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ENERGY AND LABOR FLOWS ON AN ORGANIC
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A CASE STUDY ANALYSIS OF RELATIVE SUSTAINABILITY

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Robert Williard Pigg

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ENERGY AND LABOR FLOWS ON AN ORGANIC AND AN AVERAGE CONVENTIONAL FARMING SYSTEM: A CASE STUDY ANALYSIS OF RELATIVE SUSTAINABILITY

By

Robert Willard Pigg

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ABSTRACT

ENERGY AND LABOR FLOWS ON AN ORGANIC
AND AN AVERAGE CONVENTIONAL FARMING SYSTEM:
A CASE STUDY ANALYSIS OF RELATIVE SUSTAINABILITY

By

Robert Willard Pigg

An organic dairy farm in Ingham County, Michigan was compared to a conventional farming system based on conventional dairy farms in Ingham County, state and county crop and milk yields, and farm labor budgets from several sources. The two farming systems were compared on the basis of crop yields per unit of land and labor, milk yields per cow, and energy outputs per unit of energy input.

The organic crop yields were lower than state and county averages. Milk yields from the organic farm were comparable to state averages. Crop rotations on the organic farm produced more energy per unit of energy input than did the conventional systems. Unlike a number of other studies, this study showed that energy output from the organic farm per unit of labor input was greater than or equal to the corresponding values from the Michigan conventional examples for several crops.

This thesis is dedicated to my wife Susan, whose love, support, and encouragement helped make this thesis possible.

ACKNOWLEDGMENTS

I would like to acknowledge gratefully the assistance and support of a great many people. I would like to thank my advisor Tom Edens for his patience, ideas, and his timely responses; committee members George Axinn and Richard Harwood, for their suggestions and insight; Jack Knoreck of the Cooperative Extension Service for his help with the conventional farming system; Bob Hicks of the Ingham County Soil Conservation Service who also helped with the conventional farming system, and who reminded me that despite the customary terminology, no farmer who is making a living in today's business climate can really be considered "conventional;" several area farmers I spoke with; and of course the organic farmer who generously donated so much of his time to help me with this study. Thank you all.

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CHAPTER ONE
INTRODUCTION

Expanding human populations will demand more food and fiber well into the 21st century. Agricultural production must keep pace with population growth if we are not to lose ground in our efforts to feed and clothe the planet's people.

Production growth may come about through more intensive cultivation of existing farm land, cultivation of new land, use of improved genetic varieties of plants and animals, and through improved storage, transportation, and marketing. Experience suggests that production gains are likely to be achieved at the expense of natural systems, environmental quality, and rural communities unless we adopt new approaches to agriculture (Lowrance, Hendrix, and Odum 1986).

Some approaches to agriculture designed to avoid the problems mentioned above are described as alternative, sustainable, ecological, regenerative, and low-input sustainable agriculture. These terms refer to farming systems that tend to incorporate a number of similar practices, but that also may have qualitatively distinct emphases (Reganold, Papendick, and Parr 1990). Some of the distinctions will be covered in the literature review. Common practices usually include multi-year crop rotations, less use of fossil-fuel based fertilizers and pesticides, cover crops, more diversified cropping and animal systems, more integrated cropping and animal systems, and the use of mechanical and biological means, rather than chemical applications, to control pests. **Alternative agriculture** is the term used in this paper to refer to these farming systems.

Organic agriculture is one form of alternative agriculture. Organic farms differ from the alternative farming systems described above by rejecting all fossil fuel-based and synthetic soil, animal, and plant inputs.

Alternative agriculture, however, is more than the use of certain agricultural practices; it is a systems-level approach to understanding complex interactions within agroecosystems, guided by a philosophy of reliance on internal resources (Reganold, Papendick, and Parr 1990). The common ground among alternative agroecosystems lies less in the actual practices themselves than in the **processes** used to select and evaluate practices.

Conventional agriculture is the predominant farming practices, methods, and systems used in a region."(Benbrook 1991, 5). As such, it varies over time, and according to environmental and social factors. This definition also implies that some conventional farming practices are sustainable, according to definitions presented later in this paper, when applied appropriately (Benbrook 1991). Conventional agriculture as practiced in the region of interest for this study will be defined operationally in Chapter 2.

This research study investigates differences in energy and labor flows through two qualitatively different farming systems. The purpose is to determine which of the systems is more "sustainable," according to definitions and criteria that will be presented below. It examines resource management practices associated with organic and conventional farming operations and how they affect crop yields, the embodied energy per unit of output, and the labor input per unit of output on the farming systems studied.

Agroecosystems Defined

Agricultural production takes place within agricultural ecosystems, or agroecosystems. Natural ecosystems are the starting point for all agricultural systems. Agriculture depends on basic biological and ecological processes—photosynthesis, respiration, reproduction, herbivory, competition, symbiosis, and others. These processes are modified by humans using cultivation, irrigation, fertilization, and other agricultural processes. Agricultural processes, in turn, are a function of human decisions, derived from social and economic institutions and personal goals. The resulting systems are as much social and economic systems as they are ecological, with social, economic, and physical boundaries (Conway 1990). It is these systems that are referred to as **agroecosystems**.

The concept of a **hierarchy** of agroecosystems further illuminates the definition above. Lowrance, Hendrix, and Odum (1986) presented what they call a "hierarchical approach" to agriculture which divided agroecosystems into a hierarchy of four main levels. The first level is the field, followed by the farm, watershed or region, and the nation and world levels. Finer distinctions can be made. A single milk cow can be considered as a distinct agroecosystem (Conway 1990), and intermediate systems can be described up to the world level.

At the farm level of this hierarchy, a **farming system** can be defined as a unique and reasonably stable arrangement of farm enterprises that the farm household or managers manage via clear and definable practices in response to physical, biological and socioeconomic environments, according to the goals, preferences, needs, and resources of the decision makers. Resources include land, labor, capital, and management (Shaner, Philipp, and Schmehl 1982).

Each agroecosystem makes up a subsystem of the next level of the hierarchy. Higher level agroecosystems generally have priority of action over those of lower levels, and have longer management horizons, or are concerned with longer-term behavior (Lowrance, Hendrix, and Odum 1986).

Social and economic processes become more important the higher up in the hierarchy a level is, but ecological processes, the foundation of the hierarchy, remain crucial (Conway 1990). In a similar manner, sustainability has a different meaning, and is constrained or enhanced by

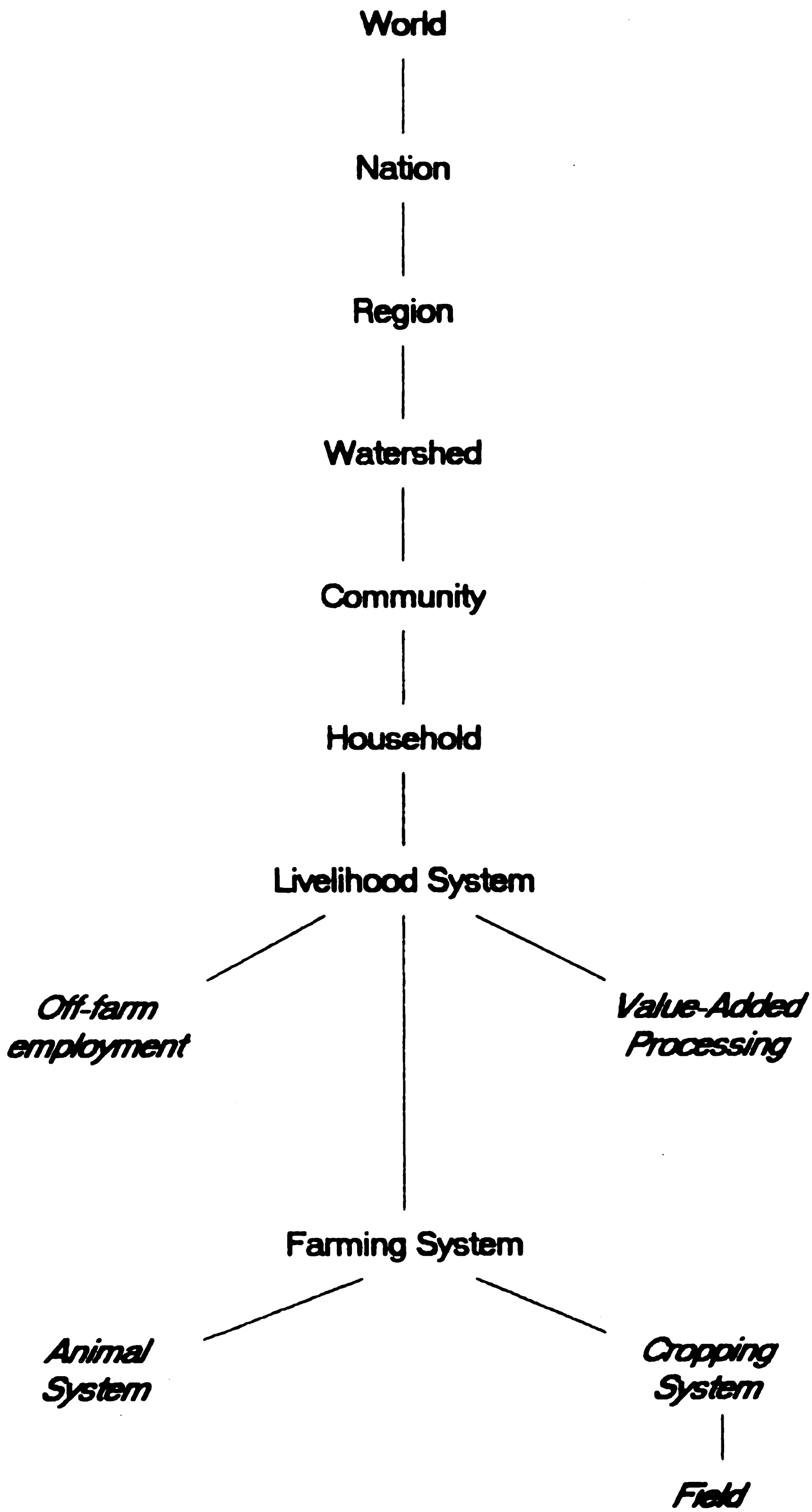

Figure 1.1 The hierarchy of agroecosystems (adapted from Lowrance, Hendrix, and Odum 1986; and Conway 1990)

