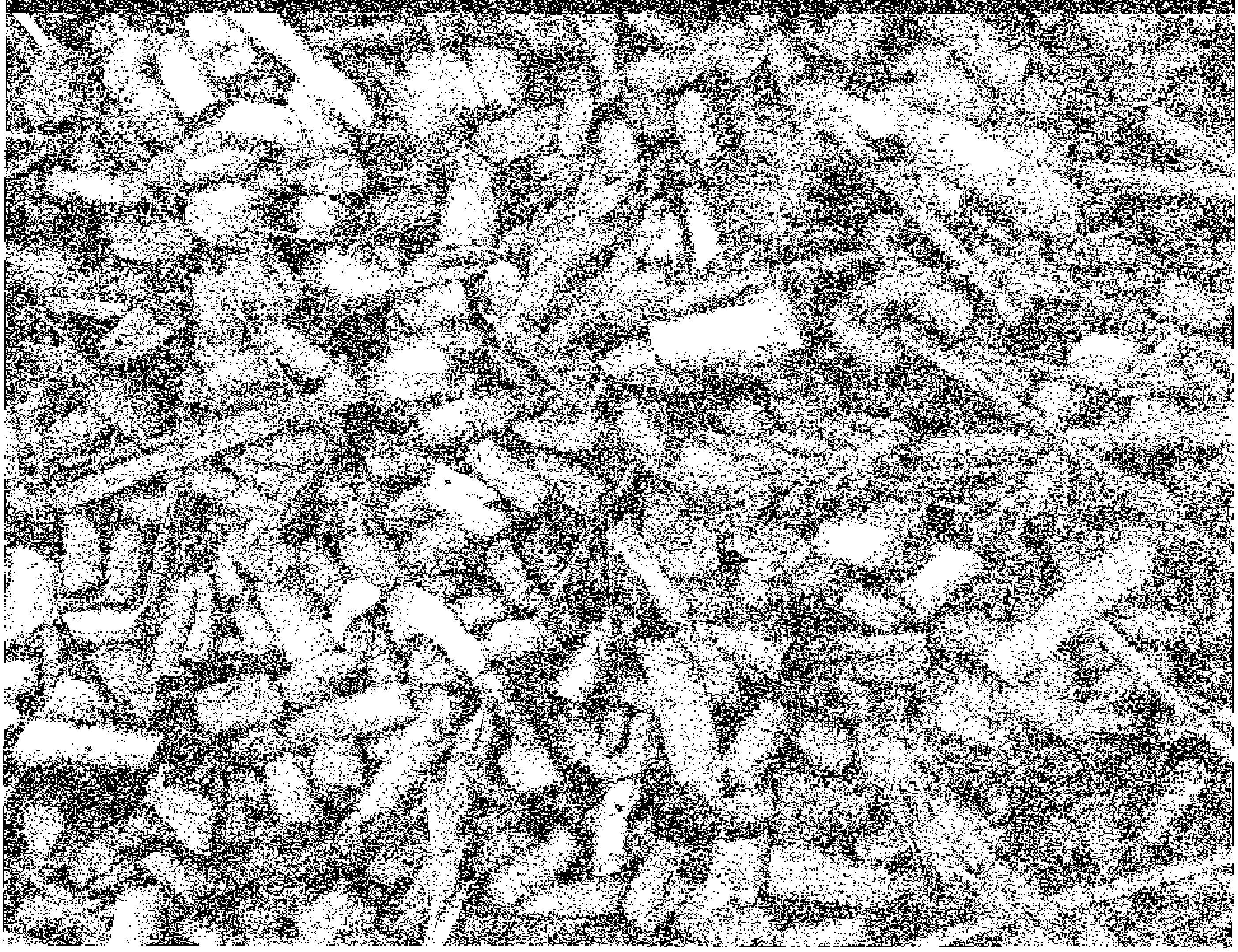
With all that in mind, The Land Institute is putting its effort into *natural systems agriculture*. We are broadening our own research, and we would like to see cooperative research programs across the country that will incorporate ecological and evolutionary principles into agriculture. The central and fundamental research questions to be addressed include: What functional or structural properties of natural ecosystems can be incorporated into new agricultural systems? What ecological and evolutionary principles can guide the development of new paradigms? Current agricultural systems feature monocultures of annual plants. Natural ecosystems feature diverse mixtures of perennial plants. Are these really two ends of a continuum? We can only know when we take away the subsidies of the former or supply subsidies to the latter. High yields, sustainability and minimal environmental costs may be brought together easier than we think.

We need to find out. That is why we need centers where groups of agronomists and ecologists can come together to consult the genius of the place, and put the nature as measure approach to work. The Land Institute and Kansas State University have agreed on a mission statement and on a cooperative effort to encourage USDA funding of research where native prairie serves as a model. We are promoting centers where teams of plant, soil and insect ecologists, plant breeders, plant pathologists, historians and modelers collaborate to develop this new kind of agriculture. We think it is time to acknowledge the reality of the ecological mosaic. If we do our work with that reality in mind we could be well on our way to solving the problem of agriculture. Now is the time to bring about the merger of agriculture and ecology. We are talking about a long-term comprehensive program, something we should pursue while we still have oil-sponsored slack in agricultural production. America has, within its power, what it takes to build an agriculture more resilient to human folly.

Wes Jackson is President of The Land Institute

Perennial Polycultures: Grain Agriculture Fashioned In The Prairie's Image

Jon K. Piper



The prairie presents a crucial ecological dilemma. Here exist some of the richest soils in the world, yet they are highly vulnerable to loss via wind and water erosion. When European settlers first broke the 5000-year-old prairie sod, they began a process of inexorable soil decline. The question for us Plains dwellers today is, can we create a grain agriculture that reflects many of the characteristics of the original prairie ecosystem that made it sustainable?

To use the prairie as a model or standard for a sustainable grain agriculture requires first appreciating the features of natural ecosystems that promote stability. Terrestrial ecosystems consist not only of plants, animals, and the fungi and microbes crucial for decomposing organic material and recycling nutrients, but also the parent material beneath the soil that provides minerals essential to the systems, water that enters as precipitation, and the solar energy captured through photosynthesis and transferred from organism to organism. Natural ecosystems regulate crucial nutrients so that inputs approximately equal outputs in a "steady state." Hence, prairie ecosystems may provide our best models for the principles necessary to achieve the tight nutrient cycling and solar driven energy flow that will be crucial to agricultural sustainability.

Prairie vegetation is a grass-dominated mixture consisting primarily of perennial warm-season and cool-season grasses, legumes, and composites growing oftentimes intermixed. The diversity of plant species with complementary niches contributes in large part to the resilience of prairies in the face of climatic extremes. Differences in growth form, type of resource use, and seasonality allow these plant species to coexist. Under the ground, one plant may produce a deep taproot, whereas its neighbor produces shallow, fine roots. Some species, legumes primarily, fix atmospheric nitrogen in addition to taking up available nitrogen in the soil. Seasonal timing of resource use differs among species, thereby reducing competition for soil water and nutrients. Warm-season grasses and drought-hardy forbs are able to withstand the hot, dry conditions of summer. Others, cool-season grasses and some forbs, persist by growing in the spring and setting seed before the onset of summer heat.

Tight nutrient cycling is a sustainable feature of the prairie we would do well to emulate. Because most nutrients are tied up in living organisms and soil organic matter year round, they are not vulnerable to loss through leaching or erosion. In prairies, critical nutrients are cycled seasonally within plants, stored in soil organic matter, or quickly taken up by plants and microbes once mineralized by decomposers in the soil.

Prairie soils are among the most productive soils in the world. The roots of prairie plants created and maintained the rich soils that made "the world's breadbasket" possible. As much as 60 to 75% of the prairie's total plant biomass occurs underground as roots, rhizomes, and crowns. Seasonal drought cycles, involving warm moist springs and summers favorable to luxuriant grass growth followed by dry summers and autumns, have led over the millennia to an accumulation of soil organic matter via root turnover. In some prairies, 30 to 60% of root biomass may turn over each summer, leaving a rich store of deep, dark organic matter that has made the highly productive U.S. grain belt possible.

In depleting the soil's original fertility, our very productive agriculture has essentially been mining over decades the fertility built up over millennia by the prairie ecosystem. Over a mere century of applying tillage agriculture to the prairie soils of North America we have lost 50% of the topsoil's original productivity. The few remnants of intact prairie serve as prime examples of inherently sustainable biotic communities in which complex webs of interdependent plants, animals, and microbes garner, retain, and efficiently recycle critical nutrients. Before we expend anymore of our precious topsoil, we should consider a model for the future for our "breadbasket" that mitigates soil erosion while providing edible seeds.

Modern industrialized agriculture is based largely on monocultures of annual crops that receive biocides, fertilizer, and fossil fuel-based energy inputs to remain productive. Such practices have resulted in soil loss and chemical contamination of soil and water. The Land Institute is studying a new model for grain agriculture, based on mimicking the prairie ecosystem, that involves diverse plantings of perennial grasses, legumes, and composites developed as grains. Polycultures of herbaceous perennial seed crops would be composed of plants that differ in seasonal nutrient use and thereby complement or even benefit one another in the field. Agroecosystems that are functional analogs of the prairie ecosystem should feature species adapted to local seasonal precipitation patterns, tight nutrient cycles, compatibility in resource use among species, soil preservation, and biological methods of crop protection.

Research on a prairie analog for agriculture is more complex than conventional studies of crop mixtures because it goes beyond simple two- or three-component systems and uses perennials instead of annuals. Very little ecological or genetic information on crop varieties appropriate for polyculture designs has been gathered, and plant breeders are only beginning to approach the problem of how to apply such knowledge to designing viable intercropping systems. Because perennial grains will be required to maintain themselves in the field for a period of years, instead of months as with annual crops, it is necessary to incorporate multiple year patterns of growth and seed yield into the research. Unlike the grower of annuals, who has some flexibility in changing crops or modifying field conditions after each growing season, farmers establishing perennial polycultures will have to forecast over several possibly very different growing seasons.

Research at The Land Institute to develop sustainable perennial polycultures necessarily addresses seed yield, maintenance of soil fertility, and management of troublesome organisms. Thus, the research encompasses four primary questions critical to the development of viable perennial polycultures:[1]

- Can a perennial grain yield as well as an annual grain crop?
- Can a perennial polyculture overyield?
- Can a perennial polyculture provide its own nitrogen fertility?
- Can a perennial polyculture manage insects, plant pathogens, and weeds?

The purpose of this article is to review some of the progress we have made within these four areas of research.

Question 1: Seed yield in perennials

Two general approaches are possible in the development of perennial grains. The first approach involves the conversion of a wild perennial into a seed crop by selecting for such agronomic characteristics as high seed production, reduced seed shattering, uniform time of maturity, ease of threshing, and large seed size. In this case, the potential crop already has the desired perennial habit, but lacks most of the characteristics that would make it a good grain crop. The difficulty facing the plant breeder is to select against some undesirable "wild" traits while retaining perennation and good nutritional qualities of seed. The second approach starts with annual grain crops and attempts to turn them into perennials by crossing them with perennial relatives. The rationale for this approach is that annual crops have already undergone domestication over the last several thousand years. Hence, they already show such agronomically favorable characteristics as edibility, high yield, large seed size, ease of threshing, synchronous maturity, and resistance to shattering and lodging.

With either approach, obtaining high seed yield from perennials is more complex than it is with annuals. Not only must the yield be high in one year, but yield must be maintained at sufficiently high levels for several years after the crop is established. Seed yields of perennial crops need to be at some acceptable level to make the perennial polyculture model compelling. For comparison, the bench-mark yield for Kansas wheat is about 1800 lb/acre, or about 2000 kg/ha. It is promising that several herbaceous perennial grasses and legumes approach or exceed this bench-mark yield.

Does the perennial habit itself set a limit on seed yield? Whereas it is true that a perennial must devote some resources to constructing and maintaining its permanent organs, an expense an annual does not bear, it is not clear that high seed production and perennation are in a strict trade-off relationship within a plant. Increased seed production may be due to more than a simple reallocation of resources from roots and stems to flowers and seeds. Instead, this increase may be associated with enhanced overall vigor, number of reproductive organs on a plant, or to green flowers and fruits that photosynthesize and to an extent "pay their own bills." Several studies of perennials have shown that increased sexual reproduction in the present leads to little or no "cost" to future reproduction or reduced survival.[2] These are promising results for our effort to breed for higher seed yield without losing a plant's perennial nature.

Development of perennial grains is necessarily a long-term process. Work at The Land Institute to domesticate perennial grains began in 1978 with an inventory of nearly 300 species for their suitability to the environment of central Kansas and promise of high seed yield. A second inventory studied the agronomic potential of 4300 collections of perennial grass species within six cool-season genera. From these inventories, a handful of perennial species was chosen for potential crop development.

Eastern gamagrass (*Tripsacum dactyloides*) is a warm-season grass native to the region stretching from the southeastern United States and Great Plains to southern Nebraska southward to Bolivia and Paraguay. Gamagrass grain is both tasty and nutritious, being about 27 to 30 % protein and 7 % fat.[3] The major limitation of eastern gamagrass as a grain crop is its low seed yield. The Land Institute has explored in its breeding program a genetic variant which produces almost exclusively female flowers and thus has the potential to increase seed yield several fold.

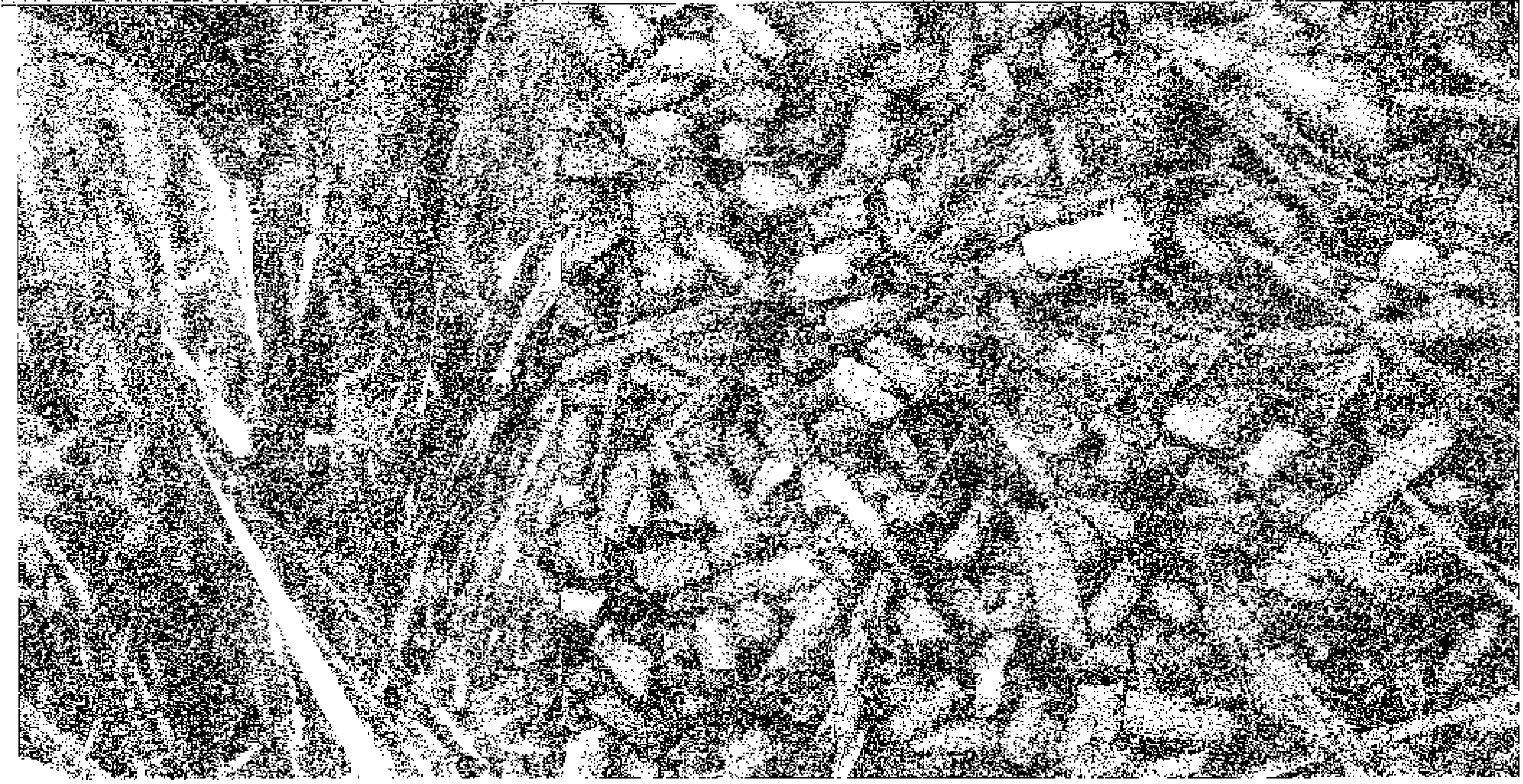
Wildrye (*Leymus racemosus*) is a distant relative of wheat, rye, and barley. It is a cool-season grass native to Bulgaria, Romania, Turkey, and parts of the former Soviet Union, that has been planted in the western U.S. to stabilize sandy soils. Grain of this species was eaten by Asian and European people historically, especially in drought years when annual grains faltered.

Illinois bundleflower (*Desmanthus illinoensis*) is a nitrogen-fixing legume that is native to the Great Plains with a range extending northward into Minnesota, east into Florida, and as far west as New Mexico. The nutritional quality of the seed (38 % protein, 34 % carbohydrate) suggests great potential as a grain crop for human or livestock consumption.[4]

Wild or Maryland senna (*Cassia marilandica*), another legume, is native to the southeastern region of the Great Plains. Although The Land Institute is not working to develop this species as a grain, because the seed appears to have low value as food, much information on its long-term patterns of seed yield has been gathered to address the biological question of whether a herbaceous perennial can produce a sustained, high seed yield.[5]

Maximilian sunflower (*Helianthus maximilianii*, Compositae) is native throughout the grasslands of the Great Plains. Its range extends eastward to Maine and North Carolina, and westward to Texas and the Rocky Mountains. In addition to its potential as a grain or oil crop (seed is 21 % oil)[6], Maximilian sunflower appears to inhibit weed growth allelopathically, and may therefore be especially important during the establishment phase of a perennial polyculture.

