Agricultural Ecosystems

by Kelly Kindscher

TABLE OF CONTENTS

INTRODUCTION

A model farm of the future was designed by some United Stated Department of Agriculture specialists and described in the February, 1970 National Geographic. It was characterized as a highly specialized super-farm with radio-controlled and totally automated machines that work fields several miles long without a wheel touching them. Their idea of a future farm assumed unlimited energy resources, a continued decrease in the number of farms, and that people would not be directly involved in the production of our food.

As we enter the 1980's, a new vision for agriculture is emerging. The reductionistic trend toward corporate control of the land, monoculture of crops, and industrialization of the entire food-production process is seen to be unsustainable and must be thwarted and reversed. The agricultural ecosystem concept is part of the new vision which can guide us toward an energy-conserving and ecologically-sound, de-centralized agriculture.

Any piece of land that grows food, even a typical corn field, can be considered an agricultural ecosystem because there is a relationship between the crop and the environment which requires cycling of energy and matter. But this is an inaccurate use of the term because most fields lack the wholeness and quality of an ecosystem. A corn field is not an ecosystem or a true agricultural ecosystem because the current methods of growing corn are an attempt to exclude life, to limit relationships, and to create monoculture. A true agricultural ecosystem will have the characteristics of diversity, permanence, and sustainability.

An agricultural ecosystem should be modeled after a natural ecosystem such as a Tallgrass Prairie or an Oak-Hickory Forest. Certain environments within natural ecosystems can serve as a model for the diversity and quality that an agricultural ecosystem should have. There are special places of native vegetation that I visit to gather wild foods that illustrate this diversity and quality. These areas are beautiful because of their natural relationship of plants to the environment.

One of these places is a swampy area that has cattails and arrowleaf plants as a result of the wet, lush environment. There are wild climbing legumes and touch-me-nots on the edge of this swamp, along with nettles which I harvest for greens in the spring. This place is known as the 'watercress patch' which people visit to gather the tasty, spicy, salad greens growing in the spring-fed water. The watercress patch is most appreciated in the late fall or early spring when there are virtually no other green plants to be found or seen. This area supports a larger sphere of life. It is a place to watch muskrats swimming and feeding on a sunny day in the late winter after the snow and ice have melted enough for their activity to begin. Waterfowl stop here to feed on duckweeds, and birds and other life make their homes and feed in and around the willow, sycamore, and cottonwood trees that surround the marsh. On drier ground, mulberries, walnuts, and other native trees add further diversity and food to this area.

It is my hope that an ecologically balanced food-producing crop system can be developed that has the quality, diversity, and beauty of this watercress patch or some other area of natural vegetation. The problems associated with developing an agricultural ecosystem that models nature are great and it is beyond the scope of this study to completely investigate all aspects of this food-producing system. Perhaps the ultimate value of this study will be to promote ecological food production and encourage concerned agricultural scientists and people with an alternative vision of the future to further investigate sustainable agricultural practices.

I have appreciated the Department of Energy Appropriate Technology

grant which has allowed me to research and develop the concept of an agricultural ecosytem. This paper is a result of that research and ideas within do not necessarily reflect those of the Department of Energy.

This paper contains five chapters. The first is a philosophical discussion of preserving land and health. The second, third, and fourth chapters discuss research that has been done which supports the agricultural ecosystem concept. The fifth chapter is the practical application of this concept and gives a hypothetical model agricultural ecosystem for northeast Kansas. This model is site specific and would be different if made for another location. However, the ecological principles which appear in this paper can be used wherever an agricultural ecosystem is being established.

The agricultural ecosystem concept involves a process of biological intensification of our agriculture. Biological processes will be used to replace chemical and mechanical ones--legumes can replace chemical fertilizer, beneficial insects and diversified plantings can replace pesticides, and perennial plants can replace herbicides and tillage. These practices can help create an agriculture that is permanent and sustainable, a renewable resource that protects soil, air, and life.

It is necessary that people are involved in growing our food. Monoculture and monotonous surroundings and work can be replaced by polyculture and diversified work in aesthetically-pleasing surroundings. We can produce food in a diverse and beautiful environment, an ecosystem which nourishes and sustains us. The work that it takes to develop and maintain an agricultural ecosystem can transcend the task and become part of the larger work of perfecting the human spirit.

716 Lake St.
Lawrence, Ks. 66044
(913) 842-1407

I

PRESERVING LAND,

PRESERVING HEALTH

The Prairie as a Model

The natural vegetation of any area should serve as the land use model for that biogeographical area. The natural vegetation preserved in wilderness or found in 'wild' places should serve as our model for agriculture. John Weaver, a plant ecologist at the University of Nebraska, spent his life studying the prairie. His valuable insights show how the prairie can be an agricultural model.

> So many species--often a total of 200 or more per square mile--can exist together only by sharing the soil at different levels, by obtaining light at different heights, and by making maximum demands for water, nutrients, and light at different seasons of the year. Legumes add nitrogen to the soil; tall plants protect the lower ones from the heating and drying effects of full insolation; and the mat-formers and other prostrate species further reduce water loss by covering the soil's surface, living in an atmosphere that is much better supplied with moisture than are the windswept plants above them. Light is absorbed at many levels; the more-or-less-vertical leaves of the dominant grasses permit light to filter between them as the sun swings across the heaven. Compared with man's crops of wheat or maize (in adjacent fields of virgin soil), fluctuations in temperature of both soil and air are much less in prairie, humidity is consistently higher, and evaporation is decreased. The prairie's demands for water and light increase more gradually and extend over a longer period of time. Less water is lost by runoff or by surface evaporation. When drought occurs, the vegetation gradually adjusts itself during a period of stress.[1]

The vegetation of the prairie and other areas of natural vegetation have two characters that are in contrast to our present agriculture. They are polyculture (a diversity of plant species) and perennialism. In order to have a more ecologically-sound agriculture, these two features will need to be incorporated into our cropping schemes. This could occur by using cover crops (possibly leguminous) along with our main crops to give us polycultures. Perennialism could be a part of our cropping scheme by using perennial cover crops, bushes and trees, or by developing perennial grain crops. If some or all of these techniques were adopted, our fields would resemble the natural plant communities in structure and would be closer to becoming sustainable agricultural ecosystems.

The Preservation of Agricultural Lands

The prairie, which could be a model for agriculture, is the only major biogeographical area that has not been preserved in a National Park. We have preserved many special areas of our country by making them into National Parks. These areas have dramatic or breath-taking scenery--either mountains, seashores, rock formation, or canyons. But there is no National Park that preserves the prairie which once covered so much of our nation's land.

Our National Parks are lands that are mostly unsuitable for agriculture. They are either too mountainous, rocky, or wet to grow crops. One of the reasons that there has been no Prairie National Park is that the prairie could be used for agriculture. Most of it was suitable for growing crops and was plowed, the rest was fenced and made into pasture.

We have a history of only preserving lands that can not be used for agriculture. It is not surprising that the soils of our agricultural lands are not preserved and protected either. They can be used and soil erosion is a lamented, but accepted, result of current farming practices. There has been a lot of talk about methods of soil conservation and some methods, such as terracing, have been helpful in slowing soil erosion. However, these methods are not enough. Soil erosion is continuing at an excessive rate. There are farming practices that can reduce and eliminate the soil erosion problem. These are discussed further in the chapter "Perennials for Permanence".

The preservation of the prairie and the preservation of agricultural lands are part of the same process because they are the protection of lands that we can use. A Prairie National Park would be preservation of land in its pristine state. The preservation of agricultural lands is the protection of the land and soil so that it is a sustainable, food-producing resource. Both are the protection of land for the future. A good portion of our agricultural lands have fertile soils because their natural vegetation was prairie. These fertile soils are a birthright that needs to be protected for our children and for our continued health.

There are many ways in which land can be preserved. Legislation and economic incentives are helpful, but the basis for preservation of the land is ultimately dependent upon our individual actions. We must all act as preservationists, protecting for the future the land that supports us and that is accessible to us. It is an action in which we are all participants. We must remember that ". . . the care of the earth is our most ancient and most worthy and, after all, our most pleasing responsibility. To cherish what remains of it, and to foster its renewal, is our only legitimate hope."[2] We need to grow food in ways that express our care and responsibility for the earth. The agricultural ecosystem concept can provide a framework and methodology for growing food in a responsible manner, which can lead us to a sustainable agriculture.

The Farmer: Removed

Modern agriculture is praised for its productiveness and for freeing farmers from drudgery. However, farmers have been removed from the food-growing process by using technologies that physically separate them from their crops.

Technological changes are not inherently evil. They need to be looked at carefully and accepted only if they are found to be beneficial to a wide-ranging set of criteria that considers the future health of the environment and all living beings. The recent changes in agricultural technology have created problems, such as contamination and poisoning by chemicals, soil erosion, dependence upon complicated and energy-intensive machines, and others. Experts tell us that these problems are side effects, supposedly incidental and indirectly linked to the new technology. But they are actually direct effects, and the technology that causes these problems must be held fully accountable for them.

The replacement of horses by tractors is an example of a technological change that removed farmers. When the tractor replaced the horse as the motive power on the farm, several things changed. The source of fuel to pull the machinery to till the soil no longer came from the soil, but came from off the farm, from oil. The introduction of the tractor helped speed the trend toward larger and larger farms. This resulted in the need for fewer farmers and so farmers were removed, eliminated through competition. Also, the farmer was elevated by the tractor. In order that the farmer could see over his machine, the seat was raised. As tractors became more powerful, the seat was raised higher and so farming actually became 'man over nature'.

With yet larger and more powerful tractors, the cab, an enclosed environment for the farmer, has almost become a necessity because of excessive noise, dirt, and heat. The farmer now operates from a different environment, removed from the agricultural environment. From an elevated, lofty throne, the farmer can see to the end of his machine and beyond to the next acres to be worked. For the power and speed, the farmer has given up his or her sense of smell, touch, taste, and hearing. These senses are now focused on the machine--removed from the land and life. Only the sense of sight remains, and what is seen, is seen from a greater distance.

With this example, I am not advocating that we 'go back' to horses, but am showing that the subtle effects of new technologies are not fully considered. Our future agriculture will surely have a greater diversity of technologies--more appropriate technologies, and the use of draft animals may be one part of those technologies.

The Incompatibility of People and Land

On a recent trip to California, I saw a further example of how people and farmers are removed from the food-growing process. I was staying in Hanford, California, in the famed San Joaquin Valley. One day I borrowed a bicycle to go out and look at the crops. The San Joaquin Valley is one of the most diversified agricultural regions in the United States. But what I saw from my bicycle, was large fields of crops grown in monoculture--cotton, alfalfa, corn, walnuts, plums, and others, in fields too large to make the vegetation diverse. There were few farms and virtually no people out in the fields. On this warm, sunny, summer day, the fields looked almost sterile--one crop only--no people, no animals, and virtually no weeds, all were removed.

Some of the fields are not even safe for people to enter. One field of plums, that were almost ripe was posted with signs saying: "Warning, Keep Out! This field has been sprayed with Guthion. No tresspassing!" This was accompanied with a skull and crossbones figure and repeated again in Spanish. If this spray is that dangerous, is it safe to ride or drive by? How long must the farmer stay out of his field? Are the plums really safe to eat? These questions have answers, but who knows the real answers.

The use of this chemical removes not only its intended target (pests), but it also removes the farmer and any other people from the field. There are certain times when (and places where) people and the land are considered to be incompatible. The value of what the land produces is considered greater than the relationship of people to the land. The farmer has been removed from the land because of the acceptance of this incompatibility.

Planting Seeds for the Future

There are people who highly value their relationship to the land. They express this in the way that they grow food. I have a friend who farmed until he was 65 years old and has been a market gardener at the edge of town ever since. He is now 89 and it is becoming more difficult for him to move around. I never see him walking without at least one hickory cane, but he still is able to grow large quantities of vegetables and fruits.

Recently, I went over to see him and to buy some fruit. He was cutting up some cull peaches for his supper and showed me some of his white seedling peaches. Although they were only about half the size of other peaches that he grew, they were very juicy and had fine flavor. He had planted the seeds that grew these trees. He cut the peaches into a can with a simplicity of movement that was unaffected by his crooked, arthritic fingers. He dropped the pits of these peaches into a can by his feet because he was going to plant them in the fall. A peach tree had died and it was time to plant another in its place.