different factors, at each level of the agroecosystem hierarchy (Lowrance, Hendrix, and Odum 1986).

It is important to realize that each level is much more than the sum of the preceding levels. It is qualitatively distinct, and possesses **singular and emergent properties** that cannot be deduced from the behavior of the constituent subsystems. Mario Bunge states two rules for studying systems, an approach he calls moderate reductionism:

> 1. "Start by studying every system at its own level. Once you have described it and found its patterns of behavior, try to explain the latter in terms of the components of the system and the mutual actions among them."
>
> 2. "Look for relations among theories, and particularly for relations among theories concerning different levels. Never skip any levels. If reduction (full or partial) fails, give up at least pro tempore." (Bunge, 1977, p. R80)

One of the premises of this paper is that much of contemporary agricultural research has inappropriately reduced agriculture to simple field level, agronomic practices, concentrating on inputs and outputs in a linear fashion. This reduction has failed to adequately describe the singular and emergent properties of agroecosystems, and a higher system-level approach is needed.

Open and Closed Agroecosystems

Agroecosystems can be characterized as relatively open or closed systems. In their most elemental form, open systems are linear production systems in which raw materials are consumed to create a product, the product is sold and consumed, and waste products are discarded into the environment. Open systems depend upon high input rates of raw materials, simplified and specialized processing steps, and sites for waste disposal (Edens and Haynes 1982; Lampkin 1986; van Mansvelt 1986). A confined animal feeding operation is a good example of an agroecosystem with relatively open cycles. A key factor in modern open systems is an extensive transportation network making long trade routes possible (Edens and Haynes 1982). Transportation and marketing expenses of agricultural inputs and products have traditionally been ignored by those evaluating modern U.S. conventional agriculture, yet they are crucial to its existence. The exclusion of these costs has given us an overly positive view of the relative benefits and costs of this dominant agroecosystem.

Closed systems are those that minimize inputs, that maximize the number of production cycles for a given factor of production, and that minimize and recycle waste products back into production inputs or products (Edens and Haynes 1982; Lampkin 1986). Climax ecosystems perhaps bear the closest resemblance to closed systems. Nutrient inputs are very low compared to nutrient levels in the system, and nutrients are recycled to very high degrees; the nutrient and material cycles are relatively closed. Because society depends upon the export of food and fiber from farming systems, contemporary agroecosystems cannot be completely closed. A relatively closed agroecosystem could be described as one in which energy inputs to the system are small compared to the amount of captured solar energy, and energy exports from the farming system do not exceed the amount of solar energy captured directly by crops, and indirectly by farm animals.

Hypotheses

General Approach

A central premise of this study is that the sustainability of an agroecosystem is directly related to its degree of openness. While sustainability has been variously described as the ability of the agroecosystem to maintain productivity when subject to major disturbing forces or shocks (Conway 1991, 1990, 1986; Marten 1988; MacKay 1989), as food sufficiency, stewardship, and community (Douglass 1984; Douglass 1985); this study will focus on a subset of these criteria. Three main variables will be used to represent sustainability: yields per unit of land (or cow), energy input per unit of crop output, and labor inputs per unit of crop and milk output.

As used in ~~this~~ study, energy is the sum of direct and indirect inputs (in units of kilocalories), of the embodied energy of ~~an input~~, plus the energy required ~~to~~ produce and

As used in this study, energy is the sum of direct and indirect inputs (in units of kilocalories), of the embodied energy of an input, plus the energy required to produce and transport the input to the farm. The degree of openness in farm cycles will be characterized by considering the organic farm as a relatively closed system, and conventional farming systems as relatively open. The organic farm does not use any inputs of commercial fertilizer or pesticides, and so compared to conventional farming systems inputs are minimized, and nutrient cycling is increased; the organic system is **relatively** more closed than the conventional system. As used in this study labor is the total of all time reported spent on a particular enterprise.

Hypotheses

Based on the considerations discussed above, the following hypotheses were developed as the basis for comparing two qualitatively distinct agroecosystems.

Hypothesis 1. The organic farm will require less non-solar energy per unit of output than the Michigan average.[1]

Hypothesis 2. The organic farm crop yields will be equivalent to Michigan averages

Hypothesis 3. The organic farm milk production per animal will be equivalent to Michigan averages

Hypothesis 4. The organic farm will require more labor per unit of output than the Michigan average.

The organic farm's crop yields will be compared to those of conventional farms in Michigan, and where possible, to farms in the same county. The crops to be compared will include corn, soybean, winter wheat, and alfalfa. Yields in bushels or tons per acre will be

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1 As used in this study, the Michigan average is determined from state yields, and from fertilizer, pesticide, tillage, and other management techniques used by farmers in a small watershed adjacent to the organic farm.

contrasted, and the two agroecosystems' productivity will be compared based on the amount of energy inputs needed to produce a unit of output.

Energy inputs will be determined by measuring all inputs to a given system, and converting the inputs into energy units.

The labor productivity of the two agroecosystems will be measured by comparing the hours of human labor required to produce a unit of output.

Organization of Study

The following chapters include a review of previous farming systems energy studies and related research. The research methods of the study will then be discussed. The results of the study follow, and conclusions based on the results of the study are then presented. The general and the specific research hypotheses will be re-examined in light of the results and conclusions.

Recommendations based on this analysis will be offered, with the goal of assisting policy makers and researchers towards more effective, efficient, and sustainable solutions to our agricultural problems. Information on the yields and the labor productivity of the two agroecosystems will allow state and local extension agents to provide current and accurate data to Michigan farmers interested in reducing fossil fuel-based farm inputs. The study will identify production methods that may have great utility if future energy prices and availability constrain farm management options. The study will also demonstrate an approach towards comparative analyses of sustainability.

CHAPTER 2
DESCRIPTION OF THE ORGANIC AND CONVENTIONAL FARMING SYSTEMS

In this chapter the organic and conventional farming systems studied will be described. The characteristic elements of the two farming systems will be discussed, and the reasons for selecting the particular systems studied will be presented.

Selection of the Organic Farm

There were several reasons for selecting the organic farm researched in this study. It is a relatively closed-system farm, which has been managed without any petrochemical-based fertilizers or pesticides or purchased fertilizers or pesticides since 1986, and it produces all of the animal forage consumed by the dairy herd. The herd consumes all of the forage grown, and the farm provides much of the feed grain consumed by the herd as well; as a result, nutrients are retained on-farm in the manure. Seed for cover crops and small grain crops is also grown on the farm.

The entire farm has been managed organically for over six years. This means it has passed through all or most of the transition effects that cause changes throughout an agroecosystem during a change from conventional to organic farming methods. Transition effects can be observed for a minimum of three years, and frequently for up to six years or more (Dabbert and Maddden 1986, Harwood 1985). The effects are usually most severe during the first several years of the changeover. Some of the biological transition effects are changes in soil ecology, in pest populations, distributions, and species; and in nutrient cycling (Dabbert and Maddden 1986, Harwood 1985). There is a learning transition effect as well. Farmers must learn how to manage their farms without fossil fuel-based inputs, and may have a steep learning curve to climb before they gain sufficient experience and expertise with organic techniques (Dabbert and Madden 1986).

The organic farm was also chosen because in many ways it is typical of moderate sized, mixed-enterprise dairy farms in Michigan and the Great Lakes region. In 1987 there were over 800 dairy farms in Michigan with herd sizes similar to the one chosen, 36 of them in Ingham County alone (Census 1989).

Most importantly, the organic farm was chosen because the farmer was willing to work with the researcher. His farm is also one of those close enough to the university to keep telephone and travel costs low.

Description of the Region and County

The organic farm is located in Ingham County in south central Michigan. Figure 2.1 shows the location of the county.