The best example of our perennial hybrid approach is the perennial sorghum work, in which hybrids have been made between some tetraploid lines of grain sorghum and collections of Johnsongrass from Kansas and California. Grain sorghum (*Sorghum bicolor*, Gramineae), a native of the African continent, is grown for animal feed in the southern Great Plains. It is weakly perennial in tropical regions, but is killed by frost in temperate latitudes. Johnsongrass (*Sorghum halepense*), a weedy relative of cultivated sorghum, is in the United States a troublesome weed that overwinters by production of rhizomes, fleshy underground stems capable of winter survival. We are exploring the feasibility of converting sorghum from an annual to a perennial grain by combining in hybrids good grain quality with the



ability to produce winter-hardy rhizomes.

The highest yields for wild perennials at The Land Institute have been for Illinois bundleflower and wild senna in which some plots have produced around 200 g/m^2 (2000 kg/ha). Peak yields of wildrye, eastern gamagrass, and Maximilian sunflower have been lower (~25 to 83 g/m^2). Increasing seed yield is therefore a priority for our plant breeding work.

The work thus far has demonstrated that it is possible to retain rhizome production in sorghum/Johnsongrass hybrids. Interestingly, there was a positive correlation between seed yield and rhizome mass in hybrid plants in a 1990 study, indicating that particularly vigorous plants had both high seed yield and rhizome production.[7] In another planting of sorghum hybrids in 1992,[8] seed yield of rhizome-producing plants averaged 172 g/m^2. As this work proceeds, it will be important to determine whether there is a necessary loss of rhizome production as good agronomic qualities are increased, or whether these two sets of traits can be combined in hybrids.

Selection of plants for use in polyculture is more complex than selection for monoculture. Plant breeding lines behave differently when grown in different planting arrangements or with different species as neighbors. Several polyculture studies at The Land Institute have revealed striking environment and neighborhood effects on yield and growth, positive and negative associations between species, and change in the direction (positive or negative) of interactions in different years.[9] Successful mixtures of perennial grains will have to accentuate positive while minimizing negative associations between species.

Question 2: Overyielding

Overyielding is the phenomenon in which crop mixtures yield more per unit area than their components yield in monoculture. This can occur when competition between members of different species is less intense than competition between memebers of the same species, or where one crop species enhances the growth of another. Canopies of neighboring crops might occupy different vertical layers, with tall crops tolerating strong light and shorter crops requiring shade or relatively high humidity. Roots of different species may explore different soil layers. Crop species may have complementary nutrient requirements, as in mixtures of legumes and grasses, especially in soils where the nitrogen supply is limited. Finally, differences in the length of the growing period or in the seasonal periods of nutrient uptake among crops can promote overyielding. Where certain crops have been grown together for centuries, as in the maize-bean-squash polycultures of traditional Mexican agrarian cultures, intercrop compatibility has increased through coevolution.

Three studies at The Land Institute have examined the question of overyielding with perennials. The first study comprised a series of monocultures and bicultures of wild senna, which does not fix nitrogen, and Illinois bundleflower, a legume that potentially fixes appreciable amounts of nitrogen. Significant overyielding occurred in this experiment by the second year, and appeared to increase with time.[10] This study indicated the benefit to a perennial of association with a nitrogen-fixing species. It also showed that polycultures can counteract the trend, observed in some perennials, toward decreasing yields in subsequent years.

In another study, 28 collections each of Illinois bundleflower and eastern gamagrass were grown in a series of monocultures and bicultures to estimate overyielding.[11] In the first year in which gamagrass produced seed, there was a 25% yield advantage in biculture based on average yields, and 19% overyielding based on best yields. In the next year, overyielding based on best yields was 8%. These favorable results demonstrate that overyielding, typical in many polycultures of annual crops, can also occur in perennial polycultures and can occur in more than one year.

Mixtures of wildrye, eastern gamagrass, and Illinois bundleflower should overyield because of the species' distinct differences in soil water and nutrient uptake.[12] A third study, begun in 1991, is examining overyielding in bicultures and tricultures of the three species. The plots for this experiment were planted on both a fertile and a less fertile soil. In 1992, the first year in which all three species flowered, 1 to 6 % overyielding occurred in both bicultures at both sites. In 1993, gamagrass seed could not be harvested from the poor soil site, nevertheless overyielding at the first site ranged from 10% for the gamagrass/wildrye biculture to 26% for the triculture. In 1994, overyielding occurred in all instances except the gamagrass/wildrye biculture at the better site.[13]

Question 3: Can a perennial polyculture provide its own nitrogen fertility?

Legumes can provide nitrogen to companion crops in two ways: either more soil nitrogen remains available for other species because legumes take up less of it, or the nitrogen fixed becomes available to other species in the mixture when the legumes' roots decay. The question is, to what extent can nitrogen-fixation by legumes compensate for nitrogen used in plant growth and removed in harvested seed? Our results so far are preliminary, but encouraging.

We have focused on Illinois bundleflower as a nitrogen supplier to polyculture as well as a significant seed yielder. The mean acetylene reduction rate (an estimate of nitrogen fixation under laboratory conditions) measured in 70-day old Illinois bundleflower plants was 141 nmoles/min.[14] This value is similar to or somewhat higher than values reported elsewhere for this species and also for 68-day old soybeans.[15]

The benefit from a nitrogen-fixing companion crop should be greater on poor soil than on a more fertile soil. A study of Illinois bundleflower grown on two soil types has shown that lower growth and yield on a poorer soil can disappear when precipitation is adequate. This result indicates that Illinois bundleflower can compensate for low soil nitrogen without reducing its growth or seed yield. Moreover, the soil nitrate concentration in four-year-old Illinois bundleflower stands at the poorer soil site was nearly identical to that on the better soil site despite very different initial nitrogen conditions.[16]

Question 4: Can a perennial polyculture manage weeds, insect pests, and plant pathogens?

Perennial polycultures can take advantage of species' overlapping growth periods to block light or usurp soil nutrients before weeds can take hold. Another biological means of weed control is allelopathy. This term refers to any direct or indirect harmful effect that one plant has on another through the production of chemical compounds that escape into the environment. Allelopathy would be especially valuable during the vulnerable establishment phase until the perennial canopy becomes established.

Evidence of weed control has occurred in two separate experiments at The Land Institute. In one study, monocultures were planted with five densities of Maximilian sunflower, a reputed allelopathic plant, and a control plot with no sunflowers. Weed biomass was significantly reduced in the sunflower plots relative to the control.[17] By the second year, a sunflower density of 3.6 plants/m^2 reduced weed biomass to a level only 25 to 50 % of the control. In the third year, weed biomass in sunflower rows in May was still only 44 % of weed biomass in the control plot. Here, effective weed

management was maintained across years despite changes in the weed community from predominantly annuals in the first year to perennials by the third year.

In the second experiment that examined weed growth, a triculture comprising wildrye, eastern gamagrass, and Illinois bundleflower, species combinations differed in their ability to control weeds.[18] Weed biomass was consistently lowest in rows with eastern gamagrass as a component, despite seasonal and yearly changes in species composition of the weed community. These results point to eastern gamagrass as the primary weed controller among the three species, probably via shading.

Research on the effects of diverse cropping systems on insect pest control confirms that polycultures tend to reduce densities of insect pests relative to monocultures. Crop diversity can provide physical barriers and masking odors that can interfere with colonization, movement, feeding efficiency, and reproduction of plant-feeding insects.[19] In addition, a polyculture environment often attracts great numbers of beneficial predators and parasitoids.

Studies using annual grains and vegetables have demonstrated repeatedly that levels of insect pests tend to be reduced in polyculture relative to monoculture. For four years, we have monitored the population density of a beetle that feeds on young leaves and flowers of Illinois bundleflower. For the first three years, density was very low, averaging less than one beetle per plant, and there were no differences among treatments. In 1994, however, the beetle population "exploded," with one plant supporting as many as 123 beetles on one census date. The good news is that beetle density was consistently lower in polycultures than within monocultures throughout most of the season.[20] This promising result indicates that polyculture reduction of insect pests is possible within fields of perennial grains.

It is well established that disease problems in agriculture often result from extreme genetic uniformity of crops.[21] Thus, an increase in diversity created by planting mixtures of species, and mixtures of genotypes within species, can reduce the spread of some plant diseases, especially those spread by insects.[22] Eastern gamagrass, in particular, is subject to a pathogen, maize dwarf mosaic virus (MDMV)[23], which can reduce seed yield dramatically in severely infected plants. We found that MDMV incidence was reduced for the first two years in plots where bundleflower was present compared to gamagrass monocultures and to gamagrass bicultures with wildrye.[24] Hence, spread of this virus by aphids appears to be reduced in some polycultures, a favorable result for the potential to manage plant disease.

Literature Cited:

[1]Jackson, W. 1985. *New Roots for Agriculture*. New edition. University of Nebraska Press, Lincoln; Soule, J. D. and J. K. Piper. 1992. *Farming in Nature's Image: an Ecological Approach to Agriculture*. Washington, DC: Island Press.

[2] Bazzaz, F. A. and D. D. Ackerly. 1992. Reproductive allocation and reproductive effort in plants. In *Seeds: the Ecology of Regeneration*, ed. M. Fenner, 1-26. Wallingford, England: C. A. B. International; Jackson, L. L., and C. L. Dewald. 1994. Predicting evolutionary consequences of greater reproductive effort in *Tripsacum dactyloides*, a perennial grass. *Ecology* 75:627-641; Piper, J. K., and P. A. Kulakow. 1994. Seed yield and biomass allocation in *Sorghum bicolor* and F_1 and backcross generations of *S. bicolor* x *S. halepense* hybrids. *Canadian Journal of Botany* 72:468-474.

[3] Bargman, T. J., G. D. Hanners, R. Becker, R. M. Saunders, and J. H. Rupnow. 1989. Compositional and nutritional evaluation of eastern gamagrass (*Tripsacum dactyloides* (L.) L.), a perennial relative of maize (*Zea mays* L.). *Lebensmittel—Wissenschaft und Technologie* 22:208-212.

[4] Piper, J., J. Henson, M. Bruns, and M. Bender. 1988. Seed yield and quality comparison of herbaceous perennials and annual crops. In *Global Perspectives on Agroecology and Sustainable Agricultural Systems*, ed. P. Allen and D. Van Dusen, 715-719. Santa Cruz, CA: Agroecology Program, University of California, Santa Cruz.

[5] Piper, J. K. 1992. Size structure and seed yield over 4 years in an experimental *Cassia marilandica* (Leguminosae) population. *Canadian Journal of Botany* 70: 1324-1330.

[6] Thompson, T., D. Zimmerman, and C. Rogers. 1981. Wild *Helianthus* as a genetic resource. *Field Crops Research* 4:333-343.

[7] Jones, T. B. 1991. Evaluation of five germplasm groups for overwintering ability and agronomic characteristics in sorghum crosses: *Sorghum bicolor* (L. Moench) x *Sorghum halepense* (L. Pers). *The Land Institute Research Report* 8:12-18.

[8] Piper, J. K., and P. A. Kulakow. 1994. Seed yield and biomass allocation in *Sorghum bicolor* and F_1 and backcross generations of *S. bicolor* x *S. halepense* hybrids. *Canadian Journal of Botany* 72:468-474.

[9] Muto, P. J. 1990. Evaluation of Illinois bundleflower and eastern gamagrass germplasm in monocultures and bicultures. *The Land Institute Research Report* 7:25-28; Piper, J. K. 1993. Neighborhood effects on growth, seed yield, and weed biomass for three perennial grains in polyculture. *Journal of Sustainable Agriculture* 4(2):11-31; Barker, A. A., and J. K. Piper. 1993. Studies of monocultures and mixtures of three perennials: I. Growth and seed yield over three years. *The Land Institute Research Report* 10:14-21.

[10]Braun, L. 1985. Overyielding in a perennial legume biculture. *The Land Report Research Supplement* 2:4-7.

[11]Muto, P. J. 1990. Evaluation of Illinois bundleflower and eastern gamagrass germplasm in monocultures and bicultures. *The Land Institute Research Report* 7:25-28

[12] Piper, J. K. 1993. Soil water and nutrient change in stands of three perennial crops. *Soil Science Society of America Journal* 57:497-505.

[13]Blume, P. 1995. Seed yields of three perennial grains in monocultures and mixtures. *The Land Report* 51: 36-39.

[14]Kulakow, P. A., L. L. Benson, and J. G. Vail. 1990. Prospects for domesticating Illinois bundleflower. In *Advances in New Crops*, ed. J. Janick and J. E. Simon, 168-171. Portland, OR: Timber Press.

[15]Lofton, S. M. 1976. *Nitrogen Fixation in Selected Prairie Legumes as Related to Succesion*. Ph.D. Dissertation. Oklahoma State University, Stillwater; Lindemann, W. C., G. W. Randall, and G. E. Ham. 1982. Tillage effects on soybean nodulation, $N_2(C_2H_4)$ fixation, and seed yield. *Agronomy Journal* 74:1067-1070.

The ultimate value of the research at The Land Institute is in its move toward an agriculture based on sunlight, with closed nutrient loops, that uses a natural ecosystem as its model. A diverse and stable agriculture that includes mixtures of perennial grains would provide numerous environmental and social benefits. The immediate environmental benefits include reduced soil loss and chemical contamination. Academically, the practice and philosophy of science would be enhanced as ecologists merge their expertise with that of agronomists to develop new insights for looking at agriculture in an ecological context and dealing with the complexity inherent in dynamic biological systems.

Developing perennial grain polycultures is necessarily a long-term effort. We have been thinking it would take 50 to 100 years for The Land Institute to breed workable grain mixtures on our own. Major funding of this work could achieve results sooner, however. Moreover, major funding would enable the work in "natural systems agriculture" to progress at several different centers across the country. The best locations for such centers would be institutions with strong traditions in both ecology and agriculture.

The long-term sustainability of agriculture, in the face of dwindling resources and increasing environmental damage, will depend upon innovative, creative, and complex approaches. Such approaches should combine ecological theory with practical agricultural research to reduce fossil fuel dependency and pollution, while maintaining adequate levels of production and enhancing soil fertility. The blend of ecology and agriculture broadens the justification for preserving relatively intact natural ecosystems, as these represent the standards for agricultural sustainability and can provide the patterns and properties transferable to more sustainable forms of agriculture. Thus, to create a domesticated prairie much new research ground remains to be broken, but hopefully, in the process, the broken ground of the prairie will be healed.

Jon Piper is Land Institute Ecologist

[16] Blume, P. 1995. Seed yields of three perennial grains in monocultures and mixtures. *The Land Report* 51: 36-39.

[17] Gernes, M. 1986. Effect of *Helianthus maximilianii* density on biomass of naturally occurring weeds. *The Land Report Research Supplement* 3:39-42.

[18] Piper, J. K. 1993. Neighborhood effects on growth, seed yield, and weed biomass for three perennial grains in polyculture. *Journal of Sustainable Agriculture* 4(2):11-31.

[19] Risch, S. J., D. Andow, and M. A. Altieri. 1983. Agroecosystem diversity and pest management: data, tentative conclusions and new research directions. *Environmental Entomology* 12:625-629; Tahvanainen, J. O. and R. B. Root. 1972. The influence of vegetational diversity on the population ecology of a specialized herbivore, *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae). *Oecologia* 10:321-346; Tukahirwa, E. M. and T. H. Coaker. 1982. Effect of mixed cropping on some insect pests of brassicas; reduced *Brevicoryne brassicae* infestations and influences on epigeal predators and the disturbance of oviposition behavior in *Delia brassicae*. *Entomologia Experimentalis et Applicata* 32: 129-140.

[20] Geisen, R. 1995. Can a perennial polyculture manage its own disease and insect pest problems? *The Land Report* 51: 34-36.

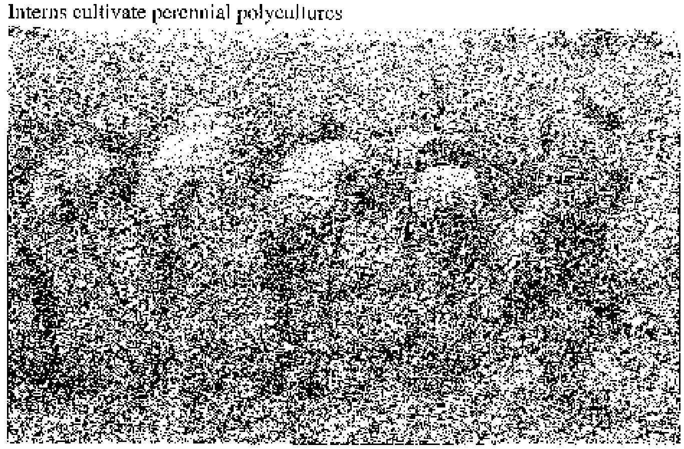
[21] Adams, M. W., A. H. Ellingbae, and E. C. Rossineau. 1971. Biological uniformity and disease epidemics. *BioScience* 21:1067-1070; Horsfall, J. G. et al. 1972. *Genetic Vulnerability of Major Crops*. National Academy of Sciences, Washington, DC; Barrett, J. A. 1981. The evolutionary consequences of monoculture. In *Genetic Consequences of Man-made Change*, ed. J. A. Bishop and L. M. Cook, 209-248. London, England: Academic Press.

[22] Altieri, M. A. and M. Liebman. 1986. Insect, weed, and plant disease management in multiple cropping systems. In *Multiple Cropping Systems*, ed. C. A. Francis, 183-218. New York, NY:Macmillan Publishing Co.; Bottenberg, H., and M. E. Irwin. 1992. Using mixed cropping to limit seed mottling induced by soybean mosaic virus. Plant Disease 76:304-306; Thurston, H. D. 1992. *Sustainable Practices for Plant Disease Management in Traditional Farming Systems*. Boulder, CO:Westview Press.

[23] Siefers, D. L., M. K. Handley, and R. L. Bowden. 1993. Sugarcane mosaic virus strain maize dwarf mosaic virus-B as a pathogen of eastern gamagrass. *Plant Disease* 77:335-339.