His action--the planting of peach pits without really knowing that he will live to see them blossom and make fruit--is an example of the care and physical action that will take us toward a healthful future. It is an example of a relationship to the land that is not removed, but is an integral part in the productivity of the land.

The Care of the Earth

The old value of productivity must be clarified. True productivity must be understood as a multiplicity of values--more than just yield or profit. Productivity should include concepts found in ecology that protect and preserve nature. Nature is easily disturbed and thrown out of balance, yet it also has a remarkable capacity to heal itself, if given enough time. Our sustenance comes from the earth and for it to continue to sustain us, we must learn to use it and care for it at the same time. We must have values for land management which promote its sustainability. E. F. Schumacher, a British economist, said that: "management of the land must be primarily oriented towards three goals--health, beauty, and permanence."[3] With these goals, productivity will then follow.

A direction of purpose toward these goals that spiritually connect us to the earth is needed for the continued protection of our environment. There is a sacredness that we can glimpse when we relate to the earth in a spiritual manner. What we experience with our senses in the spiritual realm can not be adequately expressed in words. It is beyond language and scientific proof. Actions can not be defined as spiritual or unspiritual as it is difficult to discern whether ones actions have a spiritual basis. However, our actions can express our commitment to preserving and protecting the earth. There is much work to do and responsible action will express our spiritual commitment to a sustainable and healthful future.

Holistic Health

When we talk about agriculture, about food, about the preservation of land, we are fundamentally talking about health. That should be our goal, "not in the merely hygienic sense of personal health, but the health, the wholeness, finally the holiness, of Creation, of which our personal health is only a share."[4]

We can obtain this goal of holistic health through the adoption of the agricultural ecosystem concept. It can make our agriculture healthful and sustainable. We must preserve the land and plant seeds for the future. Health is the preservation of us all. By planting peach pits when we are 89 years old, or by planting a garden or crops when we do not know when it will rain, we will be doing the work that needs to be done to perpetuate our life on earth and to keep the larger circle of life and health unbroken.

II

BIOLOGICAL INTENSIFICATION OF AGRICULTURE: POLYCULTURES

We must change our agriculture to preserve the land and our health. The problems of soil erosion, chemical contamination of our food and land, and the excessive energy usage that our present agricultural practices create are obvious. It is easy for those of us searching for a sustainable agriculture to talk of a de-centralized, utopian, future agriculture. It is difficult to see the path for the agricultural transformation that must take place. The use of biologically-intensive cropping systems or polycultures is an important step towards a sustainable agriculture.

A polyculture can be defined as any area of land that is being used for more than one crop as a time. Polycultures offer many advantages over monoculture. Their use will gradually increase when it is shown that biologically complex cropping systems can substitute for the chemical control (especially the use of pesticides and chemical fertilizers) of our present agriculture. When this begins to happen, our present agriculture will evolve into an organic agriculture (see figure 1). With a further increase in biological complexity, the energy-intensive, mechanical aspect of our present agriculture can be greatly reduced. Then, we will be using organic polycultures of annual and perennial plants and be well on our way to a more sustainable agriculture.

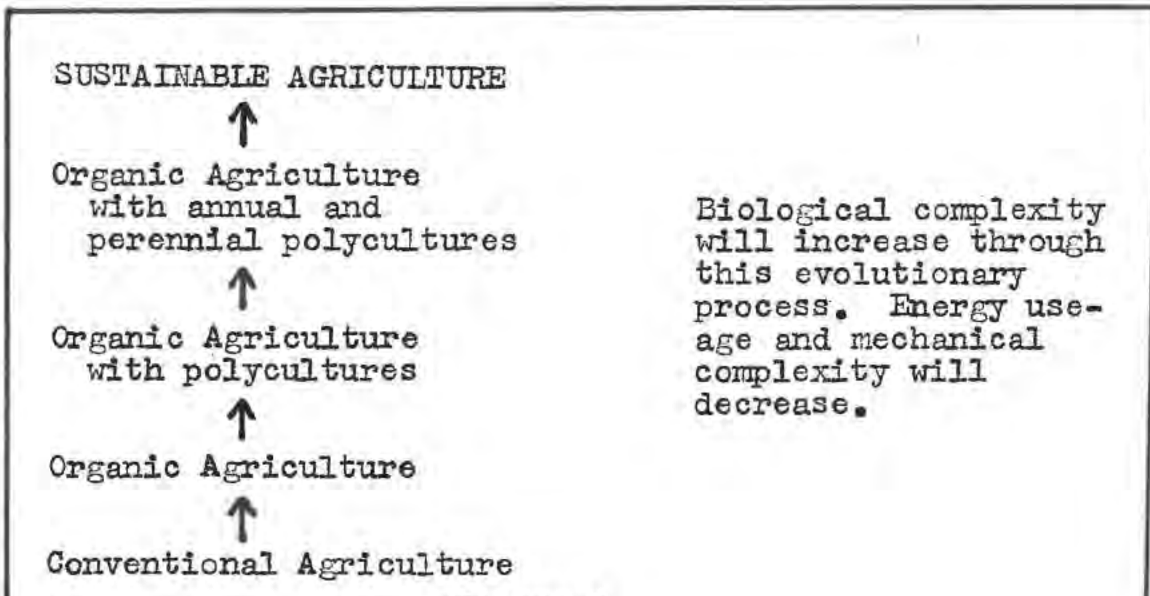


figure 1

The History of Polycultures in America

The Native Americans often grew corn, beans, and squash in polycultures. Their mixed plantings made better use of space. Their methods varied from tribe to tribe. The Omaha planted seven kernels of corn in one hill and squash seeds in the next and so on, alternating across their fields. If ground space was limited, beans were planted with the corn, the stalk serving the same purpose as poles.[1] The Seneca planted every seventh hill in their cornfields to squash and beans. Their rationale was not based upon some agronomic principle, but "because it was thought that the spirits of these three plants were inseparable."[2]

The early American colonists grew their corn in polycultures as they learned from the first inhabitants of the land. Small grains, such as wheat and rye, were grown in monoculture. But their acreages were quite small, being determined by the amount of time and work it took to harvest.

The introduction of machinery, especially the horse-drawn cultivator, the reaper, and the thresher changed agriculture. A lot of tedious work was eliminated and production per farmer increased. However, the increased complexity of technology meant a decrease in the complexity of the arrangement and number of crops grown. Monocultures became a necessity. With the further development of mechanical technology, allowing yet larger farming operations, chemical technology, through the use of synthetic fertilizers and pesticides, replaced biological technology.

Benefits of Polycultures

Monoculture allows for the isolation of one plant from all others. This is the simplest cropping system, but seldom found in nature. It is the easiest to manipulate because the only interactions are between plants of the same species, unless lack of cultivation or soil preparation has allowed the field to become weedy. But in a monoculture, simplicity is also its weakness, and so mechanical and chemical surrogates are needed to compensate for the lack of biological diversity.

Natural plant communities are diverse. A sustainable agriculture will replicate the natural vegetation of an area to as great a degree as possible. This replication process will almost certainly mean the use of polycultures. Polycultures are characterized by balance and stability. This is their true strength.

Most of the recent research on polycultures has been done in tropical, third-world countries where climate, economics, labor, and mechanization are quite different from ours. However, the basic biological processes are very informative. This research, along with the few recent studies on polycultures in temperate North America, shows the advantages and potentials of polycultures. Donald Kass, in his review and analysis of polyculture cropping systems concluded:

> . . . definite advantages over monoculture exist. In terms of withdrawal of nutrients from the soil, economic return, improvement

> of nitrogen status of the soil-plant system when one of the crops is a legume, and greater stability of yields over time, the benefits of polyculture are clear.[3]

Some studies have shown that polycultures offer other advantages too: higher crop yields,[4] more efficient water use,[5] reduced soil erosion,[6] decrease in pest loss,[7] less competition from weeds,[8] better use of light,[9] an increase in beneficial soil bacteria,[10] and a larger supply of local, fresh food.[11]

The greatest advantage of polycultures may be that more than one parameter can be maximized: for instance, the yield of one component crop and the protein content of another component crop. Probably no polyculture cropping scheme could have all of the above advantages. But many of the above advantages could be gained through proper selection of crops, careful arrangement in the field, and proper timing. Further research and experimentation are needed.

Crop Competition

In a polyculture there is more than one species of plant growing in the field at one time. It must be determined how much the different crop components interfere or compete with each other. Crops that can biologically complement each other or can self-compensate, that is, respond positively to the presence of another crop, are the ones to be selected for polyculture cropping schemes. For instance, a corn/bean crop mixture is better suited for a polyculture than other crop mixtures because of their complementary habits.

Polycultures are most advantageous when inter-specific (between crop) competition is less than intra-specific (within crop) competition. As an example, if the competition between a corn and a bean plant, at a given population, is less than the competition between a corn and a corn plant, then there will probably be advantage to growing them together. In most cases, the reduced competition allows for a higher overall plant population, thus allowing for higher yields.

Yields and Land Equivalent Ratios

The highest yield of a crop per acre will usually occur when that crop is grown by itself, in monoculture. The highest total yield of two or more crops per acre will usually occur when they are grown together, in polyculture. In a polyculture containing two crops, their individual crop yields are often less than the monoculture yield for the same area. To compare yields of a polyculture to a monoculture, a land equivalent ratio is used. This is calculated:

$$\frac{\text{Yield of crop A in polyculture}}{\text{Yield of crop A in monoculture}} + \frac{\text{Yield of crop B in polyculture}}{\text{Yield of crop B in monoculture}}$$

An interpretation of the land equivalent ratio is the number of acres of monocrops needed to produce a yield equal to one acre of the crops grown in polyculture (see figure 2).

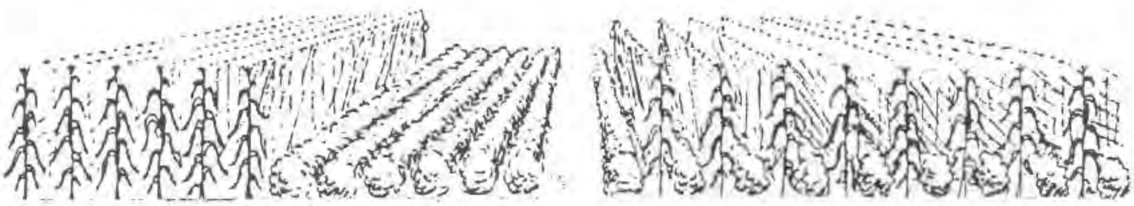
The Mechanical Dilemma

Polycultures can have higher yields, but the crop mixture may be difficult to harvest. The mechanical dilemma that a polyculture causes can be illustrated by an experience that occurred when my father planted pumpkins in one of our milo (grain sorghum) fields.

There were some places where the milo stand was uneven, so my father planted pumpkin seeds in between the milo plants. At milo harvest time, our neighbor was cutting our milo for us with his fourteen foot wide combine, when all of the sudden he stopped and yelled to us over at the truck: "Hey, there's pumpkins out here!" We hurriedly drove the pickup out to the middle of the field and picked up the pumpkins, most of which were still green. It amused me later to think of how those pumpkins stopped that acre-eating machine right in its tracks.

LAND EQUIVALENT FOR POLYCULTURE

½ acre each yields | 1 acre mixed yields



75 bushels corn | 20 bushels soybeans | 135 bushels corn and 12 bushels soybeans

135 bushels corn	@ 75 bushels per ½ acre	0.9 acres
12 bushels soybeans	@ 20 bushels per ½ acre	0.3 acres
	Total	1.2 acres

It would require 1.2 acres of monoculture corn and soybeans to produce as much as one acre in polyculture. Examples of land equivalents are listed in Figure 3.

figure 2

A bean/corn polyculture causes a similar mechanical dilemma. But it can be more easily solved, due to the nature of the crops involved. A combine would not have to be altered too much to be able to harvest both corn and beans at the same time. Since our agriculture has acheived a high level of mechanical complexity, it seems that we are capable of developing machinery for polycultures. This is a task for the mechanical engineers. It is encouraging that recent research, aimed at reducing the difficulties of a mechanized harvest of polycultures, has been quite sucessful.[12]

We have tried to perfect monoculture to fit our mechanical agriculture. Mechanical complexity has replaced biological complexity. Large-scale

LAND EQUIVALENT RATIOS

A land equivalent ratio is calculated:

$$\frac{\text{Yield of crop A in polyculture}}{\text{Yield of crop A in monoculture}} + \frac{\text{Yield of crop B in polyculture}}{\text{Yield of crop B in monoculture}}$$

Crops	Land Equivalent	Country	Reference
corn and soybeans	1.0	U.S.A.	16,17
corn and soybeans			
no fertilizer (N)	1.47	Phillipines	15
high fertilizer	1.12		
high lysine corn and			
edible soybeans	1.2-1.5	U.S.A.	23
corn and field beans	1.08-1.68	Colombia	4
corn and field beans	1.39	Kenya	9
corn and green gram	1.7	Nigeria	14
sorghum and millet	1.8	Nigeria	5

figure 3

mechanization of agriculture has only been possible with our energy-affluent times. And when the realization of an energy-scarce future occurs, our agriculture will change. To meet this change, we need to develop machines capable of handling biologically-complex polycultures. At the same time, we need to begin developing polycultures that are self-maintaining, needing little mechanical control. It will be the development of self-maintaining polycultures that brings us closer to a sustainable agriculture.