The region is characterized by broad stretches of gently sloping ground moraine that form a plain interrupted by end-moraine ridges and outwash channels. Soils are moderately well to well drained loams. The ground moraine consists of well and moderately well drained rises, and poorly to very poorly drained depressions. The ground moraine has less than 50 feet of difference in elevation over areas of several miles (Albert, Denton, and Barnes 1986). The end moraine tends to form narrow bands, from 1 to 3 miles wide, of low ridges (less than 50 feet) and swampy depressions. Most of the end moraine ridges are too steep for row crops. The average elevation of the region is 840 feet above mean sea level (Albert, Denton, and Barnes 1986).

Beech-sugar maple forests are typical on most of the ground and end moraine. Common species are black maple, pignut hickory, basswood, red oak, and white ash. Drier end moraine ridges support oak-hickory forests dominated by red and white oak.

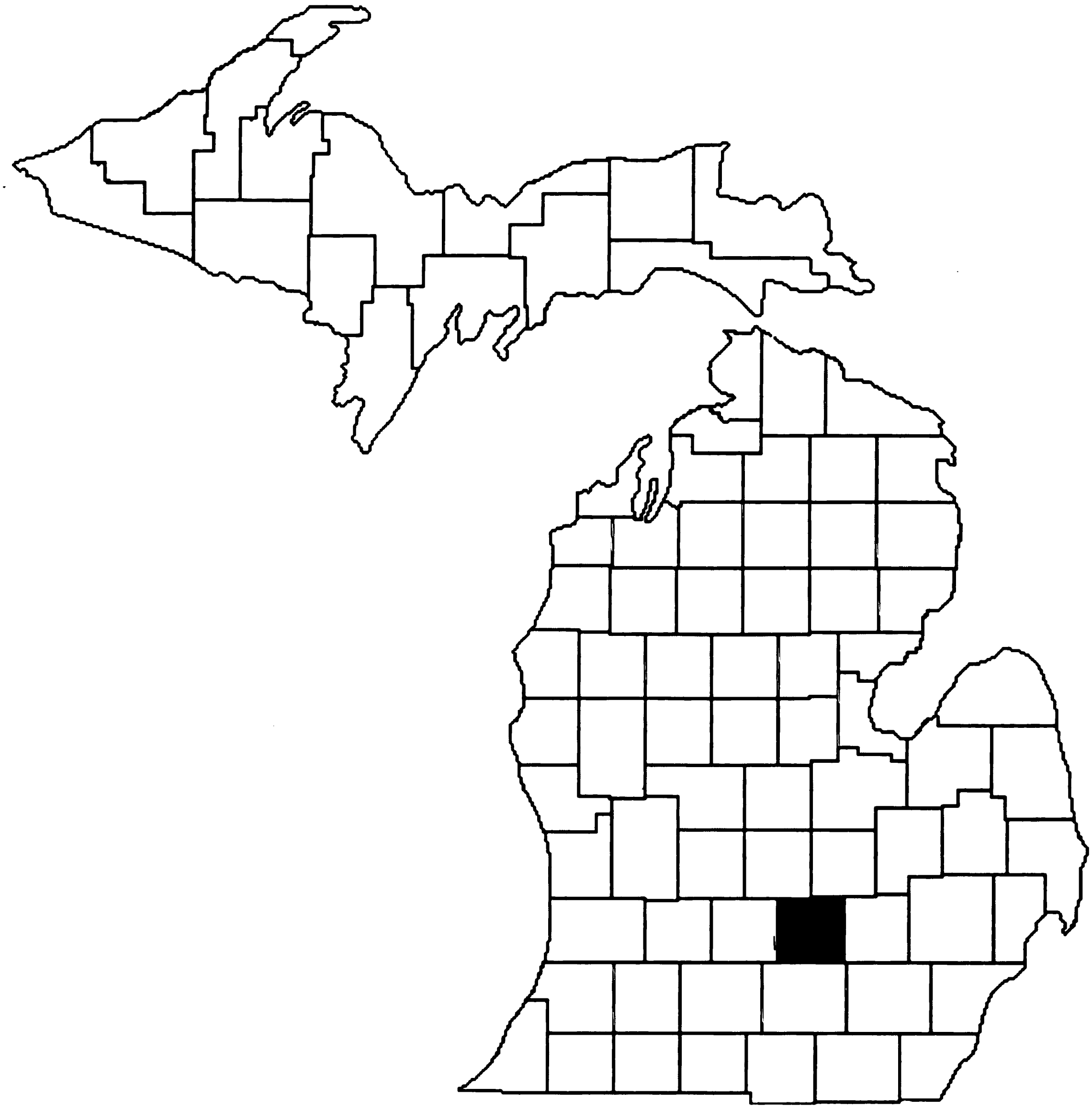

Figure 2.1 Map showing the location of Ingham County, Michigan

Poorly drained depressions support moist and swamp communities dominated by American elm, red ash, silver maple, and swamp white oak (Albert, Denton, and Barnes 1986).

The region averages 31.5 inches of precipitation per year, half of it during the growing season from May to September. The average annual temperature is 47.7 °F. The average temperature from May to September is 65.3 °F. The region's growing season averages 146 days (Albert, Denton, and Barnes 1986).

The infrastructure of the area is well developed. The county is served by all-season roads and rail, and air service is available nearby. The organic farm is served by electrical and natural gas utilities, and physical access to markets for buying and selling farm inputs and outputs is not a problem.

In 1978, agriculture was the primary land use in Ingham County by a wide margin, followed by use for residential dwellings, open shrub and grasslands, and lowland and upland forests (Planning and Zoning 1990). In spite of its role as the leading land use in Ingham County, agriculture contributed only 0.5% percent of total county earnings in 1988. This compares to an average of 3.0 percent for agriculture in rural Michigan counties, and an average of 0.9 percent for all Michigan counties (MI Dept. of Commerce 1990). Compared to the rest of the state, opportunities for off-farm employment are better than average. Unemployment in the county has consistently been at least two or three percentage points below the state average (MI Dept. of Commerce 1990).

Characteristics of the Organic Farm

Unless otherwise indicated, all information about the organic farm was collected during interviews with the farmer and his wife, or from farm records (Anon. 1992).

The organic farm is approximately 380 acres in size. The family owns 260 acres and rents an additional 120 acres from a relative. There are about 335 tillable acres of predominately sandy-loam soil, with patches of loam and muck. The potential for erosion on the farm soils is low to moderate, varying by the slope of the land (SCS-USDA 1979). None of the land is irrigated, and only about 2 percent of the farm is tiled for drainage. Much of the 45 acres of non-tillable land lies in and along the banks of a permanent creek that runs through the property. The remainder of the non-tillable land consists of poorly drained muck soils that are usually too wet to work with machinery and too far from the barns and milking parlor to graze cattle. As of the fall of 1992 there were 28 milking cows and about the same number of replacements on the farm. The family also keeps approximately 60 laying chickens at a given time. Figure 2.2 shows a map of the organic farm.

The organic farmer grew up in the area on his family's poultry farm, located on the land he now rents. It was there that he started his dairy herd and farming. He and his wife, who does not come from a farm background, have two boys and a girl, from 9 to 17 years old. The farm provides about half of the household's cash income, and his wife's off-farm job provides the other half, as well as health insurance benefits.

Farm Management

The organic farmer manages the farm and makes the final decisions on virtually all farm matters. His wife provides input, particularly on matters relating to how much time the organic farmer allocates to different farm subsystems, and on any qualitative changes in the farm. For example, she played a significant role in their decision to change to organic practices.

They began to convert their farm from conventional to organic practices in 1980. The conversion was started slowly, by leaving synthetic fertilizer off one field the first year of the transition. By 1985 no purchased fertilizer was being used. Pesticides were stopped by 1986. By 1991 all the fields and cultural practices were certified as organic by