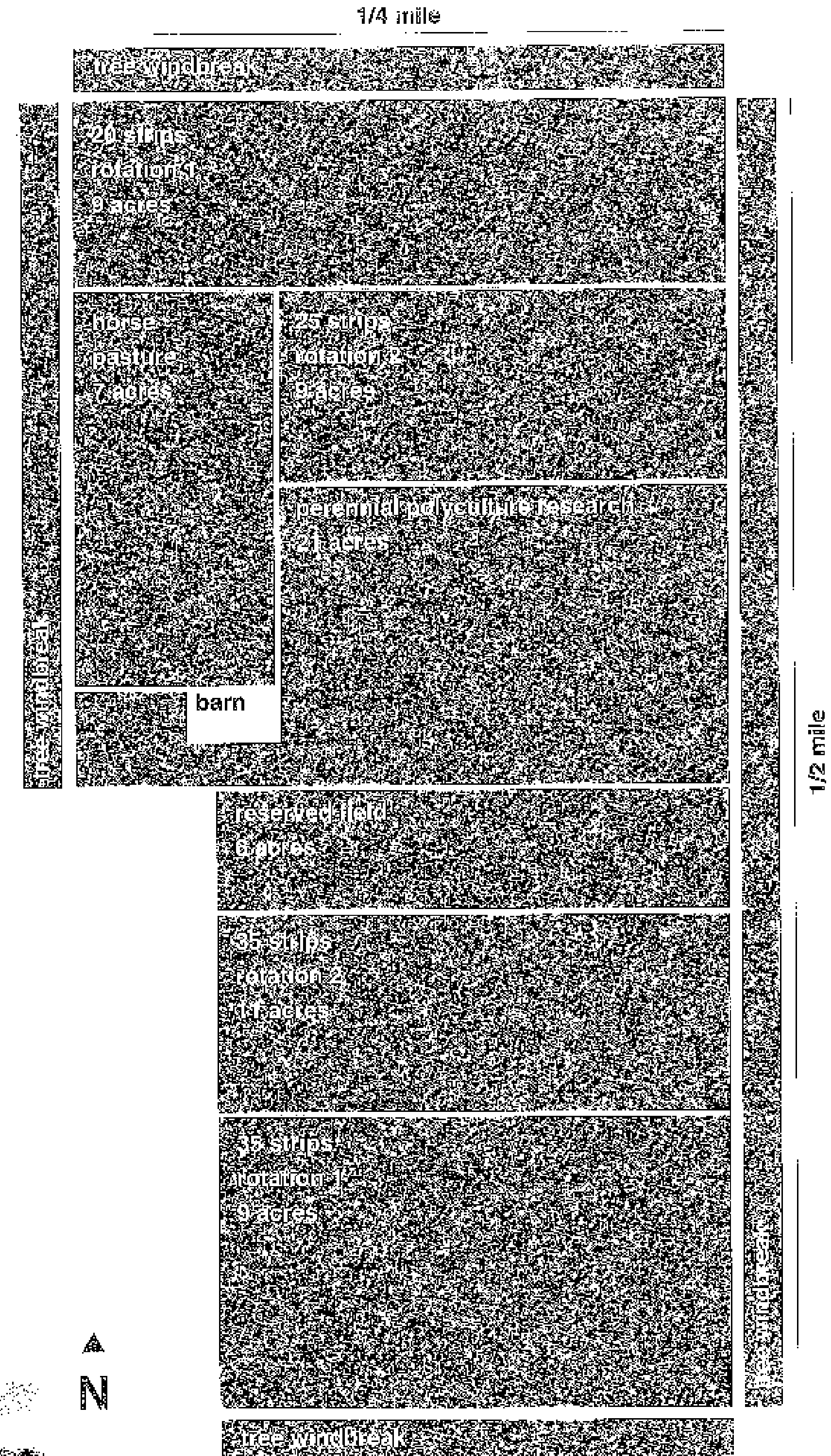
[24] Geisen, R. 1995. Can a perennial polyculture manage its own disease and insect pest problems? *The Land Report* 51: 34-36.

Interns cultivate perennial polycultures

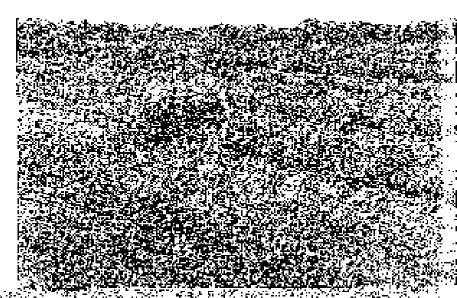


The Sunshine Farm Takes Shape

Marty Bender



Drilling grain and reaping sorghum on the Sunshine Farm.



The Sunshine Farm addresses the national problem of modern agriculture's dependence on fossil fuels. After two field seasons, the farm is up and running. Integration of crops and animals has begun, and this year we will be experimenting with renewable energy technologies. The project is unique because it involves the detailed accounting of energy, materials and labor in every task on an organic, energy-integrated farm. With two years of data in the computer database, we can begin to explore to what extent modern farms can run on sunlight. Our aim is to examine whether a farm can sponsor its own fuel and fertility, and to determine how much industrial energy society must provide to manufacture farm facilities, equipment, and inputs, in a post-fossil fuel era.

The Sunshine Farm project began with a one-year feasibility study to select the mix of crops and animals, and to choose renewable energy strategies with the greatest likelihood of success. As a research farm representative of Great Plains agriculture, the Sunshine Farm comprises 100 acres of native pasture for controlled livestock grazing and 50 acres of conventional grain, oil and forage crops in narrow strips. During the past two field seasons, staff and interns have built a five-wire high-tensile fence for draft horses, horse stalls, a six-strand barb-wire fence with a portable holding pen for cattle, several water lines and automatic waterers, a portable hen house and a portable broiler pen, a granary for storing horse feed, soybeans and sunflowers, and a double-barreled wood stove for heating the workshop. Most of the farm infrastructure is now in place.

Intern research projects to develop and analyze sustainable agricultural practices on the Sunshine Farm have begun. Innovative components on the Sunshine Farm include long-term crop rotations, narrow strip-cropping, close monitoring of soil quality, portable hen house and broiler pen, controlled cattle grazing, and exploratory incorporation of candidates from The Land Institute's research on perennial polycultures. The projects are set up as multi-year experiments that require graduate-level statistical analysis, which will lead to publication in peer-reviewed journals.

Intern research papers on initial results will be published in future *Land Reports*. Here is a brief summary. Two five-year crop rotations have been set up: 1) grain sorghum, soybeans, oats, sunflowers and sweetclover; and 2) grain sorghum, soybeans, oats, alfalfa and alfalfa again. Sometimes wheat is substituted for oats. The crops are grown in 120 thirteen-foot wide strips of four rows each, which progress through these rotations over the years. The purpose of strip-cropping is to provide many edges between different crops, which might lead to higher yields as a result of polyculture effects. However, we did not see these effects in the few strips we examined in 1994. Yields were not higher in edge rows than interior rows. This may have been because it was difficult to find field implements wide enough to control weeds in the edges, and yet not so wide that they sometimes inadvertently drift into adjacent strips. We expect these problems to be ironed out over time.

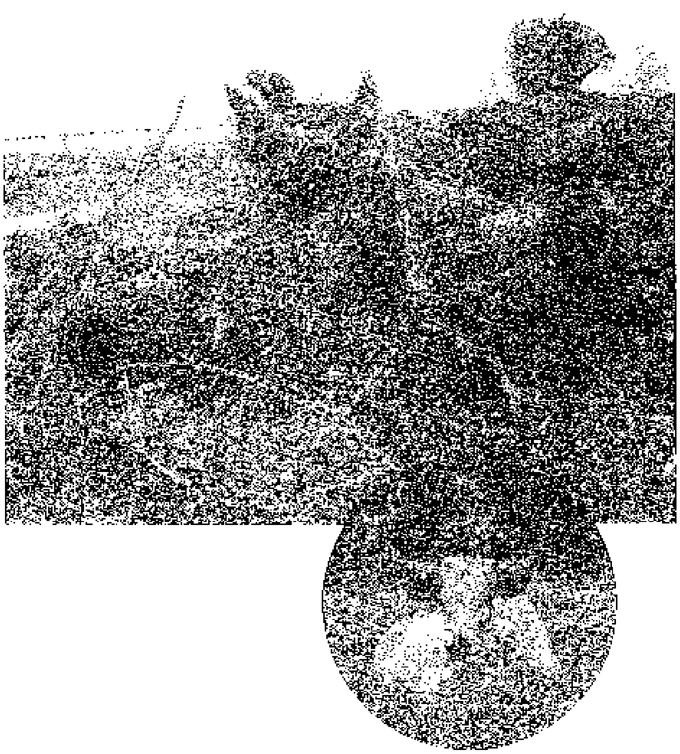
Most of our crop yields in 1994 were comparable to county averages, but we did have problems with organic sunflowers. By following the organic practice of planting in July to avoid spraying for sunflower head moths, we lost almost half our sunflowers to blackbirds in the fall. However, monitoring by Jerry Wilde of Kansas State University found very few moths or larvae in the strips, so this coming year we will plant sunflowers in June to avoid blackbird migration, and take our chances with the moth instead. Back in 1993, no one in Saline County was able to plant sunflowers during July because 18 inches of rain fell during that month. Since sunflowers are to provide about half of the oil fuel for our biodiesel tractor, these difficulties demonstrate a vulnerability that draft horses do not have because their feed can be much more flexible.

To judge the effect of crops on soil quality, we measured physical and biological properties in 30 crop strips and chemical properties in 60 strips. For three years prior to the Sunshine Farm project, the north half of the 50 acre site was planted to wheat, while the south half was in alfalfa. In 1994, soils in the south half had higher earthworm counts probably because alfalfa requires no tillage, but also had lower levels of phosphorus and potassium possibly due to the harvest of hay, which is high in these nutrients. We then compared the effects of growing grain sorghum, oats and soybeans in

1993 on soil properties in the spring of 1994. The most explicable crop effect on chemical properties was the higher nitrate level in former soybean strips, perhaps due to symbiotic nitrogen fixation by this legume. No differences were found in physical or biological soil properties since more than one year is required for these properties to be affected. We will be looking to see how soil properties change as our rotations proceed over the years.

Ultimately, we hope solar-powered farms will have perennial grain polycultures as well as conventional crops. It may be half a century before high-yielding perennial grains are bred, but right now we can examine how candidates from The Land Institute's perennial polyculture research could be used on the Sunshine Farm for forage and leguminous nitrogen fixation. Last year, we initiated an experiment to examine how compatible the native prairie legume Illinois bundleflower would be with grain sorghum and soybeans in our narrow strip-cropping system. The bundleflower increased the yields of neighboring strips of grain sorghum but not of soybeans, perhaps because soybeans fix their own nitrogen and thus did not benefit as much from the nitrogen fixed by the bundleflower. This year, we will include eastern gamagrass and mammoth wildrye in the strips as well as study bundleflower in its second year of growth.

Chicken and cattle grazing projects are also underway, and are reported by David Tepfer and Jeremy Plotkin in separate articles in this Land Report. Our farm manager, Jack Worman, has been keeping a team of Percherons at the Sunshine Farm, and using them for



plowing, planting, cultivating, and spreading compost from our composting chickens project. We have decided not to raise hogs because we want to avoid problems with adjacent homeowners.

We are employing renewable energy technologies in the form of both draft horses and tractors on the Sunshine Farm, and keeping track of the labor and energy required. AGCO (Deutz-Allis) recently loaned us a refurbished biodiesel-compatible 8630 119-HP tractor, which we will initially run on purchased soydiesel. We will explore on-farm oil production by pressing farm grown soybeans and sunflowers and feeding the left-over protein meal cake to the animals. We will begin by reassembling a dismantled oilseed press recently received from a Friend of The Land at the U.S. Department of Agriculture in Beltsville, Maryland. We are looking into processing this oil into biodiesel on-farm as a demonstration project. It is likely that guaranteed-quality biodiesel (chemically processed vegetable oil fuel) would be produced by local farmers' co-operatives on a somewhat larger scale in the future.

Electricity for drying grain, pumping water, running fence chargers and workshop tools and other needs will be provided by photovoltaic cells and wind-electric turbines on the Sunshine Farm. Western Resources, the regional public electric utility, has donated the components for a system of photovoltaic cells and storage batteries, and will begin assembling them this spring as weather permits. This system has been sized to meet the projected annual electric demand of the farm. By using automatic waterers that keep from freezing by being set in the ground, we eliminated the need for electric livestock water tank heaters in the winter, which can account for one-fourth to one-half of the electric load on a typical farm, not counting the house. The photovoltaic system will be connected to the utility grid because there may be times of the year when the power demand is greater than what is produced. The future inter-dependence of sunlight-powered farms with local fuel co-operatives and regional utility grids demonstrates that the aim of renewable energy technologies is not complete farm self-sufficiency, but reducing the use of fossil fuels as much as possible across society as a whole.

One of the central goals of the Sunshine Farm is to carefully account for all of the energy, materials and labor that actually goes into running the farm. To make this data accessible for analysis in a computer database, a taxonomy was developed to define the various farm tasks, projects, enterprises, objects, inputs, and other categories. To control the entry of the data into the computer database so that the stored information is in a uniform format for analysis, former Land Institute intern Chad Hellwinckel (now a graduate student in agricultural economics at the University of Tennessee) designed a user-friendly input screen. This screen handles complex entries, such as prorating the fuel and labor devoted to each crop in a field operation that covers more than one strip. Or, as another example, it prorates the fuel and labor for a trip into town to pick up various items that are charged to more than one farm enterprise. The computer database now contains approximately 1900 transactions that represent all the farm tasks during the past two years.

To compute the "indirect energy" required to manufacture various farm inputs before they even reach the farm gate, I conducted an extensive literature review to assemble a list of roughly fifty materials needed to constitute most farm inputs. Indirect energy is what is needed to mine, process and fabricate various ores or materials. For raw materials that could be recycled, I calculated the indirect energy for a mix of virgin and recycled materials according to: 1) the estimated recycled proportion of that material in a solar future, 2) the reduced energy that will be needed to reuse recycled materials, and 3) the increased energy that will be needed to mine or obtain lower grades of metal ores or materials as these become scarce. The indirect energy values were entered into a separate part of the database. When a farm input is entered in the database, the computer user consults the list and selects one or two raw materials that constitute most of that input. In this way we are also keeping track of the hidden energy costs of running a farm, so that we can evaluate some of the requirements and limitations of the "agricultural infrastructure" in a fossil fuel scarce future.

Determining how to run a profitable farm in today's economic environment of cheap fossil fuel-based inputs is not an important consideration at the Sunshine Farm. Economics will be the biggest wild card in the future because relative prices among goods and services are likely to shift dramatically when fossil fuel becomes scarce or expensive, and for many other unforseeable reasons. This means that current economic analysis will have little long-term applicability. Nevertheless, we are recording income and expenses for each farm transaction, and could make the database available for economists to analyze, to see whether some of our practices could potentially be worthwhile to farmers today. The Sunshine Farm Project concentrates on basic energetic and nutrient constraints in farming, which will ultimately interact with the social structure of agriculture to determine what is profitable in the future.

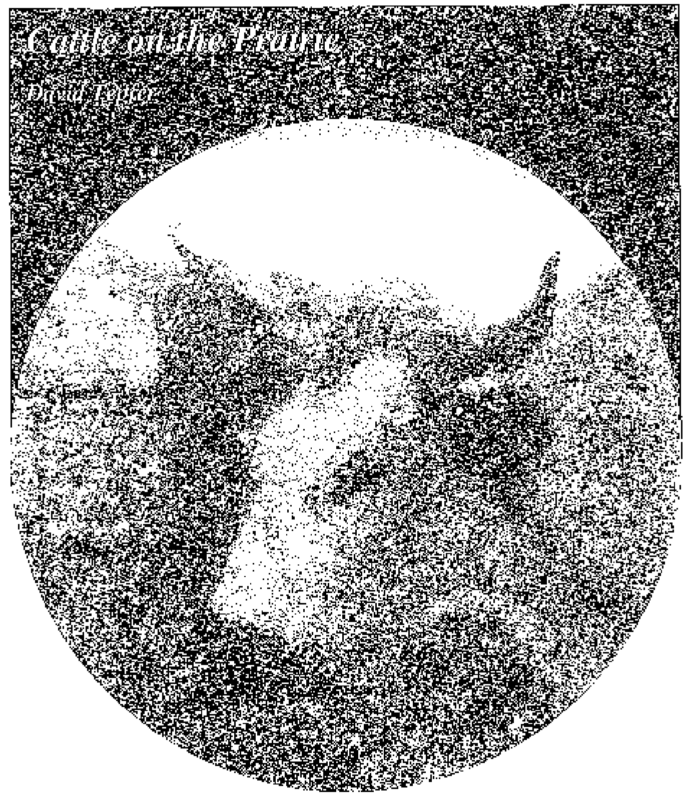
The cost of our food is currently the product of a national policy of cheap food and fuel. The data derived

from these studies will allow us to make a more complete ecological accounting of farming, which may suggest a more accurate long-term cost for what we eat. The production of annual grains using renewable energy technologies and low-input practices on the Sunshine Farm will also provide a standard for comparing the productivity of conventional grains with that of perennial grain polycultures. Thus, we hope the studies undertaken at the Sunshine Farm will lead us to a better understanding of both the opportunities and the limitations of "conventional" organic tillage and livestock farming on the Great Plains in a solar-powered future.

Agricultural researchers and farmers are showing interest in the Sunshine Farm Project. A scientific advisory committee of seven members from across the nation convened prior to the project, making research recommendations that were adopted. In conjunction with the Heartland Sustainable Agriculture Network, we have also recruited a farmer advisory committee of local farmers to improve our farming practices. We have received on-site research advice from Charles Francis of the University of Nebraska, and from several faculty at Kansas State University: Rhonda Janke, Dave Regehr, Jerry Wilde, Paula Bramel-Cox, Jay Siebert and John Blair. On-site suggestions for future testing of Sunshine Farm soil quality were given by soil scientists Michael Miller of Argonne National Laboratory, Illinois; John Doran of the U.S. Department of Agriculture, Lincoln, Nebraska; and Orville Bidwell of Kansas State University. Agronomists have attended the intern talks at the annual Land Institute research advisory group meeting at Kansas State University. I thank them all for their interest and advice, and encourage other agricultural researchers to visit and explore research opportunities at the Sunshine Farm.

Marty Bender is Land Institute Sunshine Farm Ecologist

Special thanks to the Austin Memorial Foundation, the Foundation for Deep Ecology, the Wallace Genetic Foundation, and the Clarence E. Heller Charitable Foundation for providing major funding for the Sunshine Farm.



Cattle on the Prairie

David Tepfer

At the end of a day in late October, Land Institute staff and interns watched as their major work task of the year was christened: eight Texas Longhorn cows were turned into our newly fenced pasture. As of winter there were ten, eating sweet cane and alfalfa hay grown on the Sunshine Farm. Cattle grazing on the prairie is a new sight at The Land Institute. Understanding their purpose and how they came to be here is important.

The cows are at The Land Institute as part of the Sunshine Farm Project. The farm is composed of 50 acres of flat, fertile bottom land and 100 acres of prairie on hilly uplands, and combines traditional Great Plains crops and livestock with newer energy efficient technologies. The pasture is on the 160 acres north of Water Well Road, northeast of The Land Institute's office. The cattle fill the role that animals do in any ecosystem, helping to cycle nutrients.

Grazers were a large component of the native tallgrass prairie, our model here. The hilly uplands, even the more gently sloping parts, are subject to erosion and should remain as prairie. Someday our perennial polycultures may have some place here but for now maintaining a functioning prairie ecosystem is our goal. Properly managed grazing can accomplish this goal and also allow the animals to be part of a larger farming system.