Grain/legume Polycultures

Legumes are a traditional, high protein food source. They have been important in cropping systems because they help maintain soil fertility through their symbiotic relationship with nitrogen-fixing bacteria. Legumes are also valuable as a soil-conserving cover crop, which can become the basis for self-maintaining cropping systems. For these reasons, legumes will play a major role in polycultures.

In a grain and legume polyculture, component crops, such as corn and beans, can form a beneficial relationship. They have complementary rooting systems, the corn plant being a surface feeder and the bean plant having more of a deep-rooted nature. Together they can take advantage of a larger reservoir of soil moisture and nutrients. Also, beans can quickly shade the ground, preventing competition from weeds. This has led to a yield increase in a mung bean/corn polyculture.[13]

Beans are nitrogen self-sufficient and will not compete with the heavy nitrogen-feeding corn for this nutrient. They can produce nitrogen that can be used by a following crop. However, a large portion of their nitrogen goes into seed production and if shaded, nitrogen production may decrease. In an experiment in Nigeria, growing greem gram (a tropical bean) with corn, the bean supplied the corn with nitrogen during the growing season.[14] This may be possible with other legumes if they mature before the corn crop and their nodules start to decay, releasing nitrogen to the soil.

A corn/bean polyculture is probably most beneficial at a low fertility level because added nitrogen only helps the corn crop. An experiment in the Phillipines showed that the greatest advantage for a corn/soybean polyculture came when no nitrogen fertilizer was added.[15] But highest corn yields come with a higher nitrogen fertilizer application. With a high level of management (application of fertilizer and pesticides) there have been some instances of no yield advantages using corn/soybean polycultures.[16,17]

Some experiments have shown that beans have not reduced corn yields from what they would have been in monoculture. Experiments in Columbia have shown that even with a high level of management, beans did not reduce corn yields. There was also the yield of beans, creating a land equivalent ratio of greater than one[18] (see figure 3).

Our food production process is very energy-intensive, requiring large amounts of fertilizer, water, pesticides, and tillage. These practices will change when we begin to pay the true costs for energy. We need to look at methods of food production that can give us adequate yields with less mechanical and chemical control. Polycultures may provide part of the solution to this problem.

Clover--to Maintain Polyculture Fertility

The transition from an energy-intensive agriculture that is mechanically and chemically controlled to a biologically-intensive agriculture that is maintained by the plants themselves will be a gradual process. The transition will start with the introduction of biologically-intensive farming practices.

One example is the use of self-seeding clovers, like yellow sweet clover, to keep soil nitrogen levels high. Sweet clover seed can remain viable in the soil for many years and a field that has had sweet clover go to seed on it will have sweet clover come up every year. This is the case on my father's farm in south-central Nebraska.

Three years ago, we had a field of wheat on clayish soil that received the standard fertilization of nitrogen and phosphorus for our area. As the wheat was just starting its most vigorous growth, the sweet clover seed germinated and started to come up. By wheat harvest time, the clover was two-thirds as high as the wheat. Apparently, the clover interferred little with the wheat as it yielded 40 bushels per acre, a larger than normal yield. After harvest, the clover kept on growing, along with a few weeds, until frost.

Sweet clover is a biennial and makes rather rapid growth its second year before blooming. The rate of nitrogen-fixation is highest during the blooming period and this is considered the ideal time to incorporate sweet clover into the soil. The clover made a good start its second year in the spring, and when I disked the wheat stubble and clover mixture in April, getting the ground ready to plant milo, the clover was over a foot tall and already getting stemmy and tough. The disk rode over most of the clover, without cutting it up, and by the time that it was all finally incorporated into the soil, it was already May and the clover had started to bloom. We planted the milo in the wheat stubble and clover mulch in early June, using a lister, and as it grew, it looked good enough that we did not side dress it with nitrogen fertilizer as usual. Just before the milo headed out, it was a little yellow, showing a nitrogen deficiency. This probably was due to nitrogen being tied up in the decay process of the organic matter in the soil. But this was apparently only a short-lived phenomenaon, as the milo went on to yield 88 bushels per acre, a larger than average yield.

The clover growing in the wheat is an example of a polyculture forming a biologically-intensive cropping system, that begins to replace the energy-intensive one, in this case, the use of chemical fertilizer. It is also an example of a polyculture made up of a food-producing component and a soil-enriching component.

The sustainability of a wheat/clover polyculture followed by milo cropping system is unknown. This was only an observation, not an actual experiment. It does show that there are a lot of unanswered questions and that a more biologically-intensive cropping system is adaptable to a highly mechanized farming operation. As the price of fertilizer increases, reflecting the price increase of the energy needed to manufacture it, practices such as this one may become more common. Clover/wheat and other polycultures that include a legume can reduce the need of the chemical component of our agriculture--nitrogen fertilizer.

Pest Control

Polycultures also have the potential of reducing and possibly eliminating the use of pesticides. There are many examples of decreased insect damage through the use of polycultures. In an experiment in the Phillipines, intercropping peanuts and corn greatly reduced corn borer infestation. This reduction was attributed to the increased effectiveness of the predators in the corn/peanut intercrop.[19] In another experiment with corn, scientists at the Centro Internacional de Agricultural Tropical in Columbia found that the incidence of fall armyworm damage was reduced 88% when beans were planted 20 to 40 days before corn in a corn/bean polyculture.[20]

Polycultures can reduce pest losses because they increase the diversity of crop species. It has been shown that species diversity is an important factor in preventing population outbreaks in insects.[21] The use of polycultures to reduce pest losses is another example of using biologically-intensive cropping systems to substitute for chemical control. The chapter titled "Biological Pest Management" is a further discussion of the use of polyculture to form diverse habitat for pest management.

Biologically-intensive Cropping Systems

Masanobu Fukuoka has developed a biologically-intensive cropping system in Japan that has proven itself over time. He does not till the soil and needs only minimal mechanization. His yearly cropping sequence follows.

In the fall, white clover and winter grain (either rye or barley) are broadcast into standing rice. The rice is harvested, threshed, and the straw is put back onto the field on top of the young seedlings. Rice seed is directly seeded into the field so that transplanting is unnecessary. It is broadcast into the winter grain in either late fall or early spring. In late spring, the winter grain is harvested, the straw is returned to the field, and a little manure is added. The field is flooded to germinate the rice and stunt the growth of clover, and the cyclical process is started over again.

It has taken Masanobu Fukuoka thirty years to develop this biologically-intensive cropping system. Yields are impressive--22 bushels per quarter acre for both rice and the winter grain crops. At times, rice yields reach 29 bushels per quarter acre, possibly the highest in Japan. This system produces enough food to support five to ten people, each investing an average of less than one hour of labor a day.[22]

Masanobu Fukuoka is using rice as his main crop and is working under different climatic conditions, which may offer him some particular advantages. Nevertheless, his system could possibly serve as a model for the development of biologically-intensive cropping systems for our own climatic conditions. Perhaps the most important aspect of his work is the demonstration that tillage, pesticides, chemical fertililizers, and large machines are not necessary to produce our food. Nor do the alternatives to our present practices necessitate slave labor or starvation.

Conclusion

Biological intensification of our agriculture through the use of polycultures offers many advantages. This paper discussed only the most simple polycultures, those with two crop components, but polycultures made up of several crop components would be more diverse and may offer further advantages. Polycultures can have more than just grains and legumes as vegetables, fruits, herbs, flowers, and other crops could also be included. Perennial crops will probably play an important role in polycultures. These will be discussed further in the chapter titled "Perennials for Permanence".

Biological intensification of our agriculture can lead us towards a sustainable agriculture. Polycultures can provide us the potential to eliminate agricultural chemicals and to greatly reduce the use of energy-intensive machines. Larger machines can be replaced by smaller, more human-scaled machines as we develop a truly appropriate agricultural technology to supplement our polycultures. In the future, people may decide that it is easier, less expensive, and more satisfying to work with polycultures rather than with chemicals and machines.

III

BIOLOGICAL PEST MANAGEMENT

Current pest control strategy is philosophically based on the elimination of pests through the use of chemicals. It is a strategy of eradication and should be replaced by a strategy based on ecological principles that recognize the diversity, complexity, and interconnectedness of life. A suppression of undesirable insects can be achieved without damaging the rest of the ecosystem.

Chemical control of insects through the use of pesticides puts us on what has been called a "pesticide treadmill". This treadmill effect occurs because: pesticides often cause a later resurgence of pest numbers through the inadvertant destruction of their natural enemies, pests develop resistance and new pesticides are needed for their control, and because outbreaks of secondary insects sometimes occur requiring pesticides for them too.[1] In other words, once pesticides are used, more pesticides are needed. A treadmill effect has been created.

Pesticides make us vulnerable in a fundamentally important way--they threaten our health. We do not really know the long term health effects of pesticides, but we do know that we have ingested them in the foods we eat and the air we breath. They also threaten the health of other living things and the environment. In the name of health for all living creatures, we need to practice more ecological means of pest management.

Pesticide Use--the Historical Trend

The use of chemical pesticides has increased tremendously since World War II, but the recommendation for their use is much older. In 1897, Kansas had 11,187,332 apple trees covering 2,035,000 acres (compared to only 1,800 acres of commercially grown apples in 1977).[2] The recommendations of the Kansas State Horticultural Society of 1898 show that they felt that chemical control was the answer to pest problems.

> We find we have plenty of insects; this is natural. Insects settle in a country that provides proper food for them and their larva. As apple trees are planted in new localities the insects that delight in apple-tree wood, apple-tree foliage and apple-fruits immigrate, grow, and multiply.
>
> Spraying or using some preventive or destroyer has become necessary, and the man who believes it unnecessary and intends to trust to nature or providence or God will find no truer saying than "God helps those who help themselves." Sit down calmly and watch the worms eat your trees, trust to the woodpecker and the sparrow, and you will in time buy apples from your more active, thoroughgoing neighbor, or go without.[3]

Nature could not be trusted. London Purple and Paris Green, whose active ingredient is arsenic, were most commonly advised for insect pest control of apples. They sucessfully controlled insects, but were the first step on the pesticide treadmill. DDT and other new, more dangerous, pesticides became readily available and were promoted after World War II. They were easy to use and profitable in our economic system which does not calculate the complete cost of these chemicals. It was inevitable that the seemingly addictive chemical agricultural practices became commonplace.

We are a part of nature. We can not escape it, nor should we desire to. Those agricultural practices that are denying that we live in a natural world are the ones that waste our soils and threaten our health. Pest populations can be managed by using natural methods. Population explosions of insect pests can be prevented through the process of biological intensification of our agriculture. This can be accomplished by using diverse cropping schemes (polycultures) that support beneficial insects. They are more stable than conventional cropping schemes because they will not be devastated by a single insect pest. Biological pest management can replace chemical pest control and help us develop a more sustainable agriculture.

Diversity and Stability

Conventional agricultural cropping systems lack diversity and stability. Agricultural communities are disrupted and destroyed much more frequently than natural areas because of cropping patterns and tillage. Areas of natural vegetation as contrasted to areas that have been simplified by agriculture or forestry, rarely have pest outbreaks. In subarctic regions, where the natural vegetation is relatively low and sparse, pest outbreaks occur. However, tropical forests, which are extremely diverse, are relatively free from pest outbreaks.[4] This is probably caused by greater plant diversity in these areas.

Not only are agricultural communities more simple than areas of natural vegetation, but the areas that immediately surround them are also simplified. It has become less common to allow hedges or weeds to surround fields and they are often sprayed or mowed if they do exist. Some of the 'weedy' species that occupy these areas can provide habitat and alternate food sources for predatory and parasitic insects and for birds.