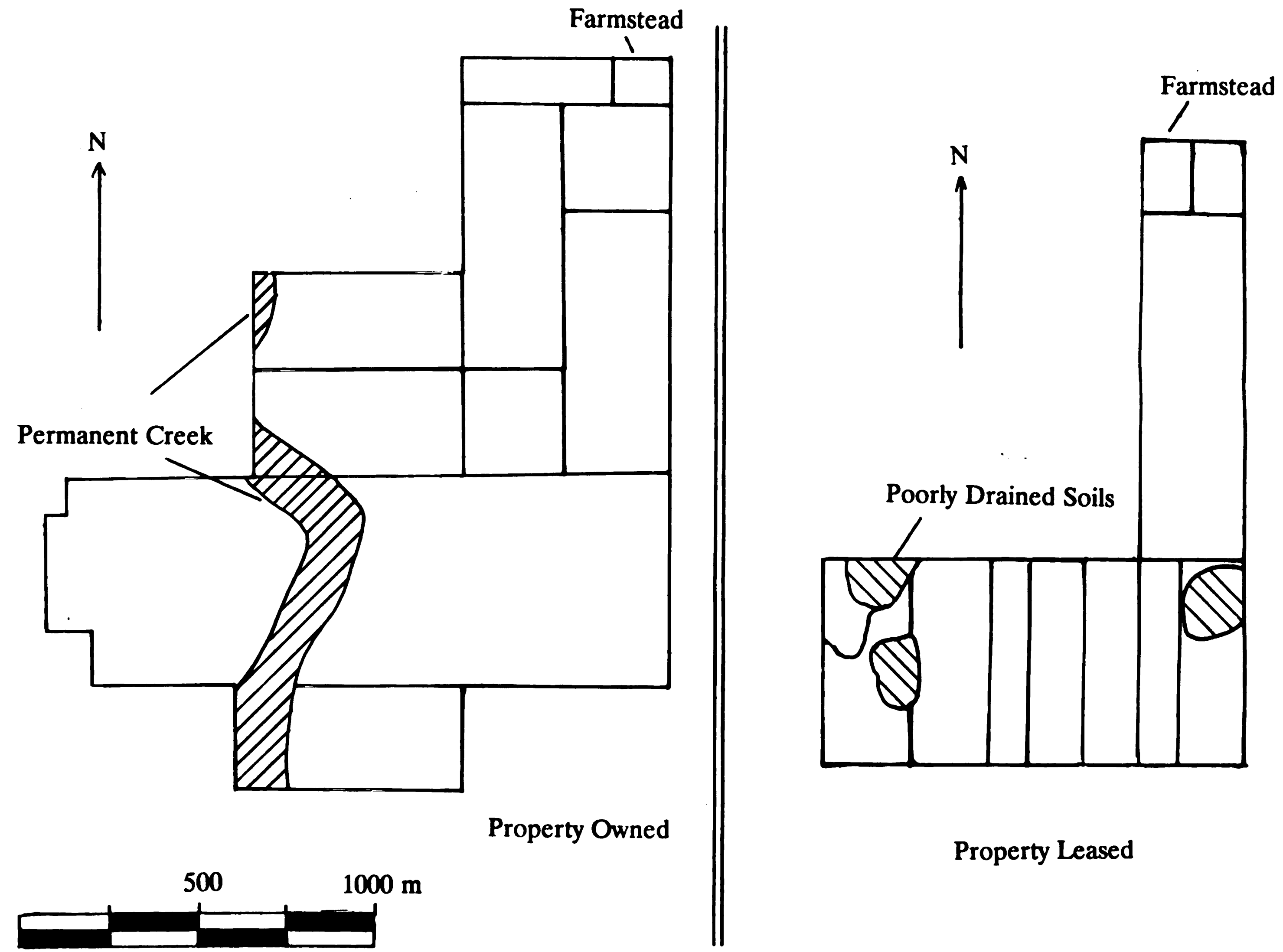

Figure 2.2 Map Showing Layout of Fields on Organic Farm

the Organic Crop Improvement Association. This certifies that no fossil fuel-based fertilizers or pesticides have been applied for at least three years. The farmer said that he found government farm programs, particularly the set-aside program, helpful in making the transition to the use of on-farm resources. He said that using organic techniques means his input costs are quite a bit lower than conventional systems, but economic considerations were not cited as key factors in their decision to convert to organic methods. He stressed the fact that he isn't really trying to maximize net profit; instead, he's trying to make a living without killing the soil, and that farmers and others need to recognize that nature sets limits, and we have to abide by them or pay the price. In other words, he is trying to optimize his net profit, and his farm's biological and economic productivity and well-being, within the constraints that result from not using synthetic off-farm fertilizers and pesticides.

The farmer commented during research interviews on the social sustainability of conventional farming systems and on the ability of this system to support economically and socially healthy rural communities. He said within the past 25 years the biggest change he's noticed in the area is the decline in the number of farm families in the area. Twenty-five years ago farms had livestock, children, and at least some of their income was from farming. Now, farms have been abandoned. He said he has seen a switch toward absentee ownership, and some farms have been bought out and rented to other farmers. He thinks single houses and housing projects will be coming to his area soon, built on former farms, because there's not enough money in conventional farming compared to other occupations. He is skeptical of agricultural technologies introduced during the past thirty years, saying he thinks few of them have really made life better for farm families, and that, based on changes in farm and rural population, and social welfare criteria, things haven't really improved. He thinks that, based on the history of previous attempts, laws and programs to correct some of these problems probably won't work.

One reason he is interested in organic farming is because he thinks it could resolve some of these dilemmas.

Figure 2.3 shows the relationship of the farm family to external forces acting on the farming system, to the system inputs and outputs, and to the internal physical and biological processes on the farm itself. While the farm family decides the amount and type of materials to import and export from the farm, external forces control the availability and price of those materials. The farm family provides physical flows to the farming system as labor inputs, and control flows as management decisions. Some outputs from farm subsystems, such as feed, manure and seed, are returned as inputs to the same or other farm susbsytems without leaving the farming system boundaries. A very small fraction of the farm output is consumed directly by the organic farm family, in the form of eggs, milk, chicken, and beef, though off-farm labor may first be used for processing the products.

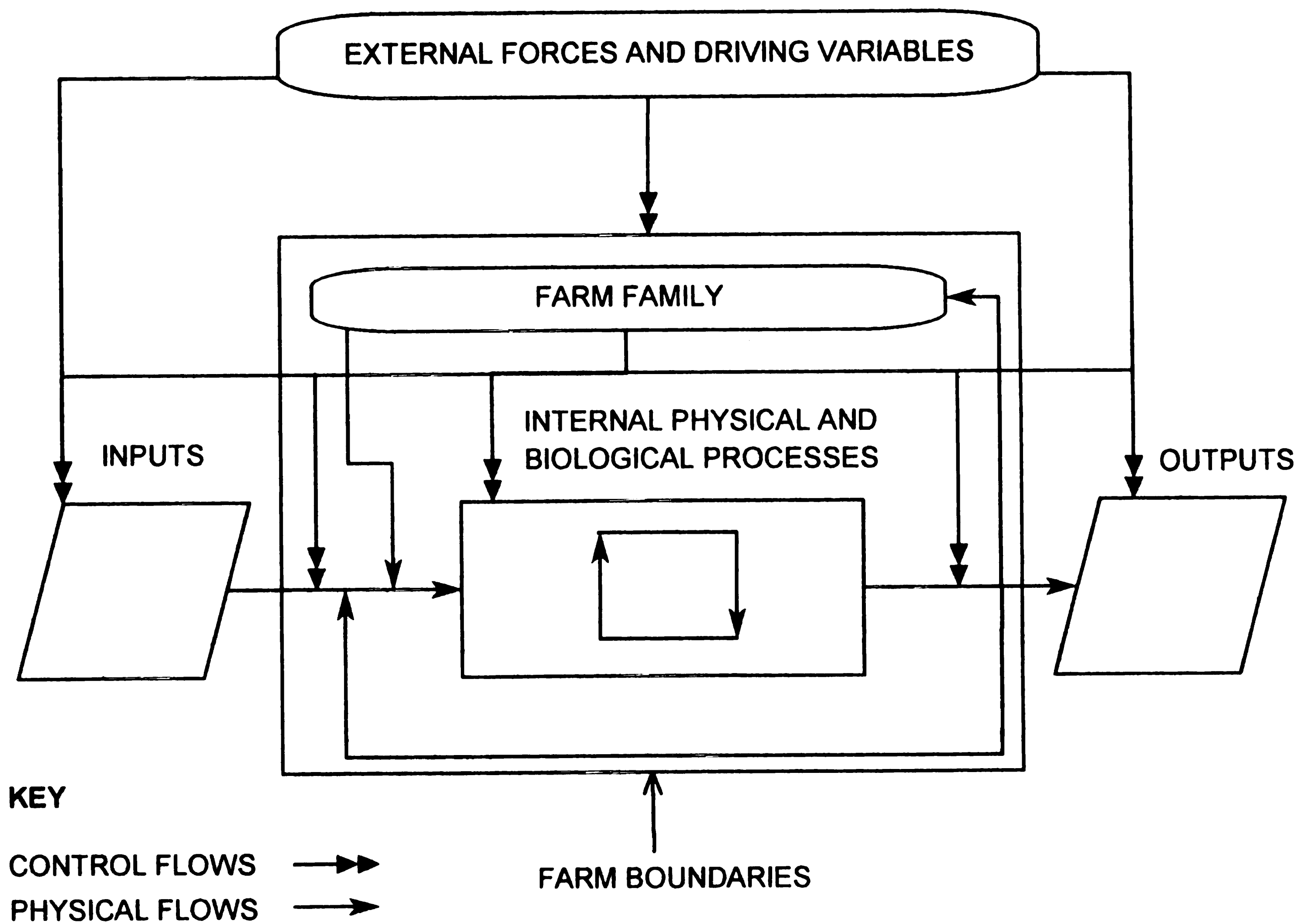

Figure 2.3 Diagram showing the relationship of the farm family to external forces, system inputs and outputs, and internal processes

Farm Labor

The farmer provides all but a small fraction of the labor for the organic farm. Neither his wife nor his children spend any significant time on field operations. However, his wife's off-farm job does provide the family with a degree of financial security, as well as benefits such as health insurance. A local teenager is employed for approximately two hours a day to do the evening milking and a few other chores. Local teenagers also help load and stack hay in the summer. He said finding teenagers to work isn't usually a problem, and they provide the balance of the labor needed to work the farm.