Just as bison grazed the tallgrass prairie, cattle will graze our prairie. Cattle do not graze exactly the same as bison, but they are easier to manage and meet our goal of using traditional crops and livestock. We are using the Texas Longhorn breed because they do better on a forage diet than other breeds, a very important trait since we intend to produce primarily grass-fed beef. Their natural disease resistance, acquired through centuries of evolving in a semi-wild state, makes them well suited to organic production practices.

The cows and their yearling calves will also be supplemented with crops and crop residues from our tillage land. Manure from their wintering area will return to the fields and help in the recycling of nutrients on the tillage land.

This production system draws on traditional practices of grazing cows and yearlings along with feeding them some harvested crops and crop residue. The similarity is intentional. As much as possible, we are using crops and livestock and production practices that are familiar and proven in this region over time. While many farms today are moving away from integration of crops and livestock, we seek to return to and build on traditional practices, modifying them as necessary based on ecological standards, and combining them with new energy efficient technologies.

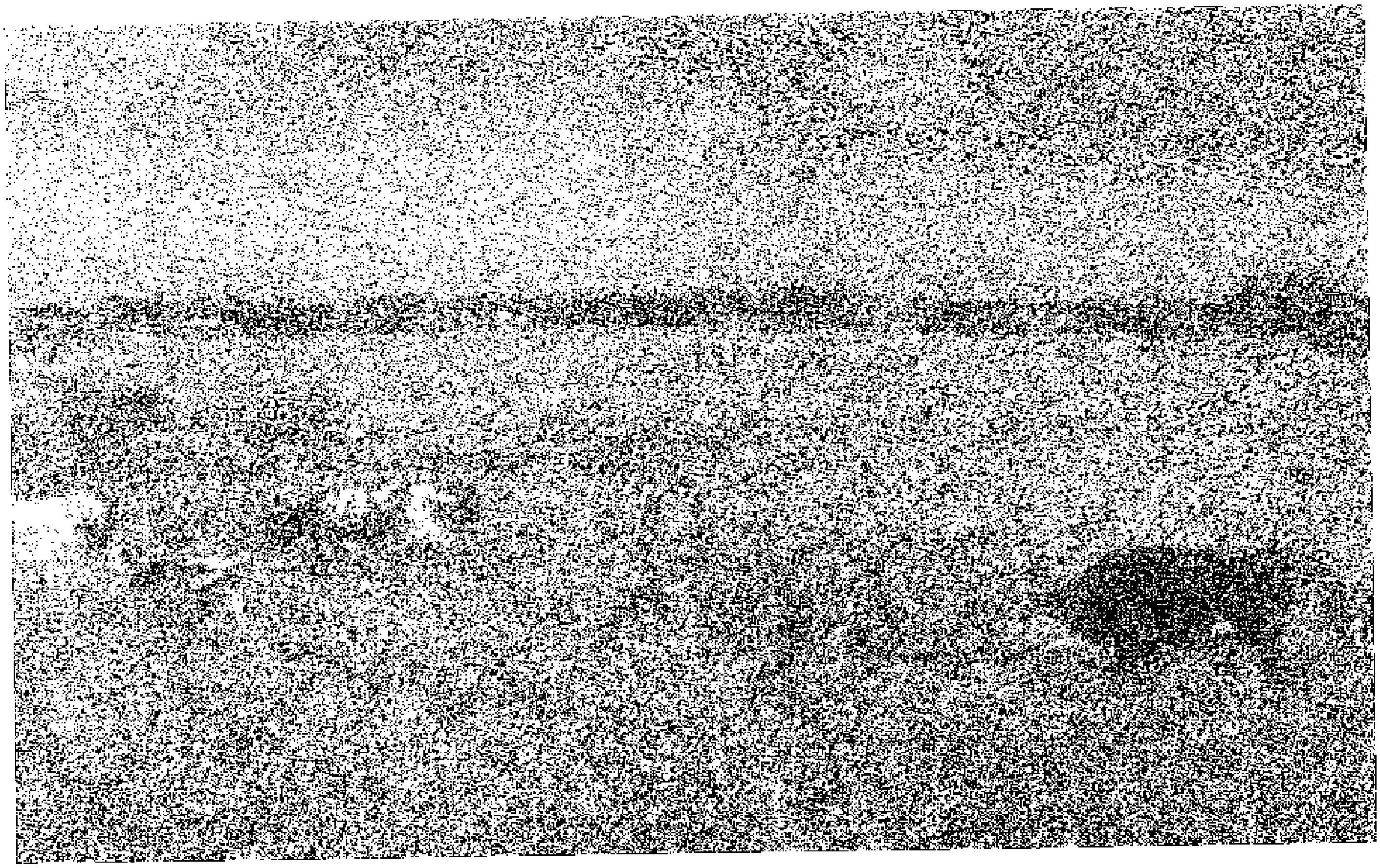
As anyone would expect, actually getting such a system up and running is no small task. Part of the perimeter fence was completed in previous years. Finishing the fence and the rest of the preparations for the cows was the intern's major project for 1994. We started working on it our first week here. With everyone taking their turn, two or three of us were out there most nice afternoons through the spring and every day in summer. We took a break from it only to prepare for Prairie Festival and for about a month at the peak harvest time in the perennial polyculture plots.

We built three-quarters of a mile of new six-strand barbed wire fence and repaired and rebuilt the rest of the fence. Perennial polyculture and grazing research plots had exclosure fences built around them. Gates were hung, swamps and gullies fenced through and around, and all of the other little details of fencing on hilly uplands taken care of. All of the interns have a greater appreciation of the skill and labor that goes into building a good fence. We won't ever look on those miles of fence seen from the highway in quite the same way.

We did a cover class analysis of nine sites on the prairie in July. This gives us baseline information on species diversity and abundance by which we can judge the effects of grazing over the life of this study. Details of this survey will appear in a future *Land Report*.

With the fence done and the cows out there, the grazing management begins. Obviously, grazing management is about controlling where and when cows graze, and one goal is high production over a long time frame. The Land Institute is also interested in grazing in a manner which relies on and preserves a healthy prairie ecosystem, and in fitting the grazing system into a diversified farm.

1994 interns Portia Blume and Kathy Holm building fence



Grazing systems differ in the number of separate grazing paddocks that are created and how often the cows are moved from one to the next. This can range from a single pasture in which the cows graze year 'round, to a hundred separate paddocks with cows moved every day, or any variation in between. The movement of the cows is timed to control how much of the forage is eaten and how long it is left to recover before being grazed again.

More frequent movement results in all of the animals being in a smaller area for a shorter period of time, which requires close monitoring of forage condition and an intense level of management. Proponents claim that this more intense management is rewarded by higher forage production and thus greater cattle gain. Short duration intensive grazing with a long rest period between grazing occurrences may more closely mimic the grazing impact of a herd of bison roaming over a large region, possibly resulting in a healthier system. The long-term effect on the ecosystem of this higher rate of harvest is uncertain, however.

Long horn cattle at The Land Institute (above)

Some scientific research, including an ongoing study at Kansas State University on tallgrass prairie much like ours, suggests that the type of grazing system may not be as important as simply the number of cows in affecting forage production and species diversity, an indication of ecosystem health. Expecting a system to increase the carrying capacity of a pasture and increasing the number of cows too much may damage the pasture.

There are other benefits from controlling where and when cattle graze. Cattle can be forced to graze hill sides, areas farther from water, close to north fence lines, and other places that they would not readily go. They can also be forced into brushy areas to help control the invasion of weedy trees. Moving fences and providing a variety of water sources alters the trails cows take and keeps them from trampling areas around water, and from overgrazing hilltops and southwest corners where they tend to loaf with their noses into the summer breeze. Letting some areas rest while more fully utilizing others may increase carrying capacity by improving range quality and evening out grazing pressure.

A further consideration in our grazing system is how it fits into the rest of the farm. A diverse, integrated farm will make many time demands on the farmer, so we will set up a system that does not require constant attention to the cows and has some flexibility and room for error. We want to learn from university and ranchers' experiences and set up a system that mimics a natural system, but to be very cautious about how much we expect it to produce and how much intensive management it demands from us to succeed.

This first year we will graze ten cows in a system of paddocks fenced by electric polywire. This light movable wire will allow us to be flexible in our paddock size and configuration and gain some of the benefits of controlling where the cattle graze. We will initially try to move the cows every few days and see how the labor requirements fit into the rest of the farm. With eight or ten separate grazing areas, each area will get about a month to rest before it is grazed again. After this year we will also be grazing yearling calves so our initial estimate of carrying capacity is important. We will need to adjust the number of cattle and their supplemental feed as we learn what the prairie can sustainably produce.

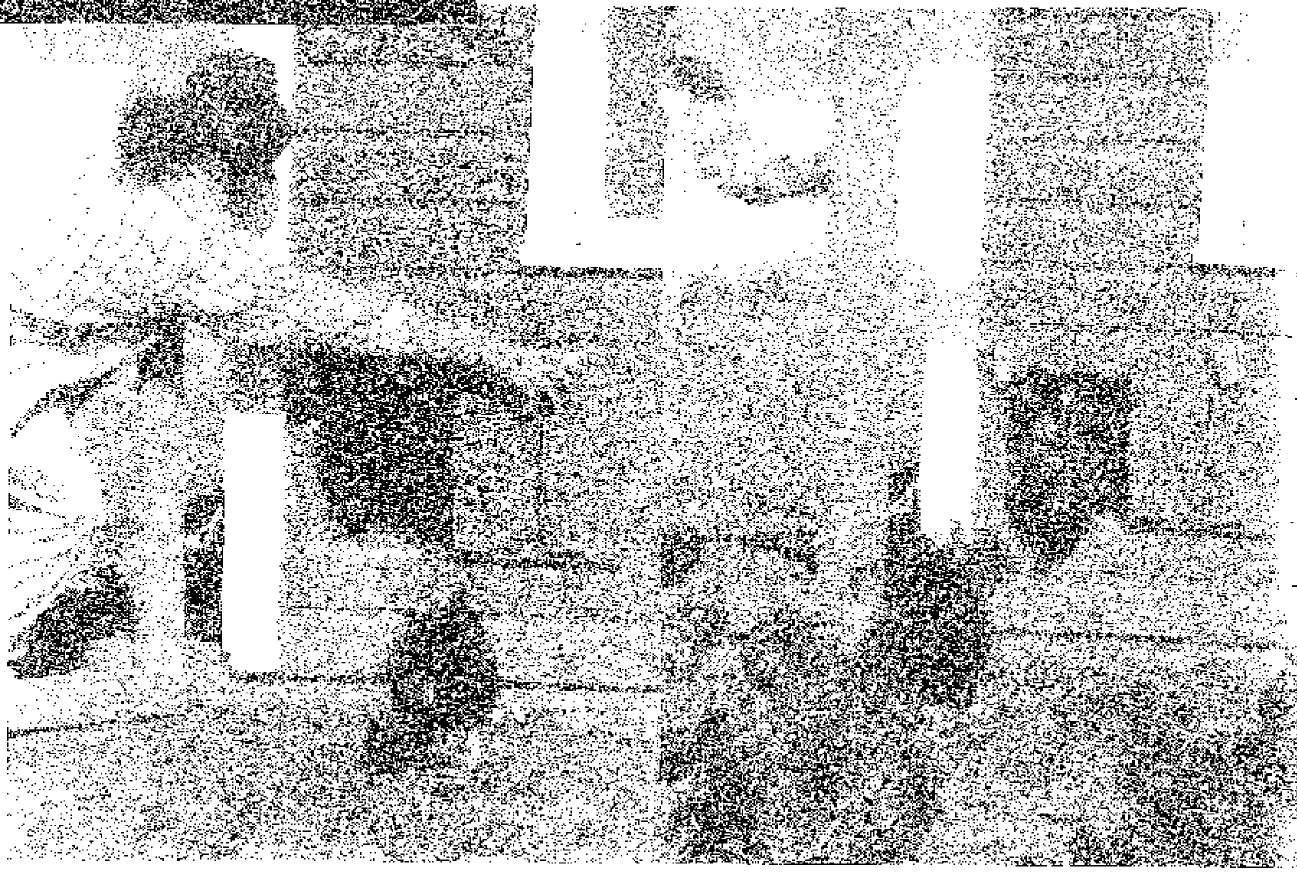
Through the remaining years of this project we will closely monitor species diversity and forage production on the grazed prairie. For comparison we have eighteen small exclosure areas fenced off within the area that is grazed, as well as 60 acres of unplowed prairie right across the fence that will not be grazed. These areas will serve as standards which will help us understand the effects of grazing on the prairie.

Seeing the fence completed and the cows turned loose was one of the climactic moments of the 1994 intern year, but it was just the first step. At first glance, these cows on the prairie at the Land Institute Sunshine Farm do not seem different from those on current farms. That is how we want it. This is a farm system based on what the best Great Plains farmers have developed and continue to improve, one that others could adopt if they wanted to become more ecologically sound, and that the rest will have to rediscover when petroleum becomes more scarce. It is within easy comprehension. It is the underlying principle of what those cows are doing that we hope will set them apart. They will graze tallgrass prairie as it evolved to be grazed and at the same time be part of a larger farm ecosystem, doing their role in cycling nutrients. And along the way, providing food for people.

Dave Tepfer is Land Institute Research Assistant

Chickens on the Sunshine Farm

Jeremy Plotkin



The Sunshine Farm project examines to what extent it is possible for a farm to meet its own energy and nutrient needs. One important strategy is to increase internal cycling. The energy the farm can capture biologically is limited by the amount of solar radiation and the efficiency of photosynthesis. The challenge is to use this energy as fully as possible. Products from one sector of the farm must be used by other sectors in order for the farm to sustain itself both biologically and energetically, and still produce some output.

The poultry operation on the Sunshine Farm works toward this tight integration. The chickens can be fed farm "waste products" such as the meal left over from soy and sunflower oil production, grain that falls on the ground during harvest, or piles of weedy hay. They can also provide work for the farm, by turning compost or spreading their own manure on the fields. The two parts of the poultry operation—a mobile broiler grazing pen and a composting chicken yard—were first attempts to explore these possibilities.

We raised 80 young meat chickens (broilers) in a mobile grazing pen similar to one designed by Joel Salatin (1993). The pen was a 10x12x3 foot wheeled cage capable of holding up to 100 broilers, open on the bottom so that the chickens could graze. By moving the pen daily to fresh vegetation, the impact of grazing was spread out. The pasture was hit hard one day, then left to recover. Manure from the chickens was spread over a wide area, turning a potential pollution problem into a fertilizer source. The green foliage supplied a feed supplement making for healthier chickens, which made for healthier meat (Salatin 1993).

Grazing is an efficient way to turn the alfalfa into a product and return nutrients to the soil. The more laborious and energy-intensive alternative is to cut hay, haul it to the barn, feed it to livestock, and ship manure back to the field. Of course, the farm needs some hay to over-winter horses and cattle, but the chickens can effectively harvest any alfalfa not needed for hay. We were curious about the effect of these two methods of harvesting on the growth of forage plants.

We conducted an experiment to quantify the impact of the chickens grazing on alfalfa, and compared it to the impact of haying. The chickens were placed on a stand of alfalfa and moved every day. Each morning when the chickens were moved, an equivalent patch right next to the pen was mowed and raked. Biomass yield and nitrogen content of samples of the regrowth were compared between the grazed and mowed plots.

The full results of this study will be reported in a future *Land Report*. The main finding was that the mowed alfalfa grew back much more vigorously than the grazed alfalfa. There was no significant difference in nitrogen content between the two treatments, probably

indicating that the fertilizer value of the manure was not being utilized by the alfalfa. This could be partly because it was extremely dry during the study period, and so the nitrogen didn't wash into the soil from the manure; or that it just wasn't available yet. Nitrogen in manure tends to become available less immediately than synthetic liquid fertilizers, though chicken manure mineralizes faster than many other manures. It may also be that alfalfa is just the wrong plant for chicken grazing. Nitrogen fertilizer is not really needed for alfalfa, since it is a nitrogen-fixing legume (Lamond 1993).

This suggests that the best use for broiler pens on the Sunshine Farm could be at the end of the alfalfa rotation, when the regrowth of the stand is no longer desired. Because alfalfa hay is harvested repeatedly over the course of the year, it represents a drain on the phosphorus and potassium fertility of the soil (Lamond 1993). By harvesting alfalfa with a broiler pen some of these nutrients would be returned directly to the soil, and there would be an additional input from the feed consumed by the broilers.

Another part of the poultry operation was the chicken-house composter. Since many farms frequently have a surplus of old or weedy hay and straw, we wanted to explore the use of chickens to facilitate composting of this material. Our 70 laying hens lived in a mobile house, within movable fence panels that enclosed several large piles of weedy hay. The hens picked through the hay, gradually working a pile down until it was relatively flat. After they had worked a pile for two weeks to a month they were moved to a new pile, and the old one was mounded back up with a tractor and bucket loader. In the process the chickens added moisture and nitrogen to the hay, helping to speed decomposition and adding to the fertilizer value of the compost. I estimate (based on feed input, and on samples taken from finished piles) that they were responsible for about 5.8% of the nitrogen in the compost. This is only a small addition to the fertilizer quality of the pile, but it could have changed the carbon-nitrogen ratio enough to make conditions more ideal for composting. The layers also speeded decomposition by turning the compost, knocking down the piles that we had built with the tractor.

Though the chickens did speed the composting process, it still took a long time and a good deal of mechanical energy. A larger animal that can turn over more material in a shorter time might work better for composting. Joel Salatin has had good success using pigs to process compost by hiding fermented grain in his piles (Shirley 1994). A better strategy for the hens might be to fence them around short sections of the trees in the windbreak, and move them periodically. Many of those trees bear fruit that is not currently harvested. The windbreak would then require less mowing, saving energy, and the chickens would get more green vegetation to eat.

There are many other ways chickens could fit into the farm operations that would be fuel efficient, perform some work for the farm, and make use of energy and nutrients that would otherwise go unutilized. Both the broilers and the layers could glean grain dropped from harvest. Another possibility would be to rotate the chickens within the native prairie pasture. Salatin does this, and reports much reduced fly populations, because the chickens break up cow manure patties where the fly larvae hatch. Because this was only the first year of the poultry project, we have many avenues still to explore. There are many alternatives for improving the integration of the poultry, and it is likely that some effective solutions can be worked out.