Increasing the diversity of agricultural communities will not necessarily increase their stability. An added species may be a competitive or a destructive species causing more harm than good. For example, introducing a competitive weed such as johnson grass or an insect such as corn earworm, which would increase the diversity of a corn field, would not increase its stability and would reduce yields.

To increase the stability of a community, the relationships between species need to be strengthened and diversified. For biological pest management to be successful, more than just an increase in the diversity of insects is needed. Effective trophic (nutritional) links between pest species and the introduced and existing predatory and parasitic species are the key to increased stability for pest management in agricultural communities. The system of checks and balances, where various predators and parasites are available to respond to a pest outbreak when needed, allow biological pest management methods to be successful.

All of our agricultural plants have wild ancestors who evolved in diverse habitats. We have selected our crop plants for their high yields and more recently for their high yields when grown in monoculture, a simple habitat. It has been suggested, in respect to pest management that: "natural systems are more stable than crop systems because their interacting species have had a longer shared evolutionary history."[5] While this may be true, a factor of greater importance seems to be that biological diversity is lacking in our agricultural communities and many species that could be present and provide their pest management function just are not present.

Also natural systems are more diverse because they have gone through successional stages and are mature communities. It seems that we should copy natural successions, by developing agricultural successions where one crop follows another, creating a more stable state.

Diversity is an inherent strength of polycultures. Current agricultural cropping schemes lack diversity, but diversity should not be increased for its own sake. Diversity that is carefully chosen and increases the stability of our agricultural communities will lead us to successful biological insect pest management.

There are many changes that we can make in our agricultural practices in order to stabilize insect populations. These include: reducing field size, retaining uncultivated refuges in the field, and eliminating cultivation--through the use of narrower rows, perennial crops, or polycultures where a low-growing, relatively non-competitive ground cover is used.

It is also important to improve the habitat for beneficial insects. This could be done by using polycultures and closer row spacings, and by selecting species of cover crops and weeds that provide protective vegetation, nectar, pollen, and harbor aphids, whose honeydew excretion is a food source for some beneficial insects. These practices would make it more likely for beneficial insects to survive and be available for pest outbreaks.

The change from annual agricultural systems that require tillage to perennial agricultural systems and other cropping schemes that eliminate tillage, will increase the stability of the agricultural insect community. This will occur because there will be a more permanent habitat for beneficial insects.

Our current agriculture can adopt many of the above changes (such as using narrower row spacings, eliminating or reducing cultivation, adopting polycultures that require no special mechanization, and providing beneficial insect habitat reservoirs) without significantly increasing food-production expenses. As the price of energy increases, these suggested changes will slow the increase of food-production expenses because they not only manage insect pest populations, but are also energy conserving.

By implementing as many changes as possible to make the agricultural community both stable and diverse, while trying to maintain relatively high yields, our fields will more closely resemble the natural plant communities from which their individual components evolved. In this way, our agriculture can become a true sustainable agricultural ecosystem.

Weeds for Pest Control

Weeds are considered to be undesirable plants and little attention has been given to their beneficial role. With proper management, weeds may play an important role in supporting predatory and parasitic insect populations. Weeds may serve as a food source for numerous insects. The goldenrod (Solidago altissima) in northern Florida, supports more than 75 different predator species that feed on aphids of the genus Uroleucon in spring.[6] In Kansas, over 350 species of insects feed on Baldwins Ironweed (Vernonia fasciculata).[7] If weeds are allowed to grow in a portion of a field, a border, or a supposed 'waste' area, they can support beneficial insects.

Weeds can cause reduced insect damage by serving as a food source, by being habitat for a secondary host insect, by altering the crop microclimate, and by making the crop less physically apparent to pests. The flowers of weeds serve as a food source, helping the predatory insects to survive when their insect hosts are scarce. In surveys of unsprayed orchards in Ontario, those orchards that had rich undergrowths of wild flowers had about 18 times as many tent caterpillar pupae parasitized and 5 times as many codling moth larvae parasitized as orchards with poor floral undergrowths.[8]

Certain families of weeds have flowers which seem to be more attractive as food sources for beneficial insects. Carrot family (Umbelliferae) and mustard family (Cruciferae) flowers seem to be especially important sources of food for many predator and parasitic insects. Carrot family flowers tend to be preferred by hymenopterans (wasps and bees) which form a large number of parasitic insect species.

Weeds can serve as hosts of alternative prey, providing habitat for an insect which is a food source for a predator or parasitic insect that feeds both on the insect on the weed, and on an insect that damages a crop. For example, the effectiveness of the tachinid fly (Lydella grisenesn), a parasite of the European corn borer (Ostrinia nubilalis) can be greatly increased in the presence of giant ragweed. Giant ragweed has a stalk borer (Papaipema nebris) which emerges before the corn borer, at the same time as the tachinid flies emerge. These stalk borers in the ragweed serve as hosts for the first generation of tachnid flies and second, third, and forth generations then attack the corn borer in large numbers. In this way, giant ragweed greatly increases the parasitism of the corn borer.[9]

There are many other examples of alternate hosts and more complicated insect feeding paths. Undoubtedly, there are many plant-insect interrelationships which we just are not aware of yet. By studying these interrelationships, we can understand to a greater degree the value of weeds and their beneficial roles. Further observation and research will help develop this method of biological pest management.

There are good reasons why weeds have such a negative image. Weeds reduce crop yields when their size or populations compete with crops. Although weeds often are important in providing habitat for pest hosts, more than 400 pest problems are caused by weeds.[10] Also crop borders and vegetation may provide habitat for undesirable insects such as grasshoppers. Certain weeds are more advantageous for pest management and these need to be carefully selected and managed to provide habitat or food for beneficial insects.

Weed management may become an important tool for pest management. Insects on weeds on the borders of fields can be driven into the adjacent crop by mowing at the proper time. One weed management technique, successfully demonstrated in England, was acheived by cutting stinging nettle in mid-June. This released the natural enemies to attack aphids in the adjoining field.[11]

The eradication of weeds has led to yield increases by removing them from competition with crop plants. By looking at weeds only on a competitve level, their benefits have been overlooked. For example, a few giant ragweeds could be left in a corn field to reduce corn borer populations. Their numbers could be small enough to insignificantly reduce corn yields while still giving some protection from these pests. The value of a few, specifically selected weeds in a field is greater than the value of a weed-free field. Pest losses could be reduced without causing large yield reductions by incorporating the benefits of weeds wherever possible.

Biological Intensive Cropping Schemes

Monoculture leads to increased insect pest populations. When a single crop is the food source for an insect pest and it is abundantly provided over a large area, then a population explosion can take place in response to the ideal conditions.

Predators and parasites are often general feeders and it is difficult for them to respond to a pest outbreak if there are not other local food sources. There is usually a time lag between an increase in pest numbers and an increase in predator and parasite numbers and this time lag is lengthened if there are no other local food sources. Also, because monocultures are lacking in suitable habitat and food for predators and parasites, their populations are usually lower than in diverse habitats. To bring pest populations to more reasonable numbers, to create more stability in agricultural insect communities, and to reduce and possibly eliminate the use of chemical pesticides, the use of biological-intensive cropping systems or polycultures are needed.

Polycultures reduce insect pest population growth through physical interference and biological interference. Physical interference of the growth of pest populations is caused by changes in color, texture, and shape of the crop mixture and by changes in micro-climate, such as a taller crop shading a shorter crop. As an example of texture causing physical interference of insect populations in polycultures, it has been observed in Malawi that hooked hairs on beans (Phaseolus spp.) trapped dispersing individuals of aphids (Aphis craccivora) and effectively reduced the rosette virus infection of adjacent peanuts which the aphids spread.

Biological interference of the growth of pest populations is the mechanism by which biological processes or interactions interfere with the growth of insect populations. One example is the chemical repulsion of plants towards insects. In an experiment in New York, collards were interplanted with tomatoes and the tomato smell produced olfactory camouflage for the collards. Flea beetles (Phyllotreta cruciferae) are attracted to collards and other cabbage family plants by a mustard oil--allyl isothiocyanate. In presence of tomatoes, the collards were more difficult to detect by the flea beetles and received only 1.4 feeding holes per cm^2 compared with 5.4 per cm^2 for those grown in monoculture.[13] This example indicates the value of aromatic plants to repel insects. Some herbs and other strong-smelling plants could provide this function as companiate crops.

Biological interference of pest populations can also occur by one crop plant supporting alternate hosts of predators and parasites for another crop plant. In southern New Jersey, Macrocentrus ancylivorus is an effective parasite against the oriental fruit moth where strawberries are frequently grown near peach orchards. This occurs because strawberries support alternate hosts for this parasite, so that it can live there over the winter.[14]

Physical and biological interference of pest population growth can take place at the same time. This occurs when a crop like brussels sprouts is undersown with clover. It has been shown that brussels sprouts have fewer aphids (Brevicoryne brassicae) when surrounded by a green background, such as a low-growing clover would provide, than when surrounded by a brown, bare soil background.[15] This is an example of physical interference as the the visual cues that the aphids use to find brussels sprouts have been interferred with, making the crop more difficult to locate.

There is also biological interference in a brussels sprouts/clover polyculture. When white clover and red clover were sown under brussels sprouts the number of cabbage butterflies (Pieris rapae) were reduced. This was due to an increase in predation by ground beetles (Harpaplus rufipes) which by feeding on other larvae in the clover, increased in number to a population where they were effective against the butterfly larvae.[16]

Polycultures provide improved habitat for beneficial insects and by physical and biological interference of insect pest population growth, they create a more stable agricultural insect community. Through the biological intensification of our agriculture, by the process of making monocultures into diversified agricultural communities, pests can be managed by more natural means. By studying the various interactions between plants, between insects, and between plants and insects, we should be able to find pest management strategies based on natural, biological processes.

Integrated Pest Management--the Transition

With the realization that chemical control of pests has its limitations and negative consequences there has been a movement toward integrated pest management philosophy. Integrated pest management is the integration of chemical and biological pest management. At the present time, there has not been much integration as chemical pest control is the most commonly used and recommended method of pest management.

Apples are one of the more difficult crops to grow without using chemical pest control. Some people and orchards grow apples organically (not using chemical pesticides), but it is quite difficult. The wormy apple, perhaps the most well-known fruit-pest problem, is caused by the codling moth. The apple we eat is not native to North America. Neither is the codling moth, as it was accidently introduced from Europe. The natural predators and parasites that the codling moth had in Europe do not exist in North America. There are approximately 120 species of parasites and 22 species of predators that are known to attack the codling moth, but only 2 species of parasites have been imported into the United States, and neither of these came from the area presumed to be the native home of the codling moth.[17]

The introduction of non-native beneficial insects is helpful for pest control, but difficult. Non-native beneficial insects may not be as adaptable to their new climate as are their pest hosts, they need suitable habitat that will probably differ from their pest hosts, and they may prove to be ineffective for other reasons.

Many apple orchards are grown in monoculture and few have any vegetation specifically maintained or planted for beneficial insect habitat. The use of polycultures in orchards could significantly reduce pest losses. Russian apple orchards are commonly undersown with such plants as buckwheat, mustard, and dill, whose flowers serve as food sources for adult Trichogramma species of wasps, which attack the eggs of the codling moth. Using this biological control system, a polyculture designed for insect control, only 3.5% of the apples were infested with codling moth larvae, as compared to 1.5% infestation with full chemical control, and 54% infestation with no treatment.[18] By making apple orchards more diverse through carefully choosing plants and crops beneficial to insect predators and parasites, pests such as the codling moth, can be significanly reduced in numbers by natural means.

Although apples are one of the most difficult foods to grow without using chemical pest control, there are numerous ways in which chemical pesticides can be reduced and possibly eliminated. The use of pesticides for apple production has a long history and the research and development of new pesticides has been awesome, while for biological pest management strategies, it has been relatively insignificant.

We will utlimately find that chemical pest control and biological pest management are mutually exclusive--we cannot have or pursue both. Chemical pest control is an attempt to chemically eradicate pests. Biological pest management is an attempt to manage and suppress pest populations. Man-made chemicals disrupt the connectivity of insect life and the health of other organisms, thereby disrupting our own lives with substances that we have no natural protection against.

The change to ecologically-sound and environmentally-safe pest management strategies will be a transition and will take some time. Pesticides are used because they work immediately and are profitable in an economic system that does not quantify the long-term health of the environment, and the health of all living beings. The total cost of chemical pesticides needs to be calculated--their expense in terms of energy, production, use and the delayed expenses of poisoning to beneficial insects, animals, and people.