Cropping Systems

The total acreage of cash, pasture, and cover crops grown on the organic farm over the four years from 1989 to 1992 ranged from 118 to 151 percent of the total tillable acreage. This increases to 123 to 157 percent of tillable acres if land in permanent pasture is excluded. Over the past four years the organic farmer has grown from 1.2 to 1.5 crops per field per yield. The low end of this range represents 1992, a year when poor weather prevented the farmer from harvesting corn and soybean in a timely manner, and keeping him from sowing cover crops for the remainder of the year.

The organic farmer grew from 110 to 160 acres of cash grains each year between 1989 and 1992, including corn, soybeans, and winter wheat, at least part of which he sells off-farm. During this time he also grew 12 to 53 acres per year of barley and oats. He had planned to pearl his organic barley, and sell it for a premium, but was unable to locate a suitable mill close enough to make it profitable.

Thirty acres of the farm were kept in permanent pasture between 1989 and 1992. From 40 to 136 acres of alfalfa for cattle feed were grown during each of these years. Ninety-five to one hundred-ninety acres were kept in cover crops of rye grain (rye), a rye-hairy vetch blend, or hairy vetch for at least part of each year from 1989 to 1992.

Between 1989 and 1992 20 to 60 acres of the farm were idle or in government set-aside programs. The farmer did not participate in the set aside program in 1990 and 1991, believing that the benefits of the program would not compensate him for the costs of applying and filling out the necessary paperwork, and lost income from his cash crops.

Crop Rotations and Nutrient Management

A set crop rotation plan is not followed on the organic farm. Instead, rotations are decided using opportunistic management techniques. The succession of crops is varied according to estimates of the availability of nutrients, the weather, labor schedules, market conditions, and other factors. However, certain patterns or trends emerge when crop histories are examined. Corn almost always follows a legume other than soybeans, typically vetch, a rye-vetch mix, or alfalfa. This is done to supply the corn with as much nitrogen as possible. Soybeans usually follow corn, though sometimes a small grain such as oats is used. Soybeans are often followed by a cover crop of rye or rye-vetch, or with another small grain, such as winter wheat.

Judging from a four year history of his crop rotations, the farmer tries to grow a cover crop that will be plowed down at least once every three or four years, and on a number of his fields cover crops have ben grown for at least part of two or three crop years in succession. Crop rotations and cover crops are used to maintain farm productivity, to capture nutrients and cycle them in the fields, and to prevent soil erosion. Table 2.1 shows a summary of the crop history of the organic farm fields.

Table 2.1 Table of crop rotations on the organic farm (Anon. 1992).

FIELD NUMBER	ACRES	1989	1990	1991	1992
1	5.5	permanent pasture	permanent pasture	permanent pasture	permanent pasture
2, S 1/2	12	hay	winter wheat-vetch mix (cover crop)	corn	soybeans followed by hairy vetch
2, N ½	12	pasture	pasture	pasture	pasture
3	10.6	permanent pasture	permanent pasture	permanent pasture	permanent pasture
4 and E½ of 5	23.8	rye-hairy vetch mix	corn	soybeans followed by vetch-rye mix	corn
5, W ½	9.7	rye	soybeans	set aside, followed by winter wheat	winter wheat followed by rye-vetch
6 and 7	35.3	corn	oats	rye and hairy vetch	rye followed by winter wheat
8	61.1	alfalfa, then corn	soybeans, then rye	rye, then vetch added	rye-hairy vetch mix
9, N 1/3	6	soybeans, then barley	barley, then clover and rye-vetch	rye-hairy vetch	set aside
9, S 2/3	12	soybeans, then barley	barley, then clover and rye-vetch	corn	oats
10	40.5	wheat, alfalfa	alfalfa	alfalfa	alfalfa
11	1.5	vegetables	vegetables	vegetables	soybeans
12	34	alfalfa	alfalfa, then corn	oats	soybeans
13 & 14	10	rye-vetch, (set aside)	rye-vetch	idle	set aside
15	10	rye-vetch	corn	soybeans	rye
16, 17, 18, 19	40	rye-vetch (set aside)	rye and hairy vetch	corn	soybeans
20, 21	12	set aside	idle	idle	set aside

Commercial inoculum is used with hairy vetch and soybeans to ensure an ample population of nitrogen-fixing symbiotic bacteria.

The farmer speculates that rye and other cover crops may be absorbing plant nutrients such as phosphorous (P) and potassium (K) from deeper in the soil, below cash crop root zones, or may be taking up forms of nutrients that cash crops cannot absorb. This was advanced as one reason soil tests on the farm have shown little or no change in the levels of N, P, and K since synthetic fertilizer applications were halted.

Dairy manure is applied to fields, but because of the small size of the dairy herd, most fields are covered once every four or five years on average at normal spreading rates of 5 or 10 tons per acre. Manure spreading retains nutrients on the farm, particularly P and K. In the forms found in manure these nutrients are less volatile than N sources in manure, such as ammonia, nor are they subject to the types of processes that lead to denitrification and loss of N to the atmosphere (NRC 1989, Rosswall 1981).

Tillage Practices

Fields are first prepared for the planting of corn, soybeans, and some small grains with the use of a moldboard plow. They are then disked once or twice, harrowed with a roller harrow, and planted. Four or more passes may be made over a field before planting.

A moldboard plow is used to incorporate cover crops into fields and to disrupt weed growth. Despite evidence that moldboard plowing can increase soil erosion, the farmer believes erosion from his fields is less than, or at least no worse than, erosion from his neighbors' fields, due to his use of cover crops, and the absorbency of his soil. He said that since he has switched to organic methods, and started planting and incorporating cover crops, his soil organic matter has increased and his soil has better structure. It does not compact as much, it is more absorbent, and his fields are becoming easier to plow. His findings are similar to and supported by those of Reganold, Elliot, and Unger (1987) and others, discussed in the literature review.

Rye, vetch, and some of the small grains are broadcast into the stubble of the previous crop to plant them, after first disking the stubble. This reduces the number of tractor passes necessary to plant from three or four to two.

Row crops are cultivated once or twice during the season to suppress weeds, and a rotary hoe is also used once or twice each season to keep weed pressure down. The permanent pasture is mowed or clipped twice each summer to encourage new growth for the cattle. Any land sitting idle is usually disked and/or mown in order to keep weed populations down.

Animal Systems

The organic farmer keeps a dairy herd of 28 milking cows, with an equal number of replacements. He also raises about 60 laying chickens. Cattle are fed a mixed ration of shelled corn, oats, soy meal, molasses, trace minerals, and vitamins year-round. The cattle also have access to as much hay as they want throughout the year. The hay is primarily alfalfa, with some orchard grass. The soy meal, and sometimes the mineral salts, are discontinued for about three months in the summer when the cattle are grazing. The cattle graze from approximately May 1 to November 1, but the quality of the grazing drops significantly after the first two or three months, by which time the cattle are back to eating as much hay as ever.

At one point feed was mixed on-farm, but a local co-op now prepares and mixes the cattle feed from farm grain stored at the co-op. Any additional grain needed is purchased through the co-op.

Cattle are fed at least some of the corn grown on the farm. Over the past four years all hay consumed was grown on the farm, with the exception of one purchase of about one month's worth of hay. The oats in the feed ration are grown on farm as well.

When there is only a small difference between the prices for commercial and organic corn and soybeans the cattle are fed corn and soybeans grown on the farm. When the price difference is larger, crops are sold for the organic premium, and less expensive commercial grain is fed to the cattle. Barley grown on farm was fed to the cattle with no problems, when the barley could not be pearled economically.

New-born calves are kept on whole milk for two months, and then started on the regular ration, supplemented with protein. Cattle are not sold for breeding purposes. The organic farmer said he has considered getting out of dairy farming, selling off the adult herd, and raising the replacements and selling them. He said he is tired of working for milk prices similar to those of 1970.[2]

Cattle are kept in tie stalls in a barn close to the household, and heifers stay in a free-stall barn. All cattle go outside every day for exercise. Gutters are cleaned mechanically. The farmer uses a pipeline milker, and feeds with two feed carts. He said that he has a low mastitis incidence, which he credits to his relatively natural feeding system and an emphasis on cleanliness. Antibiotics are used if needed, but they are not used as a matter of course, nor are subtherapeutic doses of antibiotics fed to the cattle.

The chickens are fed a commercial layer mash, purchased off-farm, supplemented with soybean and grain screenings from the farm crops. This is a very small off-farm input. The chickens are allowed to range, and live in a portion of the equipment barn.

The organic farmer does not keep any bees, and does not know of any neighbors who do. He does not rent bees, and said he has not noticed any problems with pollination. He thinks there are enough trees and woodlots in the area, especially along the creek, to provide habitat for ample populations of wild and feral bees.

2

He sold his dairy cows in February of 1993, and plans to raise replacements to milking age, when he will consider the milk market. He said that he can't imagine farming without some sort of animal component, but is not sure what that might be.