Raymond Lamond, 1993. "Alfalfa Fertility" in *Alfalfa Production Handbook*, Cooperative Extension Service, Kansas State University, Manhattan, KS

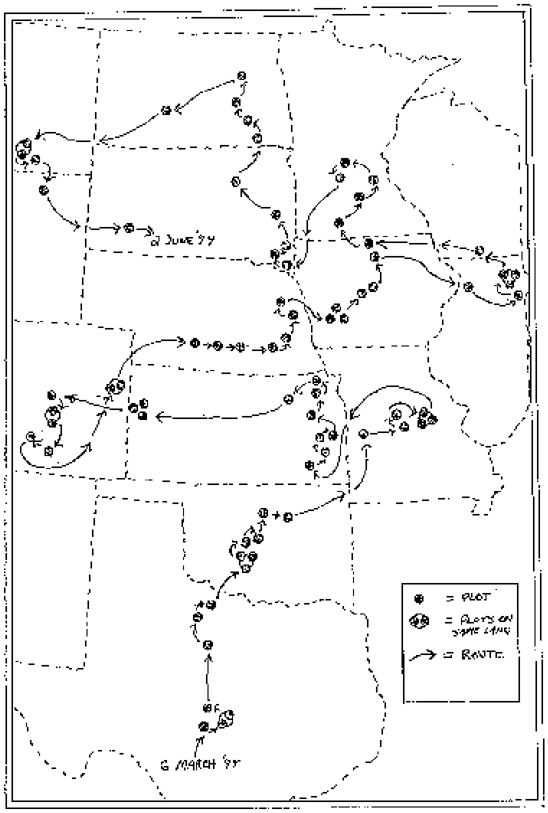
Joel Salatin, 1993. *Pastured Poultry Profit$*, Polyface, Inc., Swoope, VA

Christopher Shirley, September/October 1994. "Pig-powered Composting," *New Farm*

Jeremy Plotkin was a 1994 Intern

Great Plains Project Update

Christian Anders Petrovich



Spring '94: Christian Anders Petrovich, shown above in authentic trail garb, drives the young polycultures north across the Plains to their new homes.

Great Plains Research Fellow

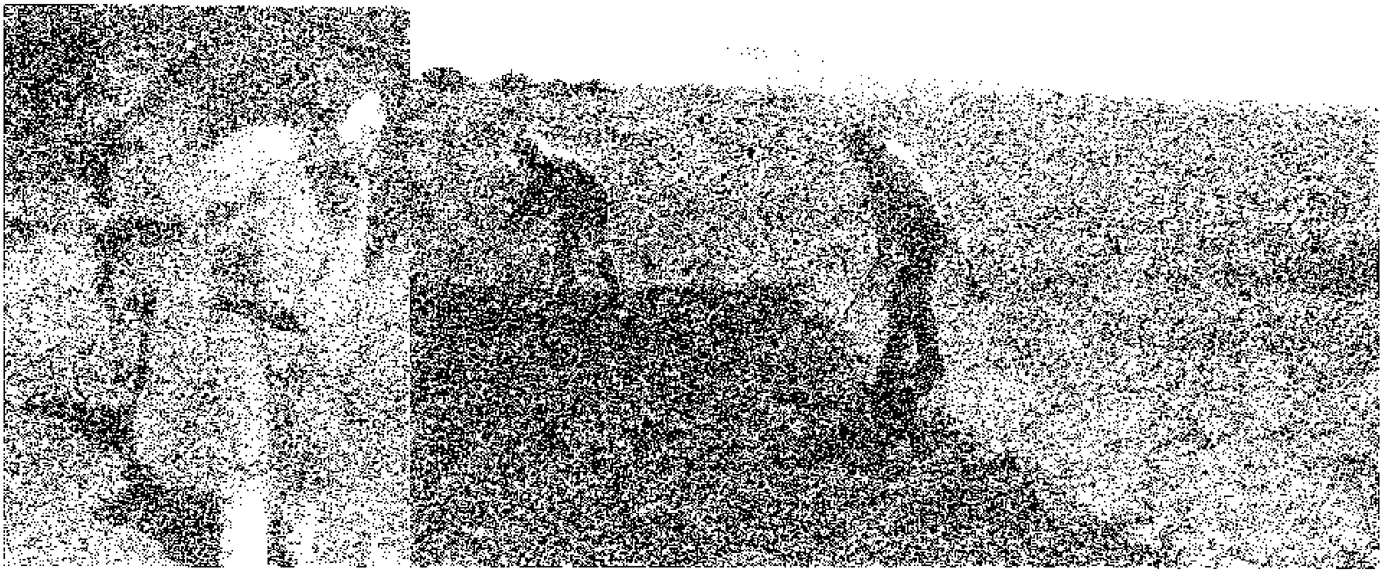
The Land Institute is looking for a Research Fellow to conduct this season's vegetative analysis of the Great Plains Project research plots. Qualifications include: (1) a close familiarity with The Land Institute's perennial polyculture research; (2) experience with prairie plant and common weed identification; (3) some experience with statistical analysis and scientific paper writing; and (4) the ability to sleep in the back of a truck. In other words, a former intern would be ideal. The Research Fellow will spend June through August 1995 in the field and the following two months analyzing and writing up the data. Please contact Wes Jackson at The Land Institute for more information.

Looking to the empty space on the dashboard where I always put my journal, I inhaled the spores of panic with the memory of the last phone call I made an hour's drive ago. The vivid image of myself leaving a summer's worth of research data, field observations, and contact phone numbers on top of my Ford's blue roof glared back at me with a piercing displeasure. The panic spores had found an opportunistic niche in me and began their exponential growth toward desperation.

A weary three hours later my eyes were tickled by the sight of my 300 page loose-leaf notebook scattered on both sides of the on-ramp to the highway for about an eighth of a mile! The papers were held against the wind of passing traffic by the patches of vetch and switchgrass they had settled into. I leapt from the truck with the raven cackles of a giddy madman and began swooping up the pages. In my left arm I clasped the precious bundle I was gathering to my chest while my fully extended right arm held each new page in a dramatic pose. I re-read my notes aloud as I went with shouts of operatic enthusiasm.

"Tom Reidy! Ha-*ha*!" *Tom is one of the 66 people in 14 states who has agreed to be a collaborating researcher in this Great Plains Research Project. He is a rancher of Longhorn cattle and a breeder of hair sheep. He rotationally grazes them together in a mixed herd on his ranch in Moody, Texas. It was early March when I first visited that ranch to plant the perennial polyculture research plot. Starting in Texas, trace the arrows on the map with your finger and you will follow the route I took — once to plant in the Spring, and again three months later to study what grew. If you pulled the whole trip out straight into a line, it would wrap once around the earth at its widest point (25,482 miles).*

"Ah ha! *Tripsacum dactyloides* (eastern gamagrass)! Seed rate: 8,000 grams per acre; Maximilian Sunflower! and Illinois bundleflower! both at 6,072 grams per acre; and Mammoth wildrye at 4,724



grams per acre!" *Although the total area of the study plots combined is 1.55 acres, it is scattered out into 75 30'x30' plots across the wide climatic ranges of the Midwest. In each plot we planted The Land Institute's four primary perennial grain candidates (listed above) with four other herbaceous perennials meant to function as companion plants. In so doing we hope to learn the geographical range and microhabitat conditions in which a polyculture of the candidate species can succeed.*

"Bruce Bacon! Ramsey, Minnesota!" *Bruce is an organic vegetable farmer, a tree consultant, and a community organizer. His family farm is a market garden cooperative, selling to restaurants in the Twin Cities, with a resident farmer population that expands and contracts with the seasons. Of the 66 groups and people like Bruce who are collaborating in this Land Institute research project 19 are farmers or ranchers; 11 are agricultural researchers, another 11 are teachers of various disciplines, 5 are non-profit organizations, and the remaining 20 are various eclectic business people and professionals. All are familiar with the Land Institute's work, and many have been contributing to and following it for 5 to as many as 16 years.*

"Hmm...What's this photograph? Ah! I must have tucked one of the pictures I took of a research plot into my notebook!" *I returned to the plots only three months after planting them to assess the state of their establishment. When you see a one season old, hand-broadcasted, unweeded, unwatered research plot it recalls memories of some nightmarish weed patch: the kind of thing many people would simply plow under. Immediate gratification is one of the first things we let go when we choose to work with perennials. This is because our slow-growing perennial seedlings may be only five inches tall in their first year as they put most of their energy into root growth. Meanwhile the annual weeds have found an ideal disturbed soil niche to exploit. Next season the perennials we planted will get a head start on the weeds and do better. Still, with a hand-broadcasted, unweeded plot we expect establishment to take three to five years before the perennials have fully taken hold and become dominant.*

The reason we took this longer approach of not watering nor weeding nor even planting in rows, is that we are working to create a self-organizing system — one that is not dependent on human inputs of fossil fuel energy or chemical herbicides. By hand-broadcasting seeds and then leaving the system to establish on its own, we do not impede the development of mutually beneficial plant interactions. By neither watering nor weeding, we leave the plants to survive only in the microhabitat conditions for which they are ecologically adapted. So although this research project will take longer to assess, and will look frighteningly weedy in the first years, it may be the methodology we need to develop a form of agriculture that behaves like a prairie.

After I had gathered all my pages back together, and thanked my lucky stars for finding them, I got back into my truck and headed over the Mississippi River again, wondering what other surprises this study would hold.

P.S. Yes, this really did happen! And oh how I danced and sang when I came across that spread of papers. These "Great Plains Project Updates" will be published periodically over the study's expected five year duration as the results of our region-wide study unfold.

Christian Anders Petrovich was a 1994 Land Institute Research Fellow

Summer Volunteers at The Land

By Kathy Holm

They came, they saw, they cultivated, pretty well sums up the summer's work of two Land Institute volunteers — Yuri Gallegos and Julie Lockwood.

Yuri Gallegos, a 26-year-old senior at the Universidad San Francisco de Quito in Ecuador, spent this past summer working as an apprentice at The Land Institute.

Yuri studies industrial engineering in Quito and is particularly interested in alternative energy, including wind generators and solar energy. While at his university he invented a rotary motor, for which he won a university prize. He is currently working with the university to develop the motor and get it patented.

While at The Land, Yuri worked primarily on the Sunshine Farm Project. He said his awareness of worldwide problems in and of agriculture increased while in Kansas.

"I really enjoyed working at The Land Institute. Kansas is beautiful and everybody was really friendly and helpful," he said, "although it was quite hot."

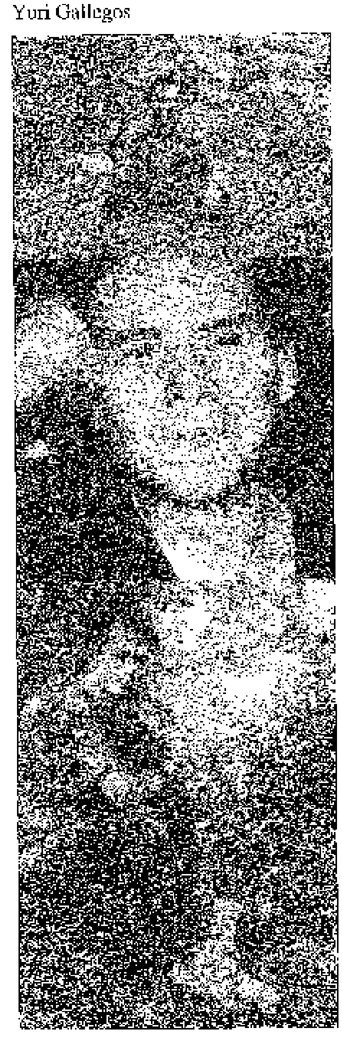
To support a collaborative research effort, the University of Tennessee, Knoxville, sent graduate student Julie Lockwood to work full time at The Land Institute this past summer. Julie, a zoology PhD student, assisted with field research and data analysis for The Land's new community assembly experiment, described in *Land Report* 49, Spring 1994.

At the University of Tennessee, she works with Dr. Stuart Pimm, Professor of Ecology, on the "community assembly" process. Their work explores the different states biological systems pass through before reaching a stable state. The community assembly experiment incorporates some of these ideas into The Land Institute's perennial polyculture work. Land Institute Ecologist Jon Piper and Intern Debbie Crockett headed up the 1994 research effort.

"I came to The Land Institute for the summer because I really wanted to get involved in the hands-on work of this experiment," Julie said. "I think it's important to have someone from the University of

Julie Lockwood

Yuri Gallegos



Tennessee to follow through on this experiment from year to year, someone who knows the plants and the research protocol."

Intern Debbie Crockett agreed. "Julie has a lot to offer us in terms of her background in community assembly. She has worked with these types of projects before and has analyzed the data sets."

Originally from Atlanta, Georgia, Julie received a BS and an MS in biology at Georgia Southern University near Savannah, and is currently in her third year at The University of Tennessee. For fun, she says she enjoys canoeing and loves to fish.

"I fish with a rod and reel and I like to work at training the fish to come up to the sound of beer cans hitting the bottom of the boat."

He's An Enigma, But He's Ours

By Kathy Holm

Interviewing John Jilka for a *Land Report* article is an exercise in pure frustration: he won't tell you anything.

If, after cajoling and trickery, John deigns to tell you something, anything — you can bet it's a tall tale.

These things about John are known: He has nine children, seven girls and two boys. He has worked for The Land Institute since 1989. Prior to The Land, John worked at Earthcare nurseries for about four years, prior to that he worked at Beech Aircraft Corporation for 21 years in the production, tool making and pattern shop. Before that he farmed. Before that he was in the Merchant Marine (those exploits, however, remain *strictly* off-the-record). He is active in the American Legion and waters and weeds the flower beds at his church, which he attends every week. His hobbies include growing wheat and gigantic turnips on ten acres of land around his home and looking after one dog, Buster, and a "scroungy" cat. He likes beer, peanuts and Old Crow whiskey.

To get more than that, to flesh out the story, one needs to turn to others to describe him. That's not a problem; everyone has John Jilka stories. The problem still is how much to believe.

"John says his favorite stew to take to potlucks is made from road-kill possum," says Volker Wittig, 1991 intern, who used to work with John "a lot" at The Land while he was there.

"I worked with John fencing on the 160 (a quarter-section owned by the Land) and everyday in early afternoon when we would see the schoolbus go by John would say, 'Oh, the schoolbus just went by, time to get the tools together and go home.'

"John's favorite way to describe how big one of the corner-posts we were setting on the 160 was, 'It took us three days to walk around it, that's how big it was.'"

John Jilka

John has numerous hobbies too, including fishing. "There's a pond north of Salina that John likes to drive up to with Buster and a boat," Volker says. "Another hobby is fixing up his 1923 Ford truck at home. He's working hard to get it done so 'he and the missus' can drive it in the Fourth of July parade in Salina this year."

Evangeline, who's married to John, is "the nicest person in the world ... She and John are the reason why their kids turned out so generous and good-hearted," Volker says. "She's also a great seamstress, a good cook and she plays the organ in church."

"John is honest, a good Christian and a good neighbor," says Max Redding, Jilka's neighbor. "He has seven real sweet daughters, two sons and a nice wife who drives a school bus. They've worked with the Mentor 4-H club for years and years. In fact John has been the project leader for swine for 15 years."

"I've got a John Jilka story for you," says Bill Conover, former pastor at the Solomon Yoked Parish in Solomon, Kansas. "One day I was walking down the street in Solomon and I hear someone call out to me, 'Hey pastor, I picked up a sinner for you today.' I turned around and it was Jack (Worman, Sunshine Farm Manager), yelling at me from the cab of his pickup truck. Jack just pointed to John Jilka, who was sitting in the front seat grinning."

"John has played the same trick on me at least five times now," says Debbie Crockett, '94 intern. "I can see him out of the corner of my eye pull his watch out of his pocket, look at it, put it back in and say, 'Debbie, what time is it?' I say, 'I don't know.' Then John squints up at the sun and tells me the exact time."

Other John Jilkaisms?

"He offers me a chew of tobacco now and then," Debbie says. "He's also fond of telling us how late he stays up baking to bring things to The Land Institute."

Of course, we all suspect that Evangeline does the baking at the Jilka house.

New Staff at Matfield Green

By Kathy Holm

The Land Institute's presence in Matfield Green got a little bit bigger with recent staff additions of Ron Armstrong and Cathy Bylinowski.

Armstrong is The Land's new fix-it person, handyman and jack-of-all-trades. He has been working on a variety of projects in Matfield Green, including fixing the ceiling, removing a coal-burning furnace and installing a darkroom in the renovated schoolhouse.

Ron grew up in Wichita and worked in Colorado for the Breckenridge Ski Corporation for 21 years. He retired at age 55 and moved to Matfield Green to be closer to his father, who lives across the street. But retirement was, well, a little dull: "I started getting antsy," Ron said. "I wanted to work again."

That's when Wes approached him about working for The Land, Ron said. He has been working since August.

"Since I grew up in Wichita, had relatives in the ranching business and a father who grew up in Matfield Green, people here welcomed me with open arms," Ron said. "It's a neat place to live, real laid back, things move at a different pace. I expect to be here quite a while."

Getting back into gardening and working with an organization that promotes "right-relationship" with the land are the things that captured Cathy Bylinowski's imagination and prompted her to work in Matfield Green for The Land Institute.

Cathy has a degree in English literature from Washington University in St. Louis yet the gardening-experience section in her resume is about five pages long. She has been involved with a variety of community gardening projects, including working with the University of Missouri Extension Service's Expanded Food and Nutrition Program for low-income people. That required helping people create backyard gardens and community gardens, writing a gardening newsletter, and teaching about food preservation, she said. She later went to work for Kansas City community gardens, where she learned a lot from Laotian and Cambodian people who brought native gardening methods with them. After that, she "drifted into social work." Cathy worked with Legal Aid in western Missouri on a migrant farm worker project and for a community service agency in Kansas City, Kansas.

When Cathy decided to return to her gardening roots, she also decided to join The Land's staff. She is now responsible for Land Institute gardens in two big vacant lots in Matfield Green. With those she hopes to provide future meals for staff, interns, conference attendees and for volunteers who come down to work in Matfield on the weekends.

Her gardening plans include incorporating permaculture design principles into the gardens, planting low-maintenance perennials and becoming a more skilled gardener. In addition to these duties she also bakes bread once a week, keeps the Lumberyard Cafe open and takes care of Land Institute-related visitors. She also hosts a ranchers meeting once a month for a group trying to form a marketing co-op.

"I'm always surprised by the friendliness of people here in Matfield Green," Cathy said. "They are generous with their time, with their gifts of food — they're really wonderful."