Environmentally-safe and -sound pest control practices are inevitable because we must protect the environment which is our home. Pest management should be based on biological interactions, and on the diversity and stability of polycultures. Polycultures can be created, through the process of biologically intensifying our agriculture, that will provide biological pest management that can sufficiently protect our crop plants.

IV

PERENNIALS FOR PERMANENCE

Perennial crops can make our agriculture more stable through their longevity and permanence. We are unnecessarily dependent upon the soil-erosion promoting annual crops for our main source of food. The search for a permanent agriculture should lead us to a perennial solution to the annual problem of growing enough food to nourish and support us.

Perennials Protect the Soil

The greatest threat to agricultural production is the loss of its foundation and resource--the soil. Annual crops have to be planted each year and in the process of seed bed preparation, and after a crop is harvested, the soil is exposed to the erosive forces of nature. The Department of Agriculture estimates that our farmlands are losing nine tons of soil per acre per year. In other words: "It costs (by erosion) two bushels of Iowa topsoil to grow one bushel of corn."[1]

No-tillage agriculture is a concept that is rapidly gaining support for controlling soil erosion while maintaining crop production. No-tillage cropping systems can reduce energy input into corn and soybean production by 7 and 18 percent, respectively, when compared to conventional tillage systems and reduce soil erosion to almost zero.[2]

These results are desirable, but the methodology is undesirable This type of cropping system should be renamed chemical tillage, or chemo-till agriculture, because it is dependent upon chemicals instead of tillage. Even higher rates of chemical pesticides and fertilizers are recommended for no-tillage agriculture than for conventional agriculture. As in other situations where chemicals are used in agriculture, their true costs are not fully considered and are externalized from the cost of production.

It is necessary for our agriculture to evolve into a no-tillage agriculture, but it needs to be composed of biological processes rather than chemical ones. Biological no-tillage agriculture can be practiced by carefully timing the planting of crops so that one crop is seeded into the proceeding crop before it is harvested, and also by using perennial crops.

Perennial crops offer the greatest potential for no-tillage agriculture, because they protect the soil by having roots that hold the soil for a period of years. There are two main kinds of perennial crops that can be used in agriculture: tree crops and herbaceous perennial crops. Many of the different pernnial plants can be grown together creating perennial polycultures that can enhance the value of their perennialism.

Tree Crops

Tree crops can make our agriculture more permanent. There are many benefits to their use, many of which they share with other perennial crops. These include: erosion control, reduced energy demands, drought resistance, productiveness (having a three-dimensional fruiting area), hardiness, shelter, shade, firewood, and lumber. Once established, they are relatively inexpensive and require little maintanence.

Tree crops can make the farm more stable, a healthy and more beautiful place. In this respect, Wendell Berry, a poet and farmer stated:

> Trees will be there (on a good farm) for their usefulness: for food, limber, fence posts, firewood, shade, and shelter. But they will also be there for comfort and pleasure, for the wildlife that they will harbor, and for their beauty. The woodlands bespeak the willingness to let live that which keeps wildness flourishing in the

settled place. A part of the health of a farm is the farmer's wish to remain there. His long-term good intention toward the place is signified by the presence of trees. A family is married to a farm more by their planting and protecting of trees than by their memories or their knowledge, for the trees stand for their fidelity and kindness to what they do not know. The most revealing sign of the ill health of industrial agriculture--its greed, its short-term ambitions--is its inclination to see trees as obstructions and to strip the land bare of them.[3]

A Renaissance for Trees

When the settlers came to the prairie states, they felt uncomfortable because of the absence of trees. Trees were important to the settlers and they planted them for their benefits and also because they made the prairie resemble their former homes back east and in Europe.

The planting of tree crops, especially fruit trees, continued after the prairie states were settled and reached its highest point at around the turn of the century. The Kansas State Horticultural Society published books encouraging fruit tree planting and care. These books, written around 1900, were titled: The Kansas Apple, The Kansas Peach, and The Kansas Cherry. Similar books were published at this time in Nebraska and other states.

Fruit trees were grown primarily for local consumption of their fruit. Only apples were exported in large quantities. Besides apples, many other fruit trees were planted in large numbers. In 1900, there were 1,666,456 cherry trees growing in the state of Kansas. This means that there were 1.13 trees per person. Jewell County, one of the northern tier of counties, had the highest cherry tree population with 68,066 trees or 3.5 trees per person.[4]

There are problems with raising tree crops and reasons why they have lost their former importance as agricultural crops, except in a few locations in the country that are the most suited to growing fruit and nuts in monoculture over large acreages. The most important problem is the inability to mechanize their care and harvest to the extent that annual crops have been. This has resulted in the need for more labor per acre than annual crops and more expense when compared to the inexpensiveness of fossil fuel driven machines.

Also because we have lived in an era of inexpensive energy, centralization of production has been most profitable. So a fruit like the apple is grown in the Yakima Valley in Washington, centralizing its production, processing, and distribution, rather than in a de-centralized manner wherever apples will grow (which includes most of the country).

The stranglehold of centralized fruit production is so strong that it is difficult to find local fruit in grocery stores even when it is in season. Apples grow well and are quite productive in northeast Kansas and yet, when one goes to a grocery store in the fall, they are more likely to find apples imported from the irrigated, Yakima Valley than to find a Kansas apple.

People are once again planting trees, especially fruit trees, around their homes and in orchards. Local fruit production requires less energy, can produce more nutritious fruit, and will become more and more economical as energy prices increase. It is time for more fruit trees to be planted. Now is the time for a renaissance of tree crops.

Tree Crops--More than just Fruit Trees

Tree crops include more than just fruit trees. They also include nut trees, trees for timber, shelter (windbreaks), sugar (such as maples), livestock feed (honey locust pods, persimmons), and for nitrogen-fixation (alder and black locust trees).[5]

The use of nitrogen-fixing trees for forestry, orchards, and mixed with other crops in fields has received little attention owing to nitrogen fertilizer being so inexpensive. The black locust is a nitrogen-fixing tree and when surrounded by other timber-producing trees, those trees nearest the locust were found to have greater height and diameter than those trees that were further away. This was attributed to the increase in the amount of nitrogen in the soil that was supplied by the locust trees. The soil under the locust trees had about 3900 pounds of nitrogen per acre. The amount of nitrogen in the soil decreased until at about 100 feet from the black locust plantation, the soil had about 1800 pounds of nitrogen per acre.[6] The black locust tree and other nitrogen-fixing trees can be used in orchards, windbreaks, and scattered in fields to provide an inexpensive and continual source of nitrogen for agricultural crops.

Often included under tree crops are other perennial woody plants. They can play an important role in a more permanent agriculture. These are woody shrubs and vines: including raspberries, currants, wild plums, chokecherries, gooseberries, and grapes. They are perennials that are hardy, productive, and some can tolerate shade.

Tree crops are an underutilized source of food, fertilizer, and shelter for crops. They can be an asset in producing food on a local level and in a more permanent fashion. The use of trees in agriculture is a practice that can lead us to a more sustainable agriculture.

> The 'tool' with the greatest potentials for feeding men and animals, for regenerating the soil, for restoring water-systems, for controlling floods and drought, for creating more benevolent microclimates for more comfortable and stimulating living conditions for humanity, is the tree.[7]

<u>Herbaceous Perennials</u>

There are many herbaceous (non-woody) perennial plants which can be used in agriculture. They comprise four main catergories: forage crops, vegetable crops, grain crops, and leguminous cover crops.

Perennial forage crops: include grasses for pasture and hay and legumes such as clovers and alfalfa. They are the only herbaceous perennial crops that are now commonly used in agriculture.

Perennial vegetable crops: require little work, besides planting them once and yearly harvest, and deserve a place in any food-producing system. Asparagus and rhubarb are the two most common garden crops that are perennials. There are many others, including perennial onions, spinach, and broccoli.[8]

Besides plants that are grown in the garden, there are many perennial wild plants that can serve as vegetables. Nettles, dandelions, and poke have traditionally been gathered for greens in the spring and are nourishing foods. Perennial vegetable crops, from both the garden and the wilds, can give us a more permanent source of vegetable foods.

Perennial grain crops: have the potential to eliminate erosion-causing and energy-expensive tillage practices. With the recent discovery of a wild, perennial corn (Zea diploperennis), there is a growing interest in developing a perennial grain crop. Research for potential perennial grain crops is underway.[9]

Perennial leguminous cover crops: are an immediate answer to reducing soil erosion and energy use in agriculture. Alfalfa and red clover (a biennial or short-lived perennial) have long been used for their forage production. They protect the soil from erosion and produce nitrogen, with the aid of symbiotic bacteria. This nitrogen is produced using the sun's energy rather than fossil fuel.

Polycultures which include perennial legumes and annual grain crops offer promise for reducing erosion while producing our staple grain crops. Careful selection of perennial legumes is necessary. A legume like alfalfa is probably too competitive and uses too much water to be a suitable crop for a grain/legume polyculture. White clover and crown vetch may be suitable for these polycultures. They are low-growing, nitrogen-fixing, perennial legumes and these characteristics make them appear well-suited for a grain/legume polyculture. Very possibly there are other legumes and other perennials (perhaps native) that may be better suited for perennial polycultures including an annual grain crop. Experiments with corn, wheat, and other grains grown with legumes in polycultures are needed to find out which combinations work best. Experiments and demonstrations are needed to promote this potentially advantageous cropping system.

Perennial Polycultures

Perennial crops offer many advantages over annual crops. These advantages can be enhanced by growing them in polycultures, which is what occurs in nature. It is possible that the most stable and productive agricultural system is a polyculture of annual and perennial plants. The process of the biological intensification of our agriculture will reach its climax state in a perennial polyculture with annual plants taking advantage of any unvegetated ground.

The planting of dwarf fruit trees in orchards is a step toward monoculture. Dwarf fruit trees are advantageous because they can be planted closer together to create higher yields and they are easier to harvest because their fruit is closer to the ground. Apple orchards planted to dwarf trees produce more apples because they have about one-third more apple-producing foliage per acre than standard sized trees.[10] The smaller radius circles that dwarf fruit trees form, can be packed closer together than standard sized trees.

Dwarf fruit trees, when planted at high population, exclude the possibility of polyculture. The trees are shading almost the total ground surface, making it difficult for another crop to grow underneath them. Standard sized trees allow more light to penetrate betweem them, provide a larger three-dimensional surface, and are probably more advantageous for polycultures than dwarf fruit trees. Tree crops that are not planted so closely together, whether dwarf or standard sized trees, can be planted in polycultures that have other crops growing underneath them. These polycultures can be designed to provide their own nitrogen, reduce insect pest problems, and maintain or increase total food yields.

One example of a perennial and annual crop polyculture is commonly called two-storied agriculture, where one crop, usually a tree crop, grows over another crop. On the Spanish island of Majorca, nine-tenths of the land in the 1950's was in tree crops. A typical farm was planted to figs in rows about 40 feet apart. Beneath the fig trees was a regular rotation of wheat, clover, and chickpeas. The clover was allowed to grow for two years and was pastured by sheep the second year. Each crop was not quite as high yielding as it would have been if grown in monoculture, producing 75 percent of their normal yield, but together they produced the equivalent of a full crop and one-half more, giving a land equivalent ratio of 1.5.[10]

Another example of a polyculture using perennial plants is Masanobu Fukuoka's mandarin orange orchard in Japan. Dispersed among his mandarin orange trees grow pines, cedars, pears, persimmons, loquats, Japanese cherries, Morishima acacia, and many other native varieties of trees. The Morishima acacia is native to Australia. It has hard wood, provides an alternate host for ladybugs, the flowers attract bees, the leaves can serve as fodder, it acts as a windbreak, and with the help of bacteria, it fixes nitrogen to enrich the soil. On the ground of his mixed orchard, white clover, alfalfa, mustard, and daikon (a Japanese radish) cover the soil. With this perennial polyculture, he has found it unnecessary to use fertilizers, insecticides, weed killers, or to cultivate. Instead, he lets the orchard manage itself.[11]

Masanobu Fukuoka's orchard is composed of different crops than would grow here because Japan has a different climate. However, it still has value as a model for ways that we can grow perennial polycultures. It is time for us to quit thinking of apple orchards as just containing apple trees. They can be polycultures made up of a wide variety of plants that provide stability and food. Besides apple trees there can be plant components that produce nitrogen, provide habitat and food for beneficial insects, and produce other types of harvestable crops without seriously decreasing apple yields.