Inputs From Off-Farm

No fossil fuel-based fertilizers, insecticides, or herbicides are purchased or used on the organic farm. In keeping with a philosophy of reliance on internal resources, organic fertilizers or pesticides are not purchased either. The primary material inputs from off-farm sources are machinery, including tractors, tillage equipment, and dairy equipment; and energy inputs of diesel fuel, gasoline, electricity, and natural gas. Off-farm inputs also include vital biological inputs in the form of seed, inoculum, and sperm and breeding stock for the dairy herd. Seed for future crops is saved from the harvest of a number of small grain and cover crops. Winter wheat, oats, rye, and hairy vetch are grown from seed harvested on farm.

There is also a flow of information from off-farm sources onto the farm. The organic farmer said his chief sources of off-farm information are other farmers, the OCIA (Organic Crop Improvement Association), the Rodale Research Center, and a few organic farming magazines. He said when he first started farming he tried to attend one or two seminars each winter at Michigan State University (MSU), and said that seminars can be a time-efficient way to get information. He said it has become easier to get information on organic farming over the years, and that there is now more information available, and institutions are opening up. Figure 2.4 shows some of the details of the physical and biological processes on the organic farm.

Farm Outputs

Milk is the most important farm product economically. Milk is sold to a local dairy co-op. Male calves are sold to beef producers, and herd culls are sold to meat processors. No cattle are sold for breeding purposes.

Corn, soybeans, and winter wheat are sold through a local farm co-op, and are sold for organic premiums whenever possible. The organic farmer estimates his corn yields are about 85 to 90 percent of those he could get using conventional techniques on <u>his farm</u>.

A small number of eggs are sold through local food co-ops for a premium price. Some hairy vetch seed is sold to neighboring farms, but is not a significant source of income.

Between 1989 and 1991 about 1.5 acres of vegetables and fruit were grown each year for organic markets. This included melons, squash, tomatoes, green beans, and sweet corn. The farmer said they did extremely well one year, but had trouble with weeds and the weather the other two years, so they stopped growing produce in 1992 for the time being.

Information is also exported from the organic farm. On-farm trials of different techniques are conducted with the Rodale Research Center and the Michigan Agricultural Stewardship Association. The organic farmer speaks to farm groups, gives farm tours, and in general shares his knowledge and experience in organic farming techniques with those willing to speak with him, as this researcher can thankfully attest.

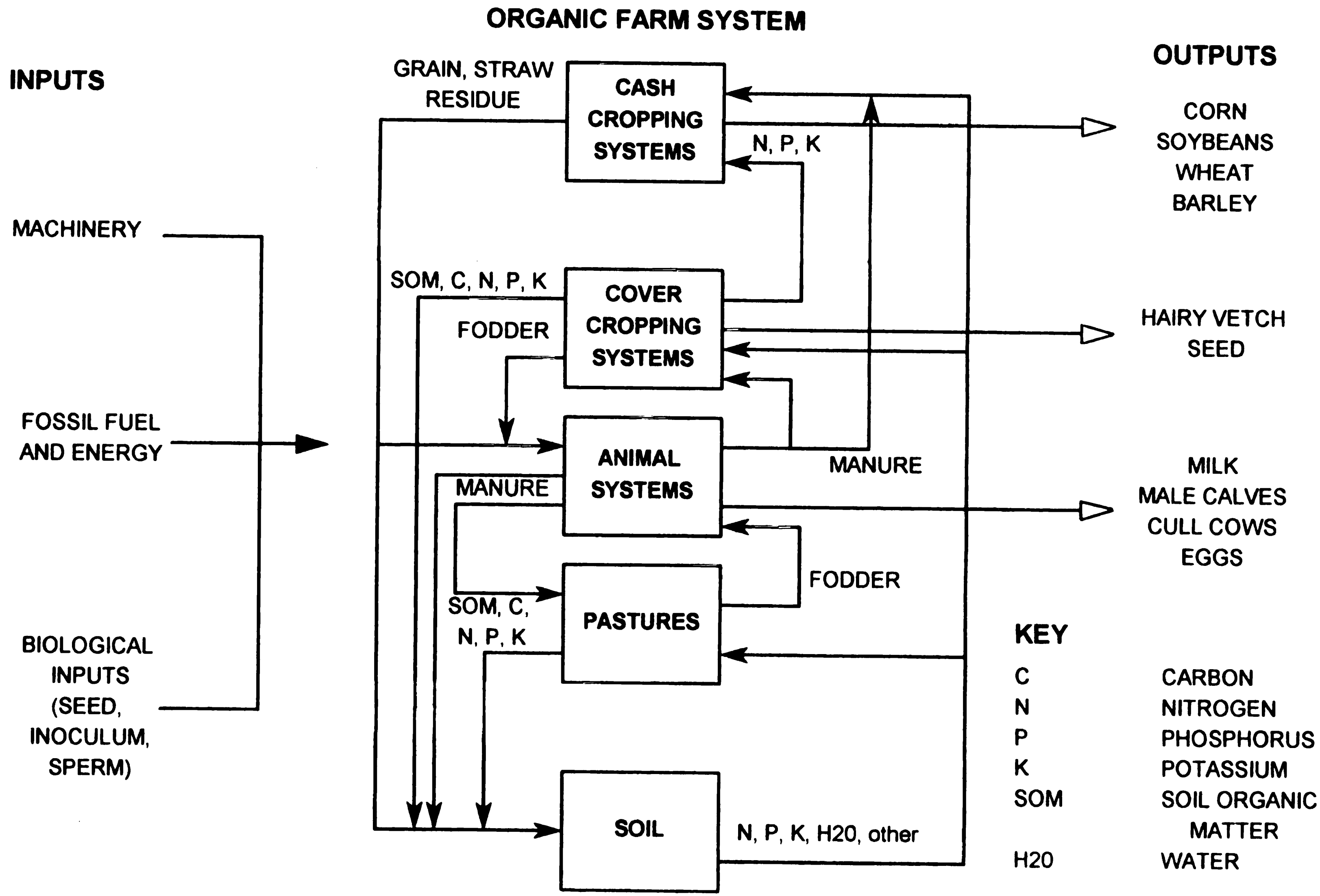

Figure 2.4 Diagram showing details of the organic farm physical and biological processes

Characteristics of the Conventional Farming System

A "composite" conventional farming system was used in this study for several reasons. It made it easier to develop a mixed-enterprise conventional system more comparable to the organic farm. The data used for the conventional farming system came from farms in the same county as the organic farm. The creation and use of a composite system meant that information comparable to the organic farm was available. It also eliminated the risk of the conventional farmer withdrawing from the study, or being unavailable to work with the researcher.

The conventional farming system used to compare to the organic system is based on research conducted by the Ingham County Cooperative Extension Service (MSU-CES) and the Ingham County Soil Conservation Service, in conjunction with the Sycamore Creek Water Quality Program. Sycamore Creek flows through Ingham County, and the farms studied are located in the county. As part of the program, extension and conservation agents determined typical rates of fertilizer and pesticide applications for different crops in the county. They described the major crop rotation of the watershed as a corn-corn-corn-soybean-wheat rotation.

The fertilizer and nutrient rates used in the Sycamore Creek program were used for the conventional farming system in this study. The rotation was used for a comparison of crop rotations as well.

Crop and milk yields used for the conventional system are state averages for the year in question. County averages were also used when possible. Labor data were compiled from three farm labor budgets.

Details on the conventional farming system, and on the assumptions used, are presented in Chapter Four: Research Approach.

CHAPTER THREE
LITERATURE REVIEW

This literature review examines definitions of sustainability and sustainable agriculture, the nature of sustainability, and some of the techniques proposed for measuring and quantifying agricultural sustainability. It then considers systems science and systems approaches, and their use in studying agroecosystems. A review of several farming systems comparisons and their results, including a discussion of qualitative differences and similarities between conventional and alternative farming systems, concludes the chapter.

Sustainability and Sustainable Agriculture

"When I use a word, it means just what I choose it to mean..." So says Humpty Dumpty in Lewis Carroll's Through the Looking Glass (Carroll p. 238, no date). Some authors claim that many writers and researchers today use the terms "sustainable" and "sustainability" in a similar manner. Conway (1991), Lockeretz (1988) and Crews, Mohler, and Power (1991) agree that "sustainability" and "sustainable agriculture" have too often been used to mean all things to all people, and they argue that these terms are losing credibility as result. A lack of consistent and clear definitions also allows critics of alternative agricultural methods to claim that conventional techniques are sustainable, and that needed agricultural research has been or is being conducted (Buttel and Youngberg 1985, Lowrance 1988). We will see, however, that consensus on the meaning of sustainability and sustainable agriculture has emerged in several areas.

Lockeretz (1988) points out possible differences between the more common terms (e.g., sustainable, alternative, low-input, ecological, and regenerative) used to describe agroecosystems that share goals such as less use of non-renewable and off-farm inputs and conservation and improvement of natural resources. He discusses the possibility that there are indeed fundamentally different concepts involved, but that authors are not always precise in selecting the appropriate term. In literal terms, he says (Lockeretz 1988) :

"sustainable" describes the ability to endure over time.

"alternative" refers to practices different from present or "conventional" norms.