Earth Songs *Benefit The Land*

The Land Institute has a special relationship with a music company called Narada and a CD called **Earth Songs*****. For the past two years, Narada has been donating part of the proceeds from sales of*** **Earth Songs** ***to the Land Institute.*** **Earth Songs** ***is a special collection of 12 compositions paying honor to the beauty and sanctity of the earth. Each selection was inspired by a poem in the verse compilation*** **Earth Prayers*****, which brought together writings ranging from D.H. Lawrence to Chief Dan George. Narada artists cover the full spectrum from acoustic to electronic, New Age, world music, and jazz and pop fusion. The selections on*** **Earth Songs** ***include David Arkenstone's "A Thousand Small Gold Bells," pianist Michael Gettel's rendering of prophetic warning from verses in Isaiah entitled "Earth Cry Mercy," and guitarist Eric Tingstad and oboist Nancy Rumbel's "In Return," an evocation of Wendell Berry's poem "Song (4)". Nancy, a former member of the Paul Winter Consort, suggested the Land Institute to Narada. If you would like to explore this music further, the Narada catalog is available at 4650 N. Port Washington Road, Milwaukee, WI 53212-1063, or by calling 1-800-966-3699.***

Changes at the Land

The Land Institute has a new full-time Office Manager and Development Associate. Stephanie Krug was Deputy City Clerk for the City of Salina for the last four years before joining the Land Institute staff. Louise Sorensen is staying on as part-time Secretary and Receptionist.

1994 Intern Dave Tepfer stays on as 1995 Research Assistant. Dave will help coordinate the fieldwork of this year's interns, continue with the Sunshine Farm Longhorn project, and start research on our ecological accounting project around Matfield Green. Our thanks to Audrey Barker, 1994 Intern Coordinator, for all her good work. Audrey is back in upstate New York, heading toward graduate studies in forestry.

And of course, thanks again to Sally Cole for her magnificent year as a volunteer here in Salina. Sally is back home in Aspen, but she remains a very active Land Institute board member.

A Memorial to a Good Friend of the Land

Recently, the Land Institute received what amounted to a small avalanche of contributions made in memory of Wally Bakken, a long-time Friend of the Land who lived in Denver. This memorial tribute had been arranged by his wife Marian, and children Stefanie, Tim and Joel. Naturally, we wanted to know more about Wally. What we found was typical of many Friends of the Land — that is, someone with a life-long love of the land, of which support for the Land Institute was but one expression.

Wally and Marian attended two Prairie Festivals, and enjoyed our inter-disciplinary atmosphere. She told us they "liked the creative and alternative work you do to change the way we approach the land. You provide hope for the future."

We would like to thank Marian for allowing us to quote from her tribute to Wally, and for their support over the years. It heartens us to remember that such people are out there. You, too, provide hope for the future.

Wally was born in Grand Forks, North Dakota, on September 29, 1934. His dad, Eddie, was a sign-painter. Wally obviously acquired his steady, artistic hand from him. From Josie, his mom, the graceful keeper of the hearth, Wally inherited, among other things, the gifts of hospitality and creating good food and family life.

When he was still very young, Wally started visiting the Bakken family farm near Adams, North Dakota. His summer visits expanded from a few weeks to where he spent every summer working for his uncle and aunt, Marvin and Belinda. This began a love of the land and farming that would remain a passion of Wally's throughout his life.

Wally Bakken

His first job as a petroleum geologist was with Amerada in Williston, North Dakota. After working fifteen years for oil companies, he became an independent consulting geologist. Because of work transfers, Wally and his family lived in Williston, Casper, Calgary, and Denver.

Wally's well-rounded life was reflected in how he spent his leisure time. He was a craftsman who enjoyed building rather than buying ready-made; fixing something himself rather than hiring a repairman. He enjoyed movies, especially those from Scandinavia. Two of his favorite's were "Babette's Feast" and "Pelle the Conqueror". He collected and read books by Ole Rolvaag and others who wrote of the settling of the prairie. Beyond that, his reading interests were varied, including history, philosophy, technical farming and building, and reflections of the natural world. He had favorite dishes he liked to cook, especially for holidays. Although certain of his siblings might disagree, Wally's lefse had no comparison!

His love for the land was a constant. Wherever he lived he always took care to plant a garden. These efforts were preparation for the dream that would become a reality in 1991. He and Marian bought a farm near Viroqua in the beautiful, rolling hills of southwestern Wisconsin. He was nurtured by working and building on this land and by the simple pleasures of walking to favorite places, making new discoveries, or sitting by the river, listening and watching.

Wally died on Friday, November 18, 1994. He was 60 years old.

Prairie Festival '94: The Pattern Which Connects

Audio Tape Order Form

Qty.	Tape #	Session Title and Speaker
	Saturday	
___	SA1	Why Study Complexity Now? Because We Can or Because We Must? Wes Jackson
___	SA2	Thinking About Complexity, Bill Wimsatt
___	SA4	From Agronomy to Indigenous Agriculture: Decolonization in the Andes, Frederique Apfell-Marglin
___	SA5	Why Is Nature Wise? Should We Put Erda Into Agriculture? Stuart Pimm
___	SA6	From Biology to Physics: How Nature Works, James Drake (Presented by Stuart Pimm)
___	SA7	Observing Birds at a Distance: A Holistic Method, Dave Sing
___	SA8	The Reservation as Place: A Geography of Hope, Frank Pommersheim
___	SA9	What's Time Got to do With it? The Prairies, Wetlands and Savannas, Now and Then, Jeb Barzen
___	SA10	The Matfield Green Project, Interns and Residents
___	SA11	Edible and Medicinal Plants of the Prairie, Kelly Kindscher
___	SA12	To Fly an Earthen Carpet: A Painter's Relationship With Her Garden, Mary Kay
___	SA13	Building Community: Some Real Life Perspectives, Kathy Collmer and Sara Wilson
	Sunday	
___	SU1	Scientists and Farmers: Systems of Knowlege and Systems of Agriculture, Stephen Marglin
___	SU2	Genes That Bind, Are They a Blessing or a Curse? Charles Sing
___	SU3	Prairie Crossing: Developing a Residential Community While Saving Prairie and Farmland, George and Vicky Ranney
___	SU4	Sustainable Agriculture in Australia, Ted Lefroy
___	SU5	Gallery Talk, Scott Jost
___	SU6	Wrestling With Urban Sprawl: Douglas County Preservation Alliance, Beverly Worster
___	SU8	Kansas Seasons and Cycles, Ken Lassman
___	SU9	Feeding Our Future, Alice Waters

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Germ Plasm Studies of Illinois Bundleflower and Eastern Gamagrass

Victor Rabinovich

Abstract

Illinois bundleflower *(Desmanthus illinoensis)* and eastern gamagrass *(Tripsacum dactyloides)* are being developed as perennial grains at The Land Institute. Here I summarize a five year study of yields of Illinois bundleflower and a first year report on gamagrass selections. Thirty-two bundleflower accessions were compared across five years to examine their yield patterns. The highest five year yield was 449 g m^{-2} (accession 1030 from Saline Co., KS) and the highest one year mean yield was 153 g m^{-2} (accession 318 from Ellsworth Co., KS). Two accessions, 1111 and 1093, have promising high yield patterns that differed from the general trend. The gamagrass study compared seed yield and disease level of five isolation plots each selected for such agronomic characteristics as high yield, resistance to Maize Dwarf Mosaic Virus (MDMV), winter hardiness, and dwarf stature. The plants that yielded best and showed the least disease were in isolation plot 4 selected for winter hardiness and forage, with a mean yield of 39 g m^{-2} and a disease rating of 0.045 on a scale from 0 to 7. The goal of our breeding program is to select for desirable traits while maintaining genetic variability in our breeding stocks.

Introduction

The Land Institute is conducting germ plasm studies to develop perennial grains for polycultures that mimic the ecological structure and function of the prairie ecosystem (Jackson 1985, Soule and Piper 1992). Plants for such polycultures should be hardy and relatively independent of the extensive inputs that the annual grain crops of conventional agriculture now require for their current high yields (Lovins et al. 1986). Perennial grain polycultures would lessen or eliminate soil erosion, reduce chemical contamination of soil and water, and avoid heavy dependence on non-renewable energy such as fossil fuels.

The projects I describe here involved two candidates being bred for perennial polycultures. We are currently selecting for such desirable traits as high seed yield, harvestability, shatter resistance, disease resistance, winter hardiness, and dwarf stature. This study focused on a subset of earlier selections from wild stands or from collections of previously developed lines (Jannink and Romig 1990, Hellwinckel 1992, Tressler 1993, Bergman 1993). The goal is to have many sources of genetic variability to incorporate as many desirable characteristics as possible into further selections.

To evaluate whether perennials are suitable for grain agriculture it is necessary to know how yield and disease level vary with time. The comparisons between different accessions and selections will lead to another selection of plants that provide healthy, disease-resistant, harvestable, and high yielding germ plasm that can be further developed to fit the perennial grain farmer's needs. One important question concerns stability of yield versus response to annual weather effects. For example, in the bundleflower study, the question arose concerning what kind of yield pattern would be preferred: a stable yield across the life span of the plant or a more variable response that can produce a great crop in good years. The major question in the gamagrass study is to compare seed yield and disease rating among isolation plots. For example, if a plot was selected for high yield, is its yield significantly different from a plot selected for disease resistance?

Materials and Methods

The bundleflower and gamagrass germ plasm plots were established as common gardens on a level Cozad silt loam soil. Gamagrass was burned in March 1994 for the first time. Each spring the bundleflower was mowed. Plots were hand-hoed twice in the spring after one mechanical cultivation to reduce weed competition and volunteers. Seeds were hand-harvested, then dried for a minimum of two to three weeks in a greenhouse before weighing.

I. Illinois bundleflower

I evaluated 32 accessions of *Desmanthus illinoensis* that were a subset of an original larger planting (Kulakow unpublished). The plot was arranged as a randomized complete block design with two replications per accession.

Table 1. Selection criteria and sources for eastern gamagrass isolation plots established in 1993

Isolation Plot	Selection Criteria	Source	No. of normal genotypes per plot
1	high yielding individuals	1988 Illinois bundleflower/ eastern gamagrass biculture	24
2	plants from the 10% highest yielding families	1989 planting from collected seed	34
3	resistance to MDMV	1989 planting from collected seed and 1988 biculture	34
4	vigorous growth, large size, disease resistance, loss of seed dormancy, and winter hardiness	Kerr Center, Poteau, OK	31
5	visually rated for dwarf stature (a trait that could improve harvestability and seed yield by devoting more of the plant's energy into seed production)	1990 nursery collection	5

Each accession was represented by 25 plants in a 6 m row, with rows 0.91 m apart. The 32 accessions were selected for further study after two years of evaluation. Ten of the accessions were chosen for their relatively stable yield, and 20 for relatively high yield. The remaining two accessions were the Soil Conservation Service's 'Sabine' and a blend of the ten highest yielding selections from previous experiments at The Land Institute.

In 1990 and 1991, we harvested 5 m strips within each row. From 1992 to 1994, 3 m strips were harvested. Harvest took place when bundles were a rich brown color and beginning to shatter. Harvest in 1994 started on 26 July and ended 28 August. Each row was harvested once. Pods were threshed by a food processor, cleaned by an office-sized Clipper seed cleaner, then weighed. Five-year yields were compared among accessions by analysis of variance (ANOVA).

II. Eastern Gamagrass Isolation Plots

Germ plasm nurseries that were established as early as 1988 provided selections for five isolation plots (Table 1). Gamagrass plants were clonally propagated from several source nurseries into isolated crossing blocks. Each isolation plot consisted of plants with similar traits for cross-pollination and recombination. Number of genotypes per plot ranged from 5 to 34. Each plot also included gynomonoecious forms of gamagrass (a mutant sex form in which all florets are female and thus seed producing) to cross with the normal plants expressing other desirable traits. The plots were spaced 100 m from each other to avoid pollen contamination. Plots ranged in size from 15 x 17 m to 17 x 17 m. A 1 m border of each plot was not harvested. For this report I focus on seed yield and Maize Dwarf Mosaic Virus (MDMV) rating of normal plants within each plot.

In May, all plants were rated on a scale of 0 to 7 for MDMV symptoms. A rating of 0 represented no symptoms of the virus, 1 to 3 were mildly infected, 4 to 5 represented moderate infection, 6 to 7 severe infection (Davis1991).

Harvest began in early July, when most of the terminal tillers had started to lose their male flowers, and was completed by 5 September. Each plot was harvested two or three times to collect the later-emerging lateral tillers. Seed yield and disease rating were compared among plots by ANOVA.

Results and Discussion

I. Illinois bundleflower

Among accessions, the highest 5-year yield was 449 g m^{-2} (Table 2). The mean 5-year yield for all 32 accessions was 326 g m^{-2} (range=131 to 449 g m^{-2}). The 5-year mean for the ten top-yielding accessions was 411 g m^{-2}. The highest accession yield for in any year was 153 g m^{-2} for accession 318 from Ellsworth Co., KS in 1992. The general yield pattern across years for all accessions was a "W" (Figure 1). The general trend was a high yield the first year, then a drop the second year to around 55 g m^{-2}. Yields in the third year rebounded to around 75 g m^{-2}, fell again to 50 g m^{-2}, and finally rebounded to 65 g m^{-2} in the final year.

Two notable exceptions to the general pattern were accessions 1093 and 1111 (Figure 2). Accession 1111 yields increased from 63.8 g m^{-2} in 1990 to 145.6 g m^{-2} in 1994. Accession 1093, the second highest yielding accession, showed yield stability across the years, in contrast to the year to year variation shown by the other accessions. Mean yield for this accession ranged only from 80.8 to 96.6 g m^{-2}.

II. Eastern gamagrass

Isolation plot 1, selected for high yield in biculture with Illinois bundleflower, and isolation plot 4, selected for forage, yielded higher than plots 2, 3, and 5 (Table 3). Isolation plots 1 and 2, selected for high yield in biculture and monoculture, respectively, had higher MDMV ratings than plots 3 and 4. Overall, the gynomonoecious plants rated higher for disease (range=1.35 to 1.57) than normal plants. The highest rating for normal plants was only 0.74, in isolation plot 2.

The first year data on yield and disease may not at this early stage indicate general long-term trends. Comparison of yield and disease level will be necessary for several years. Isolation plot 4, with high yield and low disease, contains clonal offspring with a history of overwintering in our nurseries. The original parents were selected for forage yield by James Henson at the Kerr Center for Sustainable Agriculture. Isolation plot 1, with plants selected from an earlier biculture experiment, will be compared with plants selected for high yield in monoculture, as in isolation plot 2. All plots will be compared with isolation plot 3, which contains plants selected for disease resistance. It may be too soon to conclude whether each isolation plot meets the criteria for which it was originally selected for.

The goal of polycross combination is to achieve a balance between maintaining genetic diversity in our breeding material while narrowing down the selections that show promise (Bergman 1993). For the next round of selection, promising genotypes within these isolation plots will need to be planted out for further evaluation. This new seed source would start another breeding cycle where selections would be made to start other isolation plots.

Table 2. Ten highest yielding Illinois bundleflower accessions

Accession Number	Origin (County, State)	Total 5-year yield grams/square meter	Highest yield in any year grams/square meter
1030	Saline, Ks	449	135
1093	Lincoln, OK	448	118
1111	Harvey, KS	415	97
318	Ellsworth, KS	414	153
1031	Kay, OK	414	121
294	Rice, KS	410	125
291	Saline, KS	400	110
278	Logan, KS	387	108
377	Riley, KS	386	138
1039	Wallace, KS	385	108

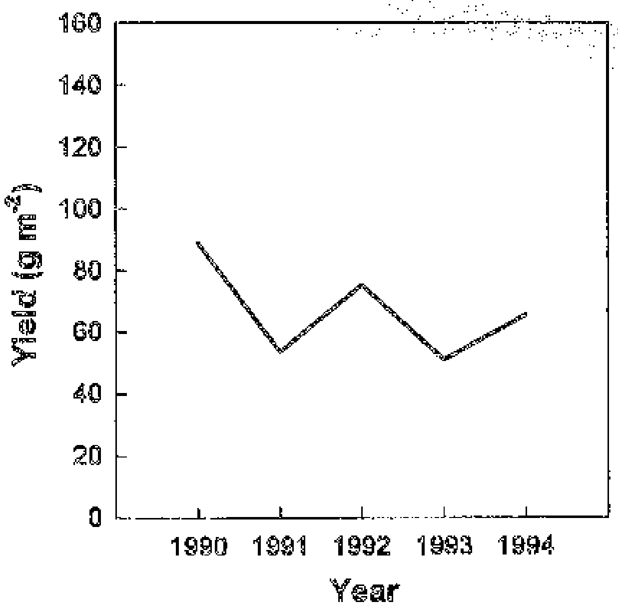

Figure 1. Mean yields for 32 accessions of Illinois bundleflower from 1990 to 1994.

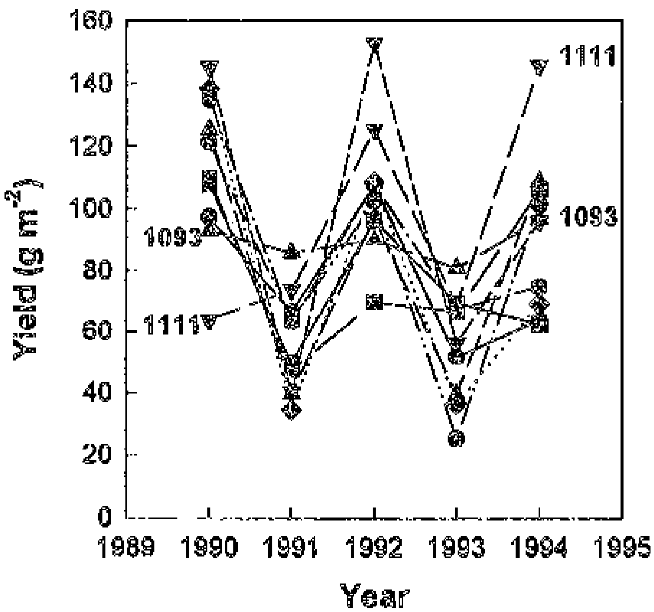

Figure 2. Year-to-year yields of the ten best-yielding Illinois bundleflower accessions, 1990-1994.

Table 3. Seed yield and MDMV rating in five eastern gamagrass isolation plots

Isolation plot	Seed yield grams/square meter	MDMV rating
1	37.2a	0.727a
2	21.9b	0.738a
3	17.5bc	0.159b
4	39.1a	0.045b
5	10.6c	0.353ab

Means within each column followed by the same letter do not differ at $p<0.05$.

Conclusion

Some high Illinois bundleflower accessions produced high seed yields that did not decline inexorably but rebounded in later years. Further breeding of high-yield bundleflower selections should produce populations that have consistent yielding patterns across several years. In gamagrass, our initial selections were verified for plants with such agronomic traits as high seed yield and disease resistance. Gamagrass performance in the isolation plots requires further observation, but first year results point to selections that are promising for our ongoing breeding program.