Polycultures of perennial and annual plants offer many advantages over annual monocultures. As the price of energy increases and as there is more demand for local and more healthful food, polycultures of perennial and annual plants will be a needed alternative. Through a process of biologically intensifying our agriculture, creating polycultures of perennial and annual plants, we can make our food-production process more sustainable and permanent.

V

THE AGRICULTURAL ECOSYSTEM CONCEPT

The agricultural ecosystem concept is an ecological method of food production. An agricultural ecosystem can be defined as: a community of agricultural crops and its environment treated together as a functional system of complementary relationships based upon transfer and circulation of energy and matter. The agricultural ecosystem model that I will present is an attempt to grow food using natural methods, often called organic agriculture or natural farming. The model is a polyculture that is less energy-intensive than normal cropping systems and is a de-centralized and sustainable method of food production.

The agricultural ecosystem concept is best suited for small-scale farmers and market gardeners. There is no ideal size, because the size depends upon what is grown, how it is grown, and where it is located. For northeast Kansas, a range of from one to twenty acres of crop land may work best.

Some of the principles of the agricultural ecosystem concept can be adopted by conventional farmers. One principle that could be adopted is to keep a continuous plant cover on the soil. The advantages from this principle will be limited by soil moisture and in those areas that are extremely dry, a yield reduction could occur. A continuous plant cover will significantly reduce soil erosion and will help stop nitrogen from leaching from the soil by storing it temporarily in plants. It also could increase the organic matter content of the soil and increase total yields through double cropping.

A continuous plant cover could be acheived with little added expense for the farmer. This could be done by seeding wheat or other winter grains, possibly with legume seed, into a corn, milo, or soybean field in the fall. A mechanical broadcaster could be attached to a tractor and while the stalks or stubble of the fall harvest are being shredded or disked, winter grain seed could be broadcast onto the field. The seed would be covered by soil or plant material and in a normal year would make some fall growth. If the wheat or other winter grain were thick enough, it could be allowed to mature in the spring and be cut for its grain. If not, it could be tilled in the spring as part of the seedbed preparation for the next crop, or the next crop could be directly planted into the cover crop with a no-till planter.

Another agricultural ecosystem principle that could be adopted is to increase biological diversity. An increase in plant diversity could add nitrogen to the soil, could provide insect protection, or could reduce or eliminate tillage and herbicides by shading the ground. This could be acheived by using polycultures. One example is a sweet clover/wheat polyculture as already described.

Another example would be a corn/mung bean or milo/mung bean polyculture. The beans would be planted between the corn or milo, either at planting time or when the field is cultivated for the last time. The beans would be grown solely for their nitrogen that they would fix and for their ground cover function, which would suppress weed growth. These are just three examples of ways that the agricultural ecosystem concept could be adopted by conventional farmers to make their farming practices more conserving of soil and energy.

Decentralized Agriculture

Monoculture has been the direct result of the centralization of agricultural production. This is the path that we have chosen because of available inexpensive energy supplies. We need to produce food locally, in a manner to make us less vulnerable to future energy shortages and also to reduce the amount of energy used in food production. Only through a decentralized agriculture, can we have agricultural systems that have the quality of the Oak-Hickory Forest or the Tallgrass Prairie ecosystems--being relatively energy and nutrient self-sufficient, mature, and self-maintaining.

A decentralized agriculture will be less energy-intensive, but more labor-intensive than our present agriculture. Agricultural labor does not have to be drudgery. Drudgery is monotonous work--a response to monoculture--where the work is repetitive and endless. In an agricultural ecosystem there will be a lot of work, but it will be variable. There will not be just one field that needs to be harvested, as there will be several crops within a field to harvest at different times. With polycultures of annual and perennial plants, there will be more variety of life surrounding the worker, more to observe and more to see that is beautiful. Beautiful surroundings lighten the work load and make work more enjoyable and satisfying. Agricultural ecosystems will be beautiful because of their diversity of flowering plants and variety of vegetation.

Reduction in Energy Used

Monocultures of annual plants are grown because our agriculture is energy-intensive and machinery-dependent. As energy becomes expensive, polycultures may become more common because they can be designed to conserve energy. Polycultures, by their complementary nature, can make the land produce more biomass per acre. This additional productivity will not necessarily be reflected directly in yields because it will be used to replace the energy-intensive components of our present agriculture.

The use of energy-intensive machinery can be decreased through the agricultural ecosystem concept, using biological processes to substitute for mechanical ones. Perennials can eliminate the need for yearly planting; annual and perennial ground covers can eliminate the need for cultivation as they can suppress weed growth; legumes can eliminate the need for nitrogen fertilizer; and certain plants can offer insect protection to the main crop plants. The advantages of these biological processes can be added together by growing crops in polycultures. The agricultural ecosystem concept, through the use of these self-maintaining, polyculture cropping systems, can reduce the mechanical component of our agriculture.

An agricultural ecosystem can be managed by tools and small machines, such as roto-tillers, walking tractors, and small-engine threshers. These small machines are very energy-efficient and allow the food-grower to be closer to the process of growing and harvesting his or her crops. With the use of tools and small machines, the food-grower can more easily perceive his or her environment and the food plants within it, thus being more aware of the interrelationships that are taking place.

The agricultural ecosystem concept can reduce energy use by reducing the transportation and processing of the food we eat. The agricultural ecosystem concept will make more food and variety of food available on a local basis. These local foods can be eaten fresh, while in season, reducing the need for processing, and they can be stored locally or processed locally for the times when this food is not in season. Fancy packaging, designed for improved marketability of foods, is not necessary when the consumers are directly linked to the producers. Protective packaging, needed for shipping food long distances, is also unnecessary when consumers buy food directly from producers.

Energy used in processing, packaging, and transportation is substantially reduced when food is grown locally using the agricultural ecosystem concept. It can also reduce the energy used to run agricultural machinery by reducing and possibly eliminating tillage, pesticides, and planting (when perennials are growing). Overall, the energy consumed in the food production process could be reduced 70 to 80 percent by using agricultural ecosystems designed for energy conservation.

The Transformation to Polyculture

The food-production process must be transformed in order to have an agriculture that is truly energy-conserving and sustainable. A decentralized agriculture, such as the agricultural ecosystem would provide, is feasible, practical, and economic, if given the same advantages as our present food production system--tax breaks and incentives, availability of loans, supportive research and recommendations by universities and extension agents. This is not likely to happen soon, as a change from our centralized, industrially-supported monocultural farming techniques will be quite slow.

Those people who have financial and political power support monoculture, not just in agriculture but as part of the American way of life. The belief that continued growth of the economy and increased consumption of resources are essential and inevitable supports monoculture. The agricultural ecosystem concept supports polyculture, sustainability, and steady-state economics. A model agricultural ecosystem can demonstrate how the transformation of monoculture into polyculture could occur. When energy gets expensive enough; when our health and lives are sufficiently threatened by agricultural chemicals; and when we realize the complete value of fresh and local foods; then the agricultural ecosystem concept can be adopted on a wide-scale basis. In the meantime, those of us with a different vision of how agriculture and culture should be, will develop and support poly-culture.

Local Food Production

The agricultural ecosystem concept encourages the decentralization of agriculture. Local production of food is one step in that direction. Food produced locally can be sold directly to consumers through farmers markets, or through food co-operatives and local grocery stores.

It is not sufficient to just grow food locally; there needs to be a local demand for its consumption. Kansas is the Wheat State, producing more wheat than any other. Production and consumption are quite removed from each other in the Wheat State. It is extremely difficult, if not impossible, to find locally grown and milled wheat flour, and even more difficult to find locally grown and milled wheat flour that is made into fresh baked bread. There is no pride in the Wheat State in the consumption of locally grown wheat. There is a bread being sold under the trade name "Kansas," but it is not found in Wichita, Topeka, Lawrence, or Dodge City, but in Tokoyo, where it is promoting the consumption of Kansas-grown wheat.[1]

Local production and consumption of food can allow us to step off our current energy-intensive agricultural path. The people of Kansas and other states need to be aware that they can help their local food-growers by buying food that they produce. They can also help themselves by buying local foods that are fresh and more nutritious, and by supporting their community which includes food-growers and processers, people such as farmers and gardeners, millers, bakers, and grocers.

There has been an interesting trend in the consumption of fruits and vegetables in the last couple decades. There has been an increase in the per capita consumption of leafy, green vegetables (lettuce, spinach, and celery) while there has been a decrease in the consumption of starchy root crops (potatoes, sweet potatoes, and turnips).[2] This has occurred mainly because the leafy, green vegetables have become available to us rather inexpensively, the year around due to inexpensive energy. This has allowed their production to be centralized (in places like southern California) and they are shipped all across the United States. The traditional winter root crops have lost their popularity and are even considered unappetizing. How many people today would say that they like turnips or rutabagas?

There has been a similar trend in fruit consumption as the traditionally popular apple has decreased in per capita consumption, while citrus fruits (oranges and grapefruit) have increased. Again, foods from afar are more popular.

An increase in local consumption of food through the agricultural ecosystem concept does not mean that oranges and other foods will not be available to areas that do not grow them. It just means that the choice between imported, exotic, and more energy-expensive foods, and local, seasonal, fresh foods will become more obvious. The people who make up a community can choose between a community that is self-reliant and one that is fragmented, dependent upon the nearest city as its indirect source of industrially-produced food. As the disparity in quality and cost becomes fully realized, locally-grown foods will become more desirable.

There are changes occurring in peoples lifestyles that support the agricultural ecosystem concept. People are finding that they enjoy the natural world and want more natural food--fresh and local--grown perhaps by a neighbor. The number of gardens has grown rapidly the last few years as people are wanting to grow their own food and are wanting quality food. With more people finding a place that they want to call home, people are learning what it means to actually be inhabitants of a place. This 'rootedness' to a place means accepting that one is a part of the community and that one wants to interact with neighbors and friends, entertaining each other, working together, and helping each other. These attitudes will encourage consumption and production of locally-grown foods.

The idea of an agricultural ecosystem means that people are a part of the food-growing process, they are not removed from it, because they must produce and consume food. A strong community focus, where the production and the consumption of food are connected because of the interrelationships between people, will be an important step in making the agricultural ecosystem concept a reality on a community-wide basis.

A Model Agricultural Ecosystem

An agricultural ecosystem is site specific. Its component crops will vary due to slope, light intensity, soils, soil fertility, and perhaps most importantly, personal preferences. Because of the lack of information on the use of polycultures and companiate cropping techniques, any effort in this direction is pioneering and any model is comprised of some guesswork. However, the model I will present is supported by research and observation previously reported in this paper.

The agricultural ecosystem that I propose is a polyculture that utilizes legumes for fertility, perennials for stability and longevity, has additional diversity, specifically designed for insect management, and produces grains, beans, fruits, herbs, and vegetables. An agricultural ecosystem will have an animal component. However, for the purposes of my research, I have focused on the plant component and am discussing those findings.

The hypothetical model agricultural ecosystem that I will describe, is situated on five acres of land in northeast Kansas, in the Kansas River valley. The area receives an average of 35 inches of rain a year and has a growing season of a little more than 180 days. This is some of the most productive land in the state and is an ideal location for a prototype agricultural ecosystem.