"low input" refers to the decreased use of goods and services from outside farm boundaries.

"regenerative" implies the ability to improve the natural resource base (some also include improving social resources).

"ecological" brings to mind natural environmental laws and processes.

He grants the possibility that these terms do refer to the same basic concepts, but that different ones are used to avoid negative connotations of previous terms, or to capture nuances writers believe previous terms did not.

In contrast to these primarily semantic issues, he introduces the possibility that the basic concepts implied by the different terms are different, but the same agroecosystems tend to be used to demonstrate these different concepts. Studies that used only the term "organic" have been cited as dealing with "low input," "sustainable," and ecological" agriculture (Lockeretz 1988). This begs the question of whether or not such systems <u>are</u> "sustainable," "alternative," or "regenerative." Lockeretz (1988) states each of these terms is a goal, independent and unique, and that at least some of them may be mutually exclusive for specific production systems.

Conway (1991) believes broad and sweeping definitions of sustainability are useful as policy statements, but don't meet the needs of agricultural researchers and farmers, who need a practicable, scientific definition open to testing and experimentation. He and others define sustainability as the ability of the agroecosystem to maintain productivity when subject to major disturbing forces or shocks (Conway 1991, 1990, 1986; Marten 1988; MacKay 1989). This is similar to Lockeretz's (1988) definition, and that proposed by Crews, Mohler and Power (1991).

Others, while admitting the usefulness of this definition, say that this definition is another term for the ecological concept of resilience (Lynam and Herdt 1989, Harrington 1992).

Crews, Mohler, and Power (1991) state unequivocally that definitions of sustainable agriculture that embrace ecological, sociological, and economic characteristics are excessively broad, and blur critical distinctions. They support a definition closer to Conway's. They maintain that sustainability is a measure of a system's ability to endure, and is constrained only by ecological conditions. They enthusiastically support efforts to increase equity, rural quality of life, and social justice, but they hold that these issues should be considered in their own right, and not crammed under the overburdened umbrella of sustainability.

Researchers also distinguish between a number of different types of agricultural sustainability. Douglass (1984 and 1985) delineates three views: sustainability as food sufficiency, as stewardship, and as community. Sustainability as food sufficiency, he says, is defined as the ability to produce enough food to meet the demand of present and future generations. Those embracing this view tend to believe that any production methods that yield marginal benefits greater than marginal costs are justifiable, even if agricultural production needed to meet food demands leads to resource use and degradation exceeding its regenerative capacity (Douglass 1984).

Sustainability as stewardship focuses on ecological approaches and perspectives, seeking to optimize farm outputs indefinitely while maintaining or enhancing the natural resource base farms depend on (Douglass 1985 and 1984). Supporters are interested in reducing population growth, the consumption of nonrenewable resources, and negative externalities caused by agricultural production. They tend to challenge the concept of dynamic economic efficiency as calculated using cost/benefit analysis, declaring that the ethics of the current generation discounting benefits accruing to future generations are dubious (Harrington 1991; Berry 1977).

Churchman (1984) also raises pointed questions about the morality of intergenerational willingness-to-pay models of allocating natural resources.

Proponents of sustainability as community hold that trends towards larger farms, and towards corporate farms, have had severe negative consequences on the quality of life in rural communities. These trends have negatively affected the ability of of farm families to maintain their consumption and livelihood. They believe it's necessary to extend stewardship to include not only ecologically sound practices, but agricultural systems that will strengthen social relations and structures, and encourage a culture of mutual concern and interest (Douglass 1984; Berry 1977).

Lowrance, Hendrix, and Odum (1986) also distinguish between several types of sustainability. They presented what they call a "hierarchical approach" to agriculture which divided agriculture into a number of levels, reflecting the different systems which dominate the level. Figure 1.1 is a diagram of one view of agroecosystem hierarchies. Sustainability has a different meaning at each level of the hierarchy. At the bottom, agronomic sustainability refers to the ability of a unit of land to maintain long-term production. Microeconomic sustainability is the ability of the farm to stay in business. At the watershed or landscape levels ecological considerations must be addressed; and government policies control macroeconomic sustainability at the regional, national and international level. In this approach, higher level subsystems generally have priority of action over lower level subsystems, and have longer management horizons, or are concerned with longer-term behavior. They discuss a flaw in this view, in that macroeconomic subsystems seldom have a longer time frame than ecological subsystems. Brown et al (1987) concur with a hierarchical approach, stating that the meaning of sustainability depends upon the dimensions, and the level of the agroecosystem hierarchy, we consider.

The author suggests that the concept of "sustainability" is best used in a relatively narrow sense meaning the ability to maintain production (desirable outputs) over time, in the face of significant disturbances or pressures.[3] This allows researchers and writers to specify key terms in the meaning (e.g. production, outputs, time, disturbances) to present an unambiguous operational definition. This is similar to the way the term "productivity" is presently used. It is understood to be the output of goods or services per unit of input. Every writer or researcher must specify what particular outputs and inputs are of interest, yet there is general agreement as to what "productivity means. "Sustainability" will be used according to this definition in this paper.

The term "sustainable agriculture" incorporates a much broader spectrum. As defined in the first chapter, agriculture systems (agroecosystems) are as much social and economic systems as they are ecological, with social, economic, and physical boundaries (Conway 1990). It follows that a sustainable agriculture must address the sustainability of social, economic, and physical systems making up an agroecosystem.

A number of researchers and public officials have proposed definitions that encompass economic, social, and physical elements. Rep. George E. Brown (D-CA), wrote that sustainability of agriculture, or sustainable agriculture, "..is a useful concept for focusing agricultural research because it captures a diverse set of concerns about agriculture as an economic system, and ecological system, and a social system." (Brown 1989 p. 102). Harwood (1988 p.2) describes sustainable agriculture as "an agriculture that can evolve indefinitely toward greater human utility, greater efficiency of resource use and a balance with the environment that is favorable both to humans and to most other species." He describes this as a "framework"

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Population growth, technological changes, the impacts of political and diplomatic policy changes, and entropy, are examples of large-scale forces affecting the sustainability of agroecosystems.

definition, that can be filled as needed with appropriate details over a relevant time frame (Harwood 1988).

Hildebrand (1990) finesses the question of defining sustainable agriculture. He points out that it can be thought of in economic, political, social, cultural, institutional, and ecological terms; and then goes on to say that since so many people use the term, it is apparently intuitively understandable. He says that sustainable agriculture is <u>not</u> a constant state, it is not a return to a former state, nor is it necessarily low input.

Benbrook (1991 p. 4) defines sustainable agriculture as "...the production of food and fiber using a system that increases the inherent productive capacity of natural and biological resources in step with demand. At the same time, it must allow farmers to earn adequate profits, provide consumers with wholesome, safe food, and minimize adverse impacts on the environment." Benbrook (1991) argues, and these representative definitions demonstrate, that there seems to be a general consensus concerning the essential elements of sustainable agriculture. Though different definitions emphasize different aspects, nearly all contain a common set of features (Benbrook 1991).

The definitions presented above agree well with the view that sustainable agriculture is a system-level <u>process</u> of adaptation to complex ecological, economic, political, and social interactions within the boundary of a given agroecosystem (Edens 1985; Reganold, Papendick, and Parr 1990). Of course, so is conventional agriculture. However, the process and the adaptations are qualitatively different. Because these two agroecosystems have distinct emergent properties, systems-level approaches, at appropriate levels of the agroecosystem hierarchy, are necessary to understand and compare them. Systems approaches will be addressed in the following section.

Systems Approaches

Churchman (1968) says that the essential concept of a system is that it is made up of a set of components that work together for the objective of the whole. Spedding (1979) defines systems as a collection of objects and their relationships existing within a boundary that is drawn by the observer, appropriate to his or her objectives. Systems, he says, are unaffected by their own outputs, and their boundaries are based on the inclusion of all significant feedback. Bawden (1991), and Bunge (1977) extend this approach, pointing out that systems arise from the relationships and connections between their constituent parts, creating an assemblage with unique and emergent properties. Elements within the assemblage are strongly interconnected compared with connections to elements outside the assemblage, and as a result a system responds to many outside forces as a whole, though only one element of the system may have been acted upon (Edens and Haynes 1982; Conway, 1991).

Checkland (1981), and Atkinson and Checkland (1988) state the four most fundamental systems ideas are emergence, hierarchy, communications, and control. Systems can also be divided into two major types: those that have clear goals or predictable outcomes; and those with ambiguous or uncertain goals and outcomes (Checkland 1981; Bawden et al 1984). The former they call hard systems; the latter soft systems. Bawden (1991) further distinguishes the two. Hard systems approaches, or what he calls ontosystemic inquiry, are based on accepting and studying entities as systems as they exist in the world—it is the study of ontological realities. Episystemic, or soft system, study, he says, is the study of "...people's perceptions of reality, on their mental processes rather than on the objects of those processes." (Bawden 1991, p. 2368). Issues associated with the subject of study, such as an agroecosystem, "...are thought about *as if* they were interrelated in some way or another." (Bawden 1991, p. 2367). While these approaches are not mutually exclusive in a single research project, it may well be that they are for a single researcher, due to the conceptual shift necessary to switch between these two world views.