Literature Cited

Bergman, K. 1993. Eastern gamagrass selection and recombination. The Land Institute Research Report 10:1-8.

Davis, A. 1991. Variation in unselected populations of eastern gamagrass for response to MDMV. The Land Institute Research Report 8:31-34.

Jackson, W. 1985. New roots for agriculture. University of Nebraska Press, Lincoln.

Jannink, J., and D. Romig. 1990. Domestication of Illinois bundleflower as a perennial grain legume. The Land Institute Research Report 7:11-15.

Kulakow, P. A. MS. Genetic variation In Illinois bundleflower. (Unpublished).

Hellwinckel, C. 1992. Comparison of stable and high seed yielding collections of *Desmanthus illinoensis*. The Land Institute Research Report 9:20-23.

Lovins, A. B., L. Hunter Lovins, and M. Bender. 1984. Energy and agriculture. Pages 68-86 *in* W. Berry, B. Colman, and W. Jackson, editors. Meeting the expectations of the land. North Point Press, San Francisco, CA.

Soule, J. D. and J. K. Piper, 1991. Farming in nature's image. Island Press, Washington, DC.

Tressler, J. 1993. Patterns of seed yield in Illinois bundleflower (*Desmanthus illinoensis*). The Land Institute Research Report 10:9-13.

Can a Perennial Polyculture Manage its Own Disease and Insect Pest Problems?

Rebecca Geisen

Abstract
We examined whether a polyculture can manage insect pests and plant diseases by monitoring densities of *Anomoea flavokansiensis*, a beetle that feeds on Illinois bundleflower, and levels of sugarcane mosaic virus maize dwarf virus B (MDMV) a disease of eastern gamagrass. Beetle populations were high this year and we found a significantly higher density of beetles on monocultures versus polycultures. MDMV was found at low levels in nearly all plots and there were no significant treatment effects in 1994 between monocultures and polycultures. The results suggest that polycultures are successful at managing pest problems and that polyculture, coupled with genetic resistance, can play a role in reducing disease.

Introduction

One of the goals of The Land Institute is to develop a sustainable agriculture, modeled on the prairie ecosystem, that features a mixture of herbaceous perennial grains. Natural communities, like the prairie, have been tailored by climatic and evolutionary forces to accommodate particular environments and to endure. Most natural ecosystems characteristically have low levels of soil loss, high species diversity, dominant perennial species adapted to local soils and climatic patterns, and an exclusively solar source of energy. Other characteristics include internal recycling of nutrients, net production equal to respiration so that total biomass approximates a steady state, high efficiency of energy transfer along food webs, and resistance to native herbivores and diseases (Soule and Piper 1992). Our perennial polyculture research, which aims to mimic the prairie ecosystem while producing edible grain, asks, can a perennial mixture successfully manage harmful insects and plant pathogens with little or no human intervention?

Species diversity, as in a polyculture, often leads to lower pest abundance relative to monoculture (Risch et al. 1983). With specialist insects, those restricted to only one or a few host plant species, polycultures tend to reduce the ability of a pest to locate its host and can attract an increased number of predators as well as create chemical interactions that can mask odors and interfere with the life cycle of the pest.

Similarly, polyculture may also reduce the incidence of insect borne disease infestations by providing physical barriers to block the movement of disease carrying insects, changing the microclimate within the mixture, and by providing genetic diversity, which may include disease-resistant populations. In many studies, disease levels in mixture are less than in monoculture (Burdon 1987).

This research project, which examines whether a polyculture can manage its own pest and disease problems, is in the fourth year of a longer term study. We measured both the density of an herbivorous insect, *Anomoea flavokansiensis* (Chrysomelidae), and the severity of a systemic viral disease on two of our perennial grains, Illinois bundleflower and eastern gamagrass, respectively. We hoped to find that, in fact, the occurrence of pests and disease is lower in polyculture than in monoculture.

Materials and Methods

Description of species and study plots

The perennial polyculture study includes three perennial species grown in monocultures and in mixtures. Eastern gamagrass (*Tripsacum dactyloides*) is a large warm-season bunchgrass with a range from southeastern United States and Great Plains southward to Bolivia and Paraguay. Wildrye (*Leymus racemosus*) is a rhizomatous cool-season grass native to southeastern Europe and western Asia. Illinois bundleflower (*Desmanthus illinoensis*) is a nitrogen-fixing legume native to the Great Plains, ranging northward to Minnesota, east to Florida and as far west as New Mexico. Eastern gamagrass and Illinois bundleflower were studied here to examine the ability of different planting mixtures to manage and discourage insect pest and disease infestations.

This study was established in March 1991 at two sites at

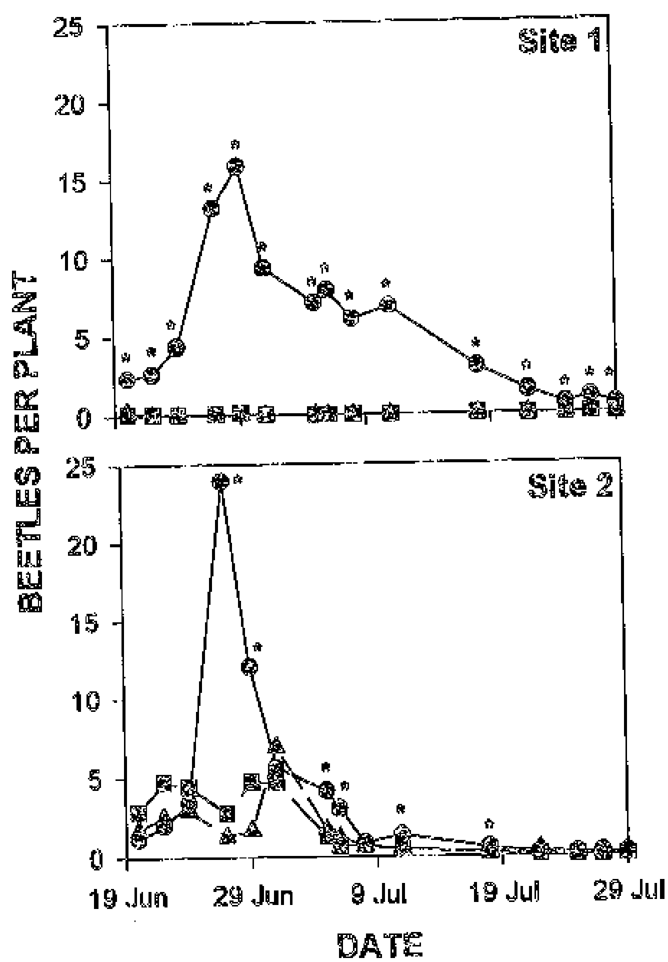

Figure 1. Mean beetles per Illinois bundleflower plant in three cropping systems at two sites in 1994. Asterisks indicate dates when beetle density was higher ($p<0.05$) in monoculture than in polyculture.

Key:
●=monoculture
■=biculture with gamagrass
▲=triculture

The Land Institute. Site 1 is located at the Sunshine Farm on a level Cozad silt loam, previously in a wheat-fallow rotation until 1990, when it was planted to alfalfa. Site 2 is a south facing eroded hillside, Kipson-Cline Complex soil. It was planted to native grasses in 1982, but had been continually cropped prior to that time.

At each site there are six cropping system treatments, each replicated three times: monocultures of eastern gamagrass, wildrye, and Illinois bundleflower; bicultures of bundleflower/gamagrass and gamagrass/wildrye; and a triculture of the three species. Plots are 7.32 by 9.75 m, with plants 0.75 m apart and rows 0.91 m apart. The outer two rows are left as borders to minimize edge effects.

From late June to early August, young leaves and flowers of Illinois bundleflower are fed upon by *Anomoea flavokansiensis.* Although the beetle feeds on other species in the Leguminosae (Moldenke 1970), locally we have found it only on Illinois bundleflower. Its development from egg to adult takes from one to two years (Erber 1990). After mating on bundleflower the beetle lays its eggs within a fecal pellet, which is then dropped to the ground and collected by ants. The ants carry the fecal pellets to their nest where the eggs hatch. The larvae then remain underground until they develop and emerge as adults (Vern Stiefel, personal communication).

The disease affecting eastern gamagrass is Maize Dwarf Mosaic Virus which is a systemic disease caused by a virus transmitted by aphids feeding on the plants. The disease overwinters in the rhizomes of a perennial host and emerges with new growth in the spring (Seifers et al 1993). Little attention has been given to the dynamics of viral diseases on perennial hosts except as an innoculum for annual crops. With time, however, effects of the disease may be more visible on perennials since pathogen-related damage may affect both fecundity and longevity (Burdon 1987).

The aphid takes up the virus as it sucks sap from an infected plant. The aphid then may infect other plants with the virus for several minutes to hours (Davis 1991). The virus subverts the host's metabolism to produce more virus particles, and reduces photosythetic area due to leaf yellowing thereby reducing seed yield as well as overwintering ability (Agrios 1978).

Procedures

Beetles were observed and counted on Illinois bundleflower from 20 June, as beetles began to emerge, until 29 July as their numbers declined. Censuses were conducted three times per week between 0700 and 0830. Some variation in the schedule occurred due to inclement weather. Beetle mating and feeding behavior on Illinois bundleflower was observed and noted.

MDMV was rated visually on eastern gamagrass using a 0-7 scale, with a 0 rating indicating no infection, 1-3 showing mild symptoms, 4-5 showing moderate symptoms and 6-7 indicating the most severe infection. Plants were rated the first week in May while plants were growing new leaves and the mosaic pattern of the disease was most discernible. Scoring for symptoms of the disease included observing overall infection of the plant as well as disease severity of individual leaves. An eastern gamagrass accession known to be susceptible to MDMV was used explicitly to study polyculture effects.

Results

Prior to 1994, insect densities were very low (<1 per plant) and there were no treatment differences. In contrast, this year insect numbers were much higher. At Site 1 peak insect density per plant was 16 and at Site 2 peak density was 24 insects per plant. At both sites Illinois bundleflower monocultures had significantly higher numbers of insects relative to bicultures and tricultures (Figure 1). There was little difference in insect density between the bicultures and tricultures. This year's data suggest that a polyculture can manage its own insect pest problems.

Eastern gamagrass infected with MDMV occurred in nearly all plots at both sites. At Site 2, a sunnier and drier environment perhaps less favorable for the aphid, there were no significant differences among treatments nor was there a change in the incidence of disease from previous years. At Site 1 initially disease severity was lower where Illinois bundleflower was a component of the plot. This effect persisted into the second year. At the same time, disease severity increased in all treatments the first three years and this year leveled off (Figure 2).

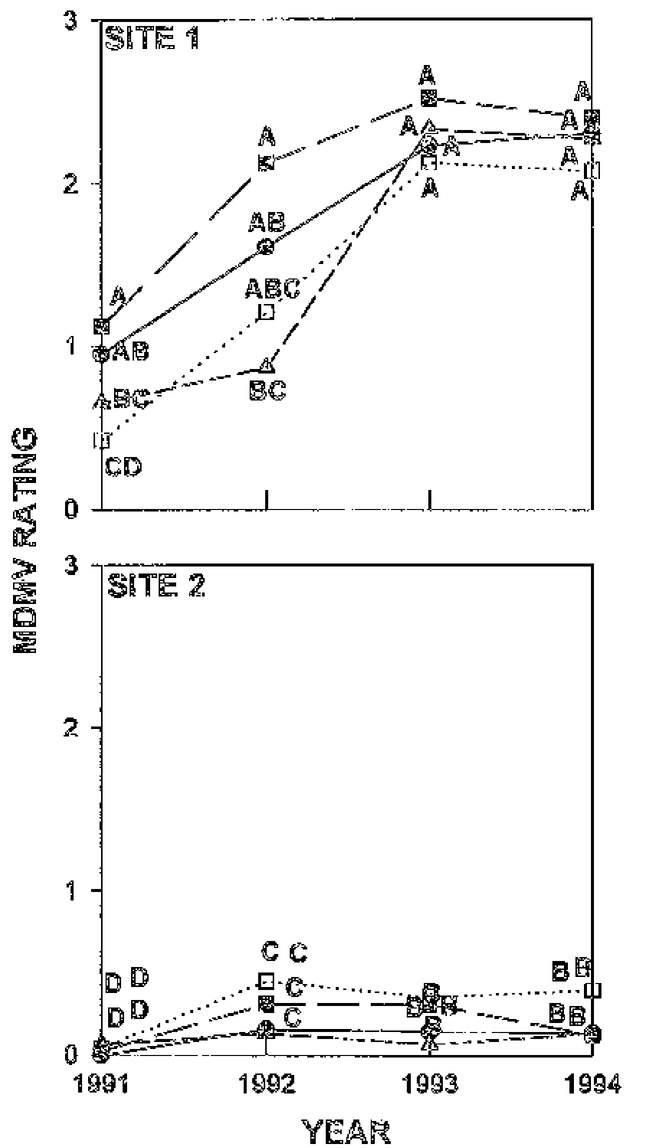

Figure 2. Mean Maize Dwarf Mosaic Virus rating on gamagrass in four cropping systems at two sites over four years. Within each year, symbols with the same letter do not differ at p<0.05 (ANOVA, Student-Newman-Keuls Test).
Key:
●=monocultures,
■=biculture with wildrye
□=biculture with bundleflower
△=triculture

Discussion

This was the first year in which there were treatment effects on the Illinois bundleflower beetle. Typical densities were more than ten times higher than in previous years. This year's high beetle populations may have been due to the natural rhythm of its life cycle, that of the ants, or both. Our results support previous research showing that incidences of specialist insects tend to be reduced by intercropping, which presumably makes it more difficult to find and to move among host plants (Andow and Rosset 1990). Our results are also encouraging because, with time, one might expect to lose the benefits of a polyculture that uses perennial plants. With annual crops, farmers use annual crop rotations to suppress insects, weeds, and diseases by effectively breaking the life cycles of the pests (Altieri 1987). In perennial polycultures, there is the risk that sooner or later the insect will colonize all plots and establish resident populations. Thus, it is pleasantly surprising that this benefit of polyculture appeared even four years after establishment.

One might ask why differences in disease severity among gamagrass treatments, especially in the Illinois bundleflower biculture, disappeared with time. The virus can reside in its perennial host for years and commonly overwinters in rhizomes. Once the virus is introduced into a population, it appears to spread (Siefers et al. 1993). In an intercropping arrangement, disease infestation may be delayed due to obstructions or chemical distractions by non-host plants. In similar research with soybean mosaic virus, disease reduction in polyculture was attributed to lower aphid landing rates, the increased chance that aphids lost infectability after probing non-host plants, or both (Bottenberg and Irwin 1992).

Our results show that it may be only a matter of time before the aphid transmits the virus throughout a plant population. It is encouraging, however, that after four years mean disease rating still remains within the "mild" category at Site 1 and near 0 at Site 2. These results suggest that in addition to a polyculture arrangement, including plants with genetic resistance to the disease is an important part of disease management.

Literature Cited

Agrios, G. N. 1978. Plant pathology. Academic Press, New York, NY.

Altieri, M .A. 1987. Agroecology, the scientific basis of alternative agriculture. Westview Press, Boulder, CO.

Andow, D. A., and P. M. Rosset. 1990. Integrated pest management. Pages 413-439 *in* C. R. Carroll, J. H. Vandermeer, and P. M. Rosset, editors. Agroecology. McGraw Hill Publishing Company, New York, NY.

Bottenberg, H., and M. E. Irwin. 1992. Using mixed cropping to limit seed mottling induced by soybean mosaic virus. Plant Disease 76:304-306.

Burdon, J. J. 1987. Diseases and plant population biology. Cambridge Univerity Press, Cambridge, England.

Davis, A. 1991. Variation in unselected populations of eastern gamagrass for response to MDMV. The Land Institute Research Report 8:31-34.

Erber, D. 1990. Biology of the Camptosomata: Clytrinae, Cryptocephalinae, Chlamisinae and Lamprosomatinae. Pages 513-552 *in* P. Jolivet, E. Petitpierre, and T. Hsiao, editors. Biology of Chrysomelidae. Kluwer Academic Publishers.

Moldenke, A. 1970. A revision of the Clytrinae of America north of the isthmus of Panama. Stanford University Press.

Risch, S., A. Andow, and M. Altieri. 1983. Agroecosystem diversity and pest control: data, tentative conclusions, and new research directions. Environmental Entomology 12: 625-629.

Seifers, D. L., M. K. Handley, and R. L. Bowden. 1993. Sugarcane mosiac virus strain maize dwarf mosaic virus B as a pathogen of eastern gamagrass. Plant Disease 77:335-339.

Soule, J. D., and J. K. Piper. 1992. Farming in nature's image. Island Press, Washington, DC.

Seed Yields of Three Perennial Grains in Monocultures and Mixtures

Portia Blume

Abstract

This was the fourth year of a long-term study to examine intra- and interspecific interactions between three perennial grains. Monocultures and mixtures of eastern gamagrass (*Tripsacum dactyloides*), wildrye (*Leymus racemosus*), and Illinois bundleflower (*Desmanthus illinoensis*) were planted in 1991 in both a favorable and less favorable growing environment. We focused on two questions this year: 1) Does each species maintain a consistent yield over time? 2) Do different mixtures continue to overyield from year to year? Wildrye and bundleflower yields are decreasing, whereas gamagrass yield increased in triculture and biculture with bundleflower. Gamagrass does better in mixture than in monoculture, whereas wildrye yields better in monoculture than in mixture. This year, bundleflower yielded better in monoculture than in mixture at the favorable site, but showed no treatment effects at the less favorable site. Tricultures and gamagrass-bundleflower bicultures overyielded at both sites this year. Gamagrass-wildrye mixtures overyielded at the less favorable site. The information we have gained over four years should help us design more stable polycultures for the future.

Introduction

The Land Institute's sustainable agriculture research uses the prairie as its model because prairies build up the soil, maintain their own soil fertility, and manage pests and plant diseases (Soule and Piper 1992). We are working to develop a "domestic prairie" that displays these ecological attributes but also yields edible seed. In addition to breeding selected perennials for high seed yield, we also experiment with different mixtures of perennials to see if candidate species yield better (overyield) when they are grown together.

Many traditional cropping systems feature mixtures that overyield (Vandermeer 1990). Overyielding can occur when competition among different species in a polyculture is less than competition between individuals of the same species in monoculture. For example, different species flower and set seed at different times, which minimizes the period when they compete for nutrients. Mixtures sometimes overyield because the component species benefit each other (Gliessman 1986). Most traditional cropping systems feature annual grains. Our challenge is to put together an overyielding mixture of perennial grains.