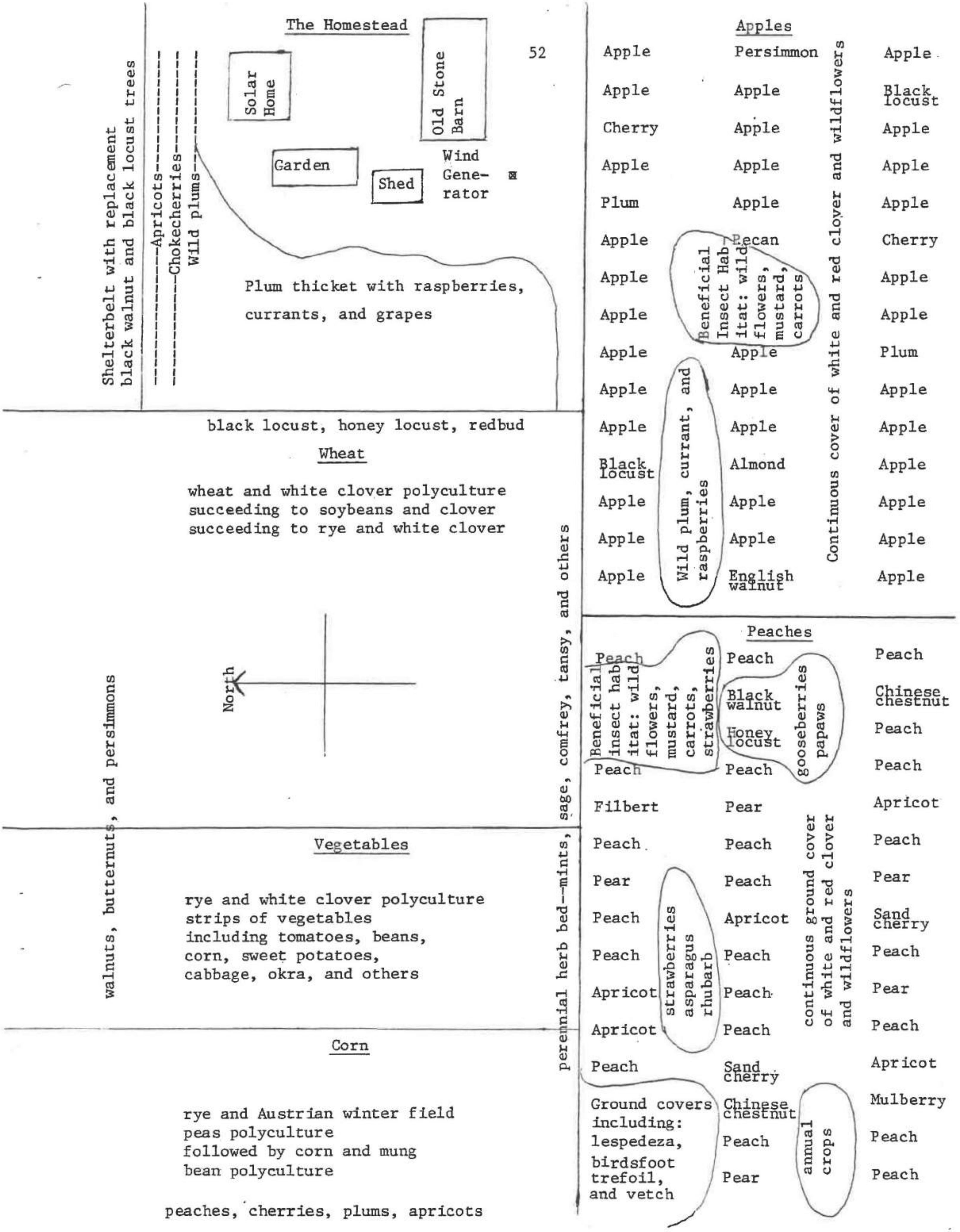
The natural vegetation of this area was on the border between Tallgrass Prairie and Floodplain Forest. The agricultural ecosystem will use both tree crops (reminiscent of the Floodplain Forest) and grains, which are grasses (reminiscent of the Tallgrass Prairie).

The five acre plot that will be the model agricultural ecosystem, is made up of three sections, each of which had separate uses. On two acres is an old orchard of apples and peaches. On two other acres, the ground was used to grow annual monocultures of either corn or soybeans. On the final acre is the homestead, with a garden and shelterbelt.

Apples as Part of an Ecosystem

The old orchard has fallen into disuse. One acre was in apple trees which have not been taken care of for at least three years. About 20 percent of the apple trees have died and can be replaced with other trees, including: black walnut, cherry, plum, persimmon, hardy varieties of almond, pecan, and English walnut. The black locust trees will be useful in supplying nitrogen and in obtaining other nutrients from the subsoil. The fruit and nut trees selected have different pests than the apple and may gain some protection by being hidden out in an apple orchard (see figure 4).

Some areas that formerly had an apple tree will be left specifically for beneficial insects. These areas will be planted to wildflowers and plants that provide food sources and shelter for beneficial insects. Many plants of the mustard and carrot family will be planted in these areas (including, but not limited to: mustard, turnips, daikon radishes, horse radish, parsnips, carrots, dill, and other herbs). Some of these (carrots, turnips, and parsnips) are tap-rooted biennials which produce roots we can eat during their first year of growth. The second year they will flower, providing nectar as food for beneficial insects, and make seed. Several of these plants in the mustard family will reseed themselves, not needing


The Homestead
Solar Home
Old Stone Barn
Garden
Shed
Wind Generator
Shelterbelt with replacement black walnut and black locust trees
Apricots
Chokecherries
Wild plums
Plum thicket with raspberries, currants, and grapes
black locust, honey locust, redbud
Wheat
wheat and white clover polyculture
succeeding to soybeans and clover
succeeding to rye and white clover
North
walnuts, butternuts, and persimmons
perennial herb bed—mints, sage, comfrey, tansy, and others
Vegetables
rye and white clover polyculture
strips of vegetables
including tomatoes, beans,
corn, sweet potatoes,
cabbage, okra, and others
Corn
rye and Austrian winter field
peas polyculture
followed by corn and mung
bean polyculture
peaches, cherries, plums, apricots
Apples
Apple
Apple
Cherry
Apple
Plum
Apple
Apple
Apple
Apple
Apple
Apple
Black locust
Apple
Apple
Apple
Persimmon
Apple
Apple
Apple
Apple
Pecan
Apple
Apple
Almond
Apple
Apple
English walnut
Beneficial Insect Habitat: wild flowers, mustard, carrots
Wild plum, currant, and raspberries
Continuous cover of white and red clover and wildflowers
Apple
Black locust
Apple
Apple
Apple
Cherry
Apple
Apple
Plum
Apple
Apple
Apple
Apple
Apple
Apple
Peaches
Peach
Peach
Filbert
Peach
Pear
Peach
Peach
Apricot
Apricot
Peach
Beneficial insect habitat: wild flowers, mustard, carrots, strawberries
Peach
Black walnut
Honey locust
Peach
Pear
Peach
Peach
Apricot
Peach
Peach
Peach
Sand cherry
Chinese chestnut
Peach
Pear
gooseberries papaws
strawberries asparagus rhubarb
continuous ground cover of white and red clover and wildflowers
Ground covers including: lespedeza, birdsfoot trefoil, and vetch
annual crops
Peach
Chinese chestnut
Peach
Peach
Apricot
Peach
Pear
Sand cherry
Peach
Pear
Peach
Apricot
Mulberry
Peach
Peach

to be replanted every year.

The ground underneath the trees will not be tilled. It will be mowed yearly, wild flowers will be encouraged to grow, and white and red clover seed will be broadcast to add a leguminous ground cover. Also in some places where more light is penetrating between the apple trees, a few bush fruits, such as wild plums, currants, and raspberries will be planted. As the orchard is changing to biological pest management techniques, the apples will mostly be used to make cider. This will help compensate for the less-than-perfect fruit expected in the transition process.

Peaches as Part of an Ecosystem

In the acre of orchard that was in peaches, almost half have died, because peach trees do not live very long. Where there are open spaces, fruit and nut trees, such as the apricot, pear, Chinese chestnut, filbert sand cherry, and mulberry can be planted. Where several trees are gone, taller and larger black walnut and honey locust trees can be planted. These two trees have a leaf structure that allows a lot of light to reach the ground. Also, they both leaf out quite late in the spring and lose their leaves relatively early in the fall. Underneath them, gooseberries and papaws will be planted because they like some shade. Black walnuts exude a chemical called juglone form their roots and it is sometimes toxic to certain plants--tomatoes, apples, and others--so they should not be planted together.

It will take some time for the newly planted trees to get very large, so in the areas where there are no peach trees, annual crops can be grown. These will be grown in polycultures using techniques that will be described for the land that was previously in annual crops.

Beneficial insect habitat will be designated at about seven or eight locations in the peach orchard, where a peach tree had died and there is an open area. These areas will be planted to wildflowers and to plants of the mustard and carrot families. Strawberries will also be planted in these areas and in a few other locations between peach trees where there is sufficient light penetrating between trees. Strawberries are an alternate host for an insect that attacks the oriental fruit moth, which is the wormy peach culprit.

Peach trees are much smaller than apple trees and more light penetrates through them and between them. Asparagus and rhubarb will be planted between the peach trees in the areas that receive the most light. They make their most rapid growth early in the spring and will compete very little with the peach trees.

The remaining uncovered ground will be planted to a perennial ground cover of white and red clover, which will be mowed yearly. Other legumes, such as birdsfoot trefoil, lespedezas, and vetches will be used on an experimental basis in the corner of the peach orchard to test their suitability as nitrogen-fixing ground covers.

The Homestead as Part of an Ecosystem

The acre that contains the homestead, garden and shelterbelt will not be changed dramatically, because the homestead and shelterbelt already express the concept of permanence. The garden will be reduced in size to just a kitchen garden that can provide salad fixings and a few vegetables that are used frequently. The reason for this is that an agricultural ecosystem is an attempt to integrate plants in polycultures; therefore the orchard, garden, shelterbelt, and field are not actually separated, but are overlapping communities.

The shelterbelt will be expanded slightly into the area that was previously garden. In this area will be planted apricots, native plums, and chokecherries, all of which have been planted in shelterbelts in the Great

Plains area and are quite hardy. The shelterbelt will be managed for its firewood production and for its fruit production in the newly planted area. If any old trees in the shelterbelt die, they can be replaced with trees that serve multiple functions (like black walnut or black locust trees). Black walnut trees, for example, can provide nuts, wood, and shelter for other crops.

The remaining ground that was formerly garden will be encouraged to become a thicket. Wild plums, currants, and raspberries will be planted here, along with grapes, which will be allowed to vine over the bushes. This area will be a reservoir for birds and other wildlife, and will also provide some food to be harvested.

Wheat as Part of an Ecosystem

The two acres that were previously in corn and soybeans present the biggest challenge to the agricultural ecosystem concept because this area was in monoculture of annual crops, the furthest removed from a diversified ecosystem. Keeping the soil protected is the first thing that can be done to make this area more stable.

On one acre of the ground, wheat and white clover will be planted together, using a hand-cranked broadcaster, in late September. The wheat provides cover while the clover is becoming established. If the clover stand seems too thin, more seed can be scattered on top of the wheat in the late winter or early spring.

The wheat and clover grow well together in the spring as they do not compete too much. Just before the wheat is harvested in late June, soybean seed will be broadcast into the the wheat/clover polyculture. The wheat will be harvested using a small combine that one of the neighbors owns. The straw of the wheat will be spread back on the field to mulch the soybean seed, helping it to germinate. It would be helpful if the combine could have big soft tires so that they would not compact the soil so much when they travel across the field.

The clover will be competitive with the soybeans for moisture while they are germinating and are seedlings. The field may be too dry to get a good stand of beans, in which case the white clover will be considered a summer green manure crop.

If the beans do get established, because of adequate soil moisture or a timely rain, the clover will provide a protective mulch and weed suppressing-function for the soybeans. Just before the soybeans are harvested in the fall or just before the field is mowed, if the beans are too thin to harvest, rye seed will be planted as the next companion crop with the perennial white clover.

Vegetables as Part of an Ecosystem

The other acre begins on the part of the crop rotation/succession where the first acre left off. Rye and white clover will be planted on one-half acre in the fall. The rye serving as a protective cover crop for the clover. Alternate strips, eighteen inches wide will be tilled in late April using a roto-tiller or a small tractor-pulled implement. The rye and clover will be mowed on the untilled, eighteen inch wide strips, stunting the clover and making the rye a mulch crop. Vegetables will be planted into the tilled strips in April and May.

Vegetables that are large, hardy, and prolific growers will be best suited for this cropping system. Some of the vegetables that will be more successful include: tomatoes, eggplant, green beans, corn, sweet potatoes, okra, potatoes, peppers, broccoli, and cabbage. A much wider variety will be planted on an experimental basis.

The clover/rye strips that had been mowed, can be raked over to add a moisture-retaining and weed-suppressing mulch next to the base of the vegetable plants once they are established. The clover between the rows will be performing a nitrogen-producing function, a weed-supressing function, and an insect-protective function. It will protect the broccoli and cabbage by providing a camouflaging, green background and beneficial insect habitat. The clover is providing many useful functions, but it will also be somewhat competitive and may reduce yields from what they would have been if the vegetables had been grown in monoculture. For the amount of labor and energy spent per pound of vegetable harvested, a vegetable/clover polyculture should be more advantageous than conventional vegetable cropping techniques. These vegetable/clover polycultures are experimental and will need some further refinement before they can show the stability of mature agricultural ecosystems.

Corn as Part of an Ecosystem

The remaining one-half acre will have corn as its main food crop. The technique for growing this crop is the least developed in the context of the agricultural ecosystem concept. This half acre will be planted to a winter cover crop of rye and Austrian winter field peas (a fall-planted, nitrogen-fixing pea). They will be turned under in early May and the ground will be planted to corn.

The weakness in this cropping scheme, the same weakness which appears in conventional agriculture, is that the soil is exposed to natural erosive forces once it has been tilled. Living plants will hold the soil more than will the plant residues of rye and peas after they have been incorporated into the soil. That is advantage of a perennial ground cover. Research is needed to determine which perennial ground cover is the most suitable for corn and other row crops.

Corn will be planted in late May or early June at 36-inch row spacings. Mung beans will be planted as a companiate crop, between the rows. Soybeans are not the best companiate crop for corn as they bloom and start to set seeds at the same time, competing during the most crucial time for crop development. Mung beans are especially well-suited for corn/bean polycultures as they grow quickly and cover the ground, thus eliminating the need for herbicides. They also mature before the corn and may provide some nitrogen for it.

The beans will be ripe before the corn and a mechanical dilemma is reached because there are no available machines to harvest both crops. The beans will be harvested by hand and run through a thresher or combine to be hulled. At the end of September, the ground will be sown to wheat and white clover and the cycle starts over again. The corn will be picked in October, and the stalks will then be cut, allowing them to fall on the wheat, which has already covered the ground with a spindly, green carpet, ready to be released from its shaded environment.

Perennials for Grain and Vegetable Polycultures

Other perennials would be introduced into these two acres of grain and vegetable/legume polycultures besides perennial cover crops. The borders of the fields would be planted to various species of tree crops. Tall-growing trees, including walnuts, butternuts, pear, and persimmons, would be planted on the north side. Fruit trees, including peaches, cherries, plums, and apricots would be planted on the west side. A row of native leguminous trees (black locust, honey locust, and redbud trees) would be planted on the east side of the field so that the crops can take advantage of any nitrogen that they might fix and to serve as a mini-windbreak. When the locust trees become too tall, they could be cut (made into a coppice), allowing the stumps to resprout. Also a perennial herb bed, including mints, sage, comfrey, tansy, and others, would be planted on the south side of the field, adjacent to the orchard, to possibly aid in insect management and serve as a source of herbs.

These grain-producing and vegetable-producing polycultures are a part of the larger process of devising ways of raising these crops that are more permanent, less energy-intensive, and still productive. This will involve the process of agricultural succession, as one technique will be replaced by another and one crop will be replaced/succeeded by a more permanent crop. The agricultural ecosystem concept provides the theoretical framework for establishing a more biologically-intensive agriculture. We know enough to plant the seeds for a more permanent agriculture. Now is the time to sow the seeds and preserve the land by creating permanence.

Conclusion

The agricultural ecosystem concept promotes a distinctive set of ecological principles that give diversity and stability to the food production process. This system of producing food allows people to work more closely with nature and to feel a spiritual connection with the earth. Agricultural ecosystems can be designed to provide numerous advantages. They can be energy conserving, more permanent, make better use of space, can reduce and eliminate the need for pesticides, tillage, and chemical fertilizers, and provide food for the local community.

The agricultural ecosystem model that I have presented is most suitable for a small-scale farmer or market gardener, but the principles can also be applied on a larger or smaller acreage. The agricultural ecosystem concept is a model-building process that will go through successional stages to a more mature food-producing plant community. Above and beyond all the advantages, is the fact that the agricultural ecosystem concept expresses permanence and ecology, and is a step toward a truly sustainable agriculture.

NOTES AND REFERENCES

I. "PRESERVING LAND, PRESERVING HEALTH

1. John E. Weaver, Prairie Plants and Their Environment. (University of Nebraska Press, 1968), 51.
2. Wendell Berry, The Unsettling of America. (Sierra Club Books, 1977), 14.
3. E. F. Schumacher, Small Is Beautiful. (Harper and Row, 1973), 112.
4. Berry, 222.

II. "BIOLOGICAL INTENSIFICATION OF AGRICULTURE: POLYCULTURES

1. George F. Will and George E. Hyde, Corn Among the Indians of the Upper Missouri. (U. of Nebraska Press, 1964), 8.
2. Arthur C. Parker, Iroquois Uses of Maize and other Food Plants. (New York State Museum, 1910), 27.
3. D. C. L. Kass, Polyculture Croppins Systems: Review and Analysis. (Cornell International Agricultural Bulletin #32, 1978), 55.
4. C. A. Francis, C. A. Flor, and M. Prager, "Effects of Bean Association on Yields and Yield Components of Maize," Crop Science. (September-October 1978, vol. 18), 763.
5. D. J. Andrews, "Intercropping with Sorghum in Nigeria," Experimental Agriculture. (Vol. 8, 1972), 149.
6. F. H. Siddoway and A. P. Barnett, "Water and Wind Erosion Control Aspects of Multiple Cropping," in Multiple Cropping. (American Society of Agronomy, Special Publication # 27, 1976), 317.
7. M. A. Altieri, C. A. Francis, A. Van Schoonhoven, and J. D. Doll, "A Review of Insect Prevalence in Maize and Bean Polycultural Systems," Field Crop Research. (vol. 1, 1978), 46.
8. W. A. T. Herrera, "Corn-legume Combinations: Recent IRRI Multiple Cropping Results," (paper at the 6th Annual Conf. of the UPLB-NFAC Intensified Corn Production Program, U. of the Phillipines, Los Banos, January, 1975), 3.
9. N. M. Fisher (citing research done by Kassam and Stockhammer in 1973), "Studies in Mixed Cropping. II. Population Pressure in Maize-Bean Mixture," Experimental Agriculture. (vol. 13, 1976), 185.
10. C. L. Deswani, T. H. M. Kibani, and M. S. Chowdhury, "Effect of Intercropping on Rhizosphere Population in Maize and Soybean," Agriculture and Environment. (vol. 3, 1977), 367.
11. Donald Q. Innis, "The Future of Traditional Agriculture," Focus. (January/February 1980, vol. 30, No. 3), 6.
12. Kass, 55.
13. Herrera, 3.
14. Akinola A. Agboola and Adeboyejo Fayemi, "Fixation and Excretion of Nitrogen by Tropical Legumes," Agromomy Journal. (vol. 64, 1972), 412.
15. S. P. Liboon and R. R. Harwood, "Nitrogen Response in Corn Soybean Intercropping," (paper at the 6th Annual Scientific Meeting of the Crop Science Society of the Phillipines, May 1975, Bacolol City), 3.
16. Doug Carter, Yield, Photosynthesis, Leaf Area Index, and Light Regimes of Corn and Soybeans Grown in Various Polyculture Cropping Systems. (Masters Thesis, Michigan State University, 1979), 71.

17. R. Kent Crookston and David S. Hill, "Grain Yields and Land Equivalent Ratios from Intercropping Corn and Soybeans in Minnesota," Agronomy Journal. (vol. 71, 1979), 43.
18. Francis, Flor, and Prager, 763.
19. Herrera, 4.
20. Altieri, Francis, Van Schoonhoven, and Doll, 46.
21. David Pimentel, "Species Diversity and Insect Population Outbreaks," Annals of the Entomological Society of America. (vol. 54, 1961), 85.
22. Masanobu Fukuoka, The One-Straw Revolution. (Rodale Press, 1978), 103.
23. A. C. Cunard, "The Influence of Interplanting on Yield Parameters of Component Plants (high-lysine corn and edible soybeans)," in J. Ruttle (ed.) "Interplanting," (Rodale Press, 1976), 25.

III. "BIOLOGICAL PEST MANAGEMENT"

1. Richard Merrill, ed., Radical Agriculture. (Harper Colophon Books, 1976), 343-44.
2. Kelly Kindscher, "The Kansas Apple," The Land Report. (No. 9, 1978), 9-10.
3. Kansas State Horticultural Society, The Kansas Apple. (1898), 188.
4. Jorma O. Tahvanainen and Richard B. Root, "The Influence of Vegetational Diversity on the Population Ecology of a Specialized Herbivore, Phyllotreta cruciferae (Coleoptera: Chrysomelidae)," Ecologia. (vol. 10, 1972), 322.
5. William W. Murdoch, "Diversity, Complexity, and Stability and Pest Control," Journal of Applied Ecology. (vol. 12, 1975), 799.
6. Miguel A. Altieri and W. H. Whitcomb, "The Potential Use of Weeds in Manipulation of Beneficial Insects," Hortscience. (vol. 12, 1975), 14.
7. personal communication with Hal Nagel, Professor of Biology, Kearney State College, Kearney, Nebraska.
8. K. Leius, "Influence of Wild Flowers on Parasitism of Tent Caterpiller and Codling Moth," Canadian Entomologist. (vol. 99, 1967) 444.
9. B. H. Zandstra and P. S. Motooka, "Beneficial Effects of Weeds in Pest Management--A Review," PANS. (vol. 24, 1978), 335.
10. M. A. Altieri, A. van Schoonhoven and J. Doll, "The Ecological Role of Weeds in Insect Pest Management Systems: A Review Illistrated by Bean (Phaseolus vulgaris) Cropping Systems," PANS. (vol. 23, 1977), 195.
11. R. M. Perrin, "The Role of the Perennial Stinging Nettle, Urtica dioica, as a Reservoir of Beneficial Natural Enemies," Annals of Applied Biology. (vol. 81, 1975), 289.
12. R. M. Perrin and M. L. Phillips, "Some Effects of Mixed Cropping on the Population Dymanics of Insect Pests," Ent. Exp. and Appl. (vol. 24, 1978), 387.
13. Tahvanainen and Root, 332.
14. Peter R. Atsatt and Dennis J. O'Dowd, "Plant Defense Guilds," Science. (vol. 24, 1978) 25.
15. Judith G. Smith, "Influence of Crop Background on Aphids and Other Phytophagous Insects on Brussel Sprouts," Annals of Applied Biology. (vol. 83, 1976), 1.
16. Zandstra and Motooka, 336.
17. S. C. Hoyt and E. C. Burts, "Integrated Control of Fruit Pests," Annals of the Entomological Society of America. (vol. 65, 1974), 237.
18. Zandstra and Motooka, p. 334.

IV. "PERENNIALS FOR PERMANENCE

1. Wendell Berry, The Unsettling of America. (Sierra Club Books, 1977), 11.
2. Ronald E. Phillips, Robert L. Blevins, Grant W. Thomas, "No-Tillage Agriculture," Science. (vol. 208, 1980), 1109.
3. Berry, 182.
4. Kansas State Horticultural Society, The Kansas Cherry. (1900), 57.
5. For further information on tree crops, see: J. Russell Smith, Tree Crops. (Devin-Adair, 1953), and J. Sholto Douglas and Robert A. de J. Hart Forest Farming. (Rodale Press, 1978).
6. A. G. Chapman, "The Effects of Black Locust on Associated Species with Special Reference to Forest Trees," Ecological Monographs. (vol. 5, 1935), 46, 59.
7. Douglas and de J. Hart, 1.
8. For a futher discussion on perennial vegetable crops, see: Robert A. de J. Hart "Ecological Perennial Horticulture--a New Organic System," The Soil Association. (vol. 5, 1979), 6-7.
9. For a further discussion on perennial grain crops, see: Wes Jackson "Soil Loss and the Search for a Permanent Agriculture," The Land Report. (No. 4, 1978), 10-16, and Wes Jackson and Martin Bender "Eastern Gama Grass: Grain Crop for the Future?" The Land Report. (No. 6, 1978), 6-9.
10. Don R. Heinicke, "The Micro-climate of Fruit Trees. III. The Effect of Tree Size on Light Penetration and Leaf Area in Red Delicious Apple Trees," Proceedings of the American Society for Horticultural Science. (vol. 85, 1964), 33.
11. Smith, 17.
12. Masanobu Fukuoka, The One-Straw Revolution. (Rodale Press, 1978), 63.

V. AGRICULTURAL ECOSYSTEMS

1. "'Kansas' bread can be found only in Tokoyo," Kansas Farm Bureau News. (vol. 32, no. 10, September 1980), 22.
2. Jules Janick, Horticultural Science. (W. H. Freeman and Co., 1972), 6.