The Land Institute has experimented with various mixtures of perennials, of which some have overyielded (Braun 1985, Muto 1990). Many of the dominant plants in tallgrass prairie are warm-season grasses, cool-season grasses, and legumes (Piper 1993a). An experiment was begun in 1991 with mixtures and monocultures of eastern gamagrass (*Tripsacum dactyloides*), a warm-season grass, wildrye (*Leymus racemosus*), a cool-season grass, and Illinois bundleflower (*Desmanthus illinoensis*), a nitrogen-fixing legume. We want to know in what ways interactions between different plant species change with time, so our main questions this year were: How does yield of each species change with time? Will some mixtures continue to overyield as time passes? In this paper I describe the set-up of the polycultures, report our results for this year, and discuss the implications of the results for future polyculture designs.

Materials and Methods

Eastern gamagrass is a large bunch grass that is native to the Great Plains. Its range extends from Iowa to Texas and south to Bolivia and Paraguay (Great Plains Flora Association 1986). Wildrye is a grass native to Eurasia and may have been harvested as a food crop, especially during droughts (Burritt 1986). Illinois bundleflower, another native of the Great Plains, occurs as far north as Minnesota, east to Florida, and west to New Mexico (Great Plains Flora Association 1986).

Plots were established in March 1991 on two sites at The Land Institute. Site 1 is a level Cozad silt loam that was in a wheat-fallow rotation until 1990, when it was planted to alfalfa. Site 2 is an eroded, south-facing slope on a Kipson-Clime complex soil. After being cropped for many decades, in 1982 it was seeded with native grasses. When the experiment began, Site 1 had higher levels of soil organic matter and some nutrients (NO_3, total nitrogen, and potassium) than Site 2 (Piper et al. 1991).

Plots were planted in a substitutive design in which overall density was constant at 1.46 plants m^{-2}. Eighteen plots were planted at each site. Plots contain eight rows, oriented east to west. Each plot is 7.32 x 9.75 m, with rows 0.91 m apart and plants 0.75 m apart within rows. To eliminate edge effects, no data were taken from the outer two rows.

Six cropping treatments are repeated three times each at each site. Treatments consist of monocultures of each species, 1:1 alternate plant bicultures of Illinois bundleflower and eastern gamagrass and of gamagrass and wildrye, and 1:1:1 randomized tricultures of all three species.

Results and Discussion

Cropping system effects on seed yield patterns

In 1994, gamagrass yielded significantly better in mixture than in monoculture (Figure 1). Seed yield per plant has increased over the years for gamagrass in tricultures and in bundleflower bicultures, whereas yield in monoculture decreased this year. Yield in biculture with wildrye is decreasing at Site 1 but rebounding at Site 2. This result, together with results from another polyculture experiment (Piper 1993b), suggests that gamagrass, a relatively large plant, grows better with other species than with other gamagrass plants. Gamagrass also depletes soil nitrogen more than wildrye or bundleflower (Piper 1993c), and polyculture plots that contain gamagrass tend to have lower NO_3 levels than wildrye or bundleflower monocultures. Yields may therefore be higher in triculture and biculture with bundleflower because of bundleflower's nitrogen-fixing ability.

In contrast to gamagrass, wildrye yields better in monoculture than in mixture (Figure 2). Since 1993, however, >75% of wildrye plants have died, with most mortality occurring at Site 2. As a result, wildrye plot yield dropped from 1993 to 1994 in all treatments at both sites. Wildrye yielded <1 g per plant in all treatments at Site 2, and in biculture and triculture at Site 1. Data from previous work suggest that wildrye yield is highest in the first or second reproductive year (Piper and Towne 1988, Barker and Piper 1994), which could help explain this year's decrease. Weather may also have affected yield. Whereas 1992 and 1993 were wetter than normal, 1994 was a dry year, especially during the late spring when wildrye flowers and sets seed. Finally, over time wildrye seems to suffer in competition with gamagrass. As gamagrass grows larger, it may shade out wildrye and may also compete better for soil resources. In general, wildrye has not persisted well in this polyculture experiment, indicating that central Kansas is too hot and dry for this Eurasian cool-season grass.

In 1991 and 1992, bundleflower yielded better in mixture than in monoculture. Since 1992, bundleflower yield has been decreasing in mixtures. In 1994, bundleflower performed better in monoculture than in the mixtures at Site 1 (Figure 3). At Site 2, the yield pattern was similar, but with no significant treatment differences. Bundleflower yield has decreased in all treatments at both sites from 1993 to 1994. The primary reason for lower yield is rodent grazing of bundleflower taproots at Site 1 during the 1993-1994 winter, which killed

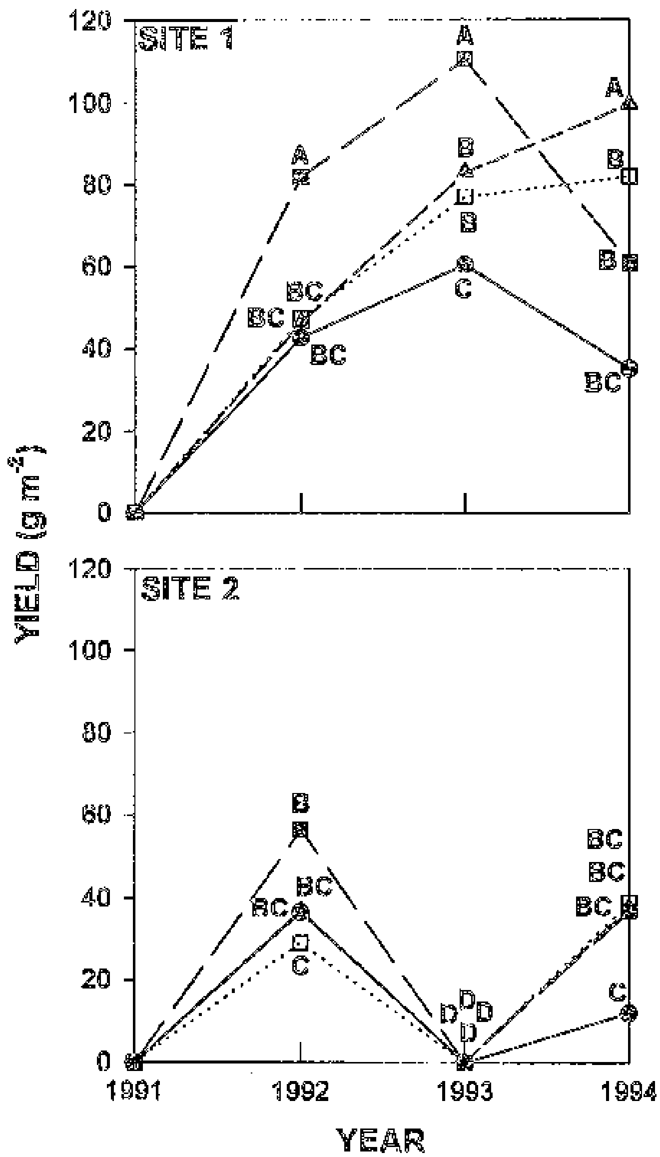

Figure 1. Mean gamagrass seed yield in four cropping systems at two sites over four years. Within each year, symbols with the same letter do not differ at $p<0.05$ (ANOVA, Student-Newman-Keuls Test).

Key:
●=monocultures,
■=biculture with wildrye
□=biculture with bundleflower
△=triculture

many of the plants. A second reason could be that bundleflower yields tend to rise and fall from year to year (Rabinovich 1995). This could have been a low year for bundleflower yield in this experiment. I counted dead plants as zeroes in my averages. If I had included yields of living plants only, bundleflower plants in monoculture would have averaged 104 g m^{-2} at Site 1, resulting in a four-year yield pattern more similar to Rabinovich's results. A third reason for lower 1994 yield could be that bundleflower tends to deplete soil water more than gamagrass or wildrye (Piper 1993c). In this dry year, low soil water may have limited bundleflower growth. Finally, leaf beetles (*Anomoea laticlavia*) were present at high densities on bundleflower plants (Geisen 1995) and may have eaten enough flowers and young seed pods to reduce yield significantly.

Overyielding

Tricultures and gamagrass-bundleflower bicultures at Site 1 overyielded in 1994 (Table 1). At Site 2, all three cropping mixtures overyielded. On the surface, these numbers are encouraging, but a closer look shows that gamagrass was responsible for almost all of the overyielding. Yield from the other species never accounted for more than 0.25 of the total LER averages. In one case, the gamagrass/wildrye biculture at Site 2, all the wildrye was vegetative; the gamagrass accounted for 100% of overyielding. Gamagrass plot yield was frequently higher in biculture and triculture than in monoculture, despite the fact that monoculture plots contain two to three times as many plants as the other treatments. This suggests that gamagrass individuals are too dense in the monocultures, which suppressed yield. LER calculations assume that the monoculture yield is optimum. Our LERs may therefore be too optimistic, because it appears that gamagrass yields better at

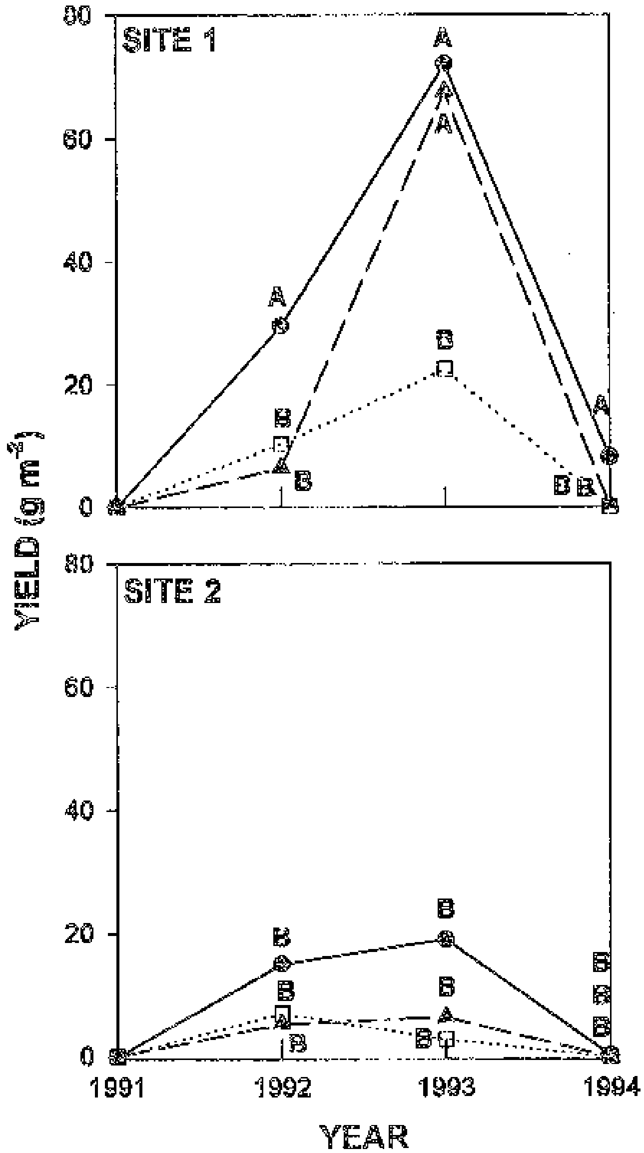

Figure 2. Mean wildrye seed yield in three cropping systems at two sites over four years. Within each year, symbols with the same letter do not differ at p<0.05.

Key:
⊗=monoculture
□=biculture with gamagrass
△=triculture

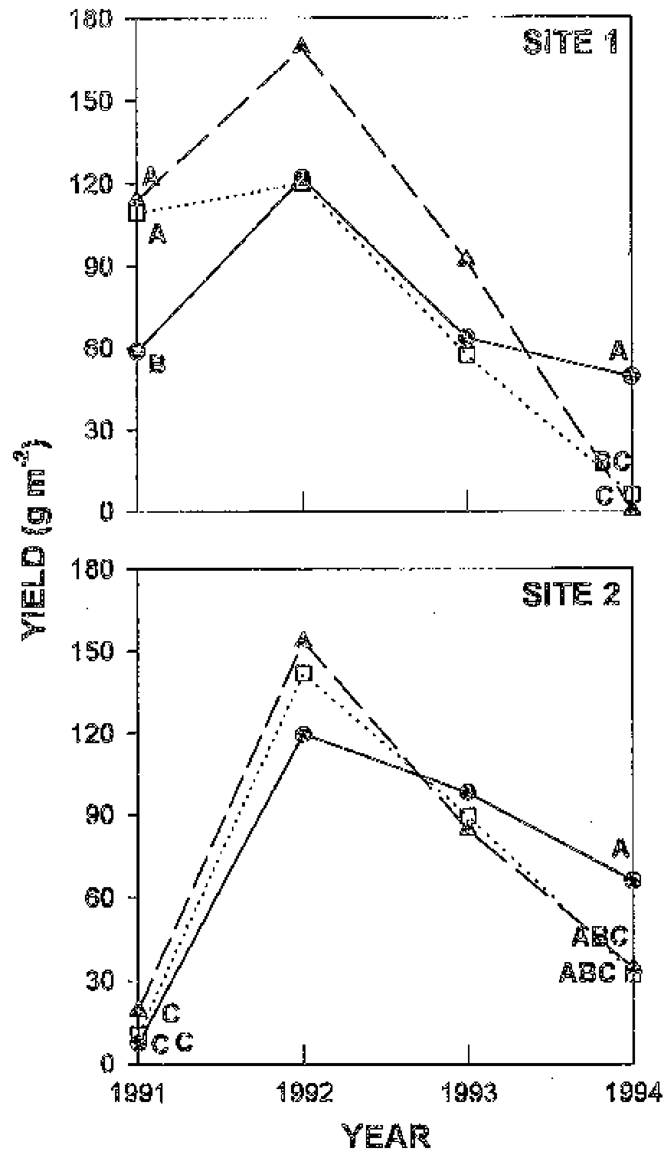

Figure 3. Mean bundleflower seed yield in three cropping systems at two sites over four years. Within each year, symbols with the same letter do not differ at p<0.05.

Key:
⊗=monoculture
□=biculture with gamagrass
△=triculture

lower densities, as when neighboring plants die, or when it can spread out because its neighbors are smaller species.

Ideally, each cultivar in a perennial polyculture should contribute substantially to overall yield. We have not yet achieved this ideal. Instead, our mixtures may be shifting toward a gamagrass monoculture. One reason for this may be that wildrye tends to yield better in its first and second reproductive years (Piper and Towne 1988), and bundleflower yields tend to rise and fall in a "W" shape over five years (Rabinovich 1995), but gamagrass yields typically increase during the first few reproductive years. Therefore, gamagrass has become the dominant species in the polycultures over time. Another explanation could lie in work indicating that the higher initial species diversity is, the more likely it is that a stable community will result (Lockwood and Pimm 1994). Our polycultures contain a maximum of only three species (not including weeds). A perennial polyculture may need to contain many more species initially in order to persist as a diverse community for several years.

Conclusions and Recommendations

After four years, some patterns are emerging in these plots. Wildrye yield is decreasing. Bundleflower yield is currently decreasing, but may rebound. Gamagrass yield is increasing in mixture with bundleflower. Gamagrass seems to benefit when intercropped with bundleflower, and wildrye does poorly when grown with gamagrass.

At this point, I can offer some recommendations about the design of future perennial polycultures. Cool-season grasses are uncommon in our prairie, and therefore may never be important components in future polycultures for central Kansas. They may find a niche as nurse crops for warm-season grasses, however. Because of the strong performance of gamagrass, and because warm-season grasses constitute most of the biomass of the local prairie (Piper 1993a), more warm-season grass species should be included in new polyculture experiments. We may also want to add more legumes to our polycultures to see if legumes and warm-season grasses will consistently yield well together. Different species produce their highest yields in different years, so we may want to space our plantings out over time so that one or two species in a polyculture will be yielding well every year. Finally, more persistent perennial polycultures will probably contain more species, including sunflower relatives, than our current experiment. We have much to learn, but we are beginning to have an idea of what a persistent, high-seed-yielding perennial polyculture will be like.

Table 1
Land Equivalent Ratios (LERs) for three cropping mixtures.

Treatment	1992 Site 1	1992 Site 2	1993 Site 1	1994 Site 1	1994 Site 2
Gamagrass/wildrye biculture	1.06	1.03	1.10	0.87	1.53
Gamagrass/bundleflower biculture	1.05	1.01	1.13	1.02	1.90
Triculture	0.78	0.91	1.26	1.09	1.22

Note: An LER>1 indicates overyielding. No gamagrass was harvested at Site 2 in 1993.

Literature Cited

Barker, A. A., and J. K. Piper. 1993. Growth and seed yield of three grassland perennials in monocultures and mixtures. The Land Institute Research Report 10:14-21.

Braun, L. 1985. Overyielding in a perennial legume biculture. The Land Report Research Supplement 2:4-7.

Burritt, B. 1986. Leymus: a plant with a history of human use. The Land Report 28:10-12.

Geisen, R. 1995. Can a perennial polyculture manage its own disease and insect pest problems? The Land Report 51: 34-36.

Gliessman, S. R. 1986. Plant interactions in multiple cropping systems. Pages 82-95 *in* C. Francis, editor. Multiple cropping systems. Macmillan Publishing Company, New York, NY.

Great Plains Flora Association. 1986. Flora of the Great Plains. University Press of Kansas, Lawrence.

Lockwood, J. L., and S. L. Pimm. 1994. Species: would any of them be missed? Current Biology 4: 455-457.

Muto, P. J. 1990. Evaluation of Illinois bundleflower and eastern gamagrass germplasm in monocultures and bicultures. The Land Institute Research Report 7:25-28.

Piper, J. K. 1993a. A grain agriculture fashioned in nature's image: the work of The Land Institute. Great Plains Research 3: 249-272.

Piper, J. K. 1993b. Neighborhood effects on growth, seed yield, and weed biomass for three perennial grains in polyculture. Journal of Sustainable Agriculture 4(2):11-31.

Piper, J. K. 1993c. Soil water and nutrient change in stands of three perennial crops. Soil Science Society of America Journal 57:497-505.

Piper, J. K., M. Mack, and V. Wittig. 1991. Interactions within monocultures and mixtures of three perennials. The Land Institute Research Report 8: 35-39.

Piper, J. K., and D. Towne. 1988. Multiple year patterns of seed yields in five herbaceous perennials. The Land Institute Research Report 5: 14-18.

Rabinovich, V. 1995. Germ plasm studies of Illinois bundleflower and eastern gamagrass. The Land Report 51:31-33.

Soule, J. D., and J. K. Piper. 1992. Farming in nature's image. Island Press, Washington, DC.

Vandermeer, J. H. 1990. Intercropping. Pages 481-516 *in* C. R Carroll, J. H. Vandermeer, and P. M. Rosset, editors. Agroecology. McGraw-Hill Publishing Company, New York.

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