Checkland (1981) says that soft systems methodology is an iterative process for investigating and acting upon real world problems. He summarizes the process in the following steps. The first is finding out about a real world problem. The next step is naming or defining some systems of purposeful activity relevant to the situation and its improvement. The systems named are then modelled, based on transformations of real or abstract inputs into outputs. These models are then compared with the real world activities, after which changes that are both desirable and feasible are defined and debated. The final stage of this process in implementing the changes selected (Checkland 1981; Atkinson and Checkland 1988).

They go on to state that practically all systems-based work is rooted in the concept of a system as an adaptive whole that can react to a changing environment (Atkinson and Checkland 1988). They argue that soft systems methodology (SSM) is itself an adaptive whole, and the use of models of purposeful systems within SSM also reflects the notion of systems as an adaptive whole. They believe that the advantages of SSM could be weakened if the metaphor of systems as an adaptive whole becomes too pervasive. They propose two alternatives to yield new images of systems. One is to abandon the idea of systems as purposeful entities while retaining the notions of wholeness and emergence. The adaptive and purposeful whole changes to something better described by the metaphor of the net. A second possibility is to combine several purposeful systems in more complex wholes that do not pursue a single purpose in a unitary manner (Atkinson and Checkland 1988). Some of the systemic metaphors that follow from the second choice are combative, contradictive, host/parasite, syndicalist, and imperialistic system (Atkinson and Checkland 1988). Patten and Odum (1981) propose a definition of natural ecosystems similar to this second possibility.

In a rebuttal of a paper by Engelberg and Boyarsky (1979), The Noncycbernetic Nature of Ecosystems, Patten and Odum (1981) present a strong case for considering ecosystems as cybernetic systems. They argue that variables such as production, respiration, population sizes, and species diversity can be regarded as "..components of an objective function that is to be maximized or minimized subject to a set of constraints." (Patten and Odum 1981 p. 889). They say these can be regarded as analogues of goals in teleological systems, but that teleological metaphors of ecosystems are just that.

They define cybernetic systems as a special class of input-output, or cause-and-effect systems, for which input is determined at least in part by output. Feedback is output that is returned to input, that can come to control the system. They go on to demonstrate that ecosystems possess the necessary characteristics of cybernetic systems—analogues of goal directedness, information networks, feedback, and regulation and stability. They state that the true issue (well described by Engelberg and Boyarsky) is how to think about ecosystems and place them in a scheme of known systems (Patten and Odum 1981). They describe ecosystems as "the level of organization concerned with the orderly, not chaotic, processing of energy-matter" controlled by feedback in the form of diffuse and decentralized informational processes (Patten and Odum 1981 p. 894).

The Gaia hypotheses of Lovelock is perhaps the most striking example of this view. Lovelock explicitly rejects arguments that his hypothesis implies or requires a teleological system (Lovelock 1990). It is clear from his work that he views Gaia much the same as Patten and Odum (1981) view ecosystems—as resulting from the coevolution of ecosystems through energy, matter, and information flows and feedback cycles resulting in orderly, negentropic populations and environments. The concurrence of their views is to be expected, for Lovelock says he has felt a special empathy towards Eugene Odum's writings (Lovelock 1990).

Few would argue that farms are purposeful agroecosystems, controlled and guided by owners or managers. However, even at the farm level system objectives may not be clear, or may result only from comflicting or mutually exclusive human desires. At watershed and larger levels of agroecosystems, the direction and amount of change over time in an agroecosystem can best be thought of as a vector, resulting from and expressing all human and nonhuman forces acting upon the system (Axinn 1988; Harwood 1992). Agroecosystems at these levels resemble the complex wholes described by Atkinson and Checkland (1988), Patten and Odum (1981), and Lovelock (1990), lacking a single purpose. Axinn's concept of change as a vector, resulting from the interaction of reinforcing, opposing, or tangential biological, physical, technical, economic, social, and political forces, offers a valuable tool for studying systems, such as large-scale agroecosystems, that do not fit the metaphor of the adaptive whole (Axinn 1988).

In the next section methods of comparing organic and conventional farming systems, and their sustainability, will be presented. Moderate reductionism, as suggested by Mario Bunge (1977), will then be used to examine some of the singular and emergent properties of different agroecosystem levels. In keeping with this approach, higher levels, such as national and international levels, will be considered first. Intermediate and lower-level agroecosystems and their properties will then be analyzed, and their usefulness in explaining higher-level system properties will be considered. The advantages and disadvantages of energy analysis as a tool for agroecosystem analysis in the context of moderate reductionism will be presented. The results of previous whole-farm comparisons will be discussed, and some qualitative differences between ecological processes on conventional and organic farms will be introduced to suggest causes for differences observed in productivity and sustainability.

The Comparison of Organic and Conventional Agroecosystems

Agroecosystems can be compared on the basis of several system properties. These properties—productivity, stability, sustainability, and equitability—can be specified and observed

(Conway 1990; Conway 1986; Marten 1988; Harrington 1992). Productivity is the net increment in useful product per unit of resource or input; stability is the constancy of production despite small, regular stresses (Conway 1990; Conway 1986; Marten 1988; Harrington 1992). Sustainability, as previously defined, refers to the ability of a system to maintain productivity of desirable goods and services when subject to major disturbances, or shock (after Crews, Mohler, and Power 1991; Conway 1990). The equitability of a system is the evenness of distribution of a system's productivity among beneficiaries, according to criteria mutually agreed upon by system residents (after Conway 1990; Marten 1988). Marten (1988) includes autonomy as a key system property, which he defines as the self-sufficiency of an agroecosystem.

Farmers and others place different values on the system properties above. There are numerous tradeoffs possible for a single system property, and between system properties. Subsistence farmers may emphasize land productivity; industrialized farmers tend to value labor productivity (Marten 1988; Whyte 1991). Much of the U.S. agroecosystem appears to favor productivity over ecological sustainability (Edens and Haynes 1982). Subsistence farmers may value sustainability and stability over productivity. Tradeoffs also occur across agroecosystem levels. A regional project may emphasize production at the expense of farm level stability. There has been very little quantitative analysis of the trade-offs between agroecosystem properties according to Conway (1991).

Stability and sustainability are by definition measured over time. Trend analyses of productivity, equity, and autonomy also require us to measure and analyze these properties over time. The optimal time frame suitable for monitoring systems varies. Some properties and potential problems are best studied over a time frame of 5 to 25 years, such as short-term changes in productivity or equity, loss of soil nutrients, pest and disease problems, and rapid soil erosion (Lynam and Herdt 1989; Harrington 1991). Other factors require a longer time line—from 20 to 100 years or more. The sustainability of petrochemical-based agriculture, desertification, salinization, and early changes in climate and atmospheric composition are examples of this class (Harrington 1991). It's conceivable that very long time frames, from 100 to 1000 years, might be needed to investigate issues like long-term climate change, or the loss of genetic diversity (Harrington 1991).

Edens (1985) describes labor productivity and yield per unit of land area as two of the most seductive quantitative criteria for evaluating agricultural performance. Many others are possible—goods and services per unit of input or per unit of cost, costs such as tons of soil lost or pounds of phosphorus leaked from the physical agroecosystem. Still, there are valid reasons for evaluating agroecosystems on the basis of their labor and land productivity, not the least of which is because they are common measures and so allow comparison with a great many systems. An alternative agroecosystem that cannot match our present system in terms of total yields and yields per acre would not be considered sustainable by those who embrace the food-sufficiency approach to sustainability (Douglas 1985), nor would those alternative practices be adopted widely (NRC 1989). A third reason is that there is a growing body of evidence, some of which will be summarized later in this chapter, that alternative agroecosystems can achieve the yields, and in some instances the labor productivity, of conventional farming systems. If alternative systems can secure the benefits of present techniques while avoiding many of the costs, then based on rational criteria, they should be adopted.

Measurement of Sustainability

There are a number of quantitative and non-quantitative methods that can be used to measure sustainability. Trend analysis of yields or other outputs of interest over time can be conducted from field to regional or national levels. However, this method may not detect problems of sustainability. Productivity growth from higher input levels, for example, could mask declining resource quality (Harrington 1991).

Lynam and Herdt (1989) propose total factor productivity (TFP) as the appropriate measure of sustainability at the cropping system or farming system level. They define TFP as the total value of system outputs over one time period divided by the total value of inputs to the system for the same period (Lynam and Herdt 1989). They present TFP as an economic measure, yet it appears well suited for use with energy units. This method is primarily a measure of efficiency; it cannot distinguish between productivity changes due to technology, input levels, or resource quality, nor does it address the demand for system outputs. It is focused on the plot or farm level, and it would be extremely difficult to use at a regional level (Lynam and Herdt 1989; Harrington 1991).

Direct estimation of the contribution of different factors to yield can also be used to estimate changes in sustainability. This approach can be powerful, as it explicitly measures trends in state and control variables, it controls for land type changes, and changes in input levels; and it identifies positive and negative factors affecting yields. This information can then be integrated into models for assessing the near future. It is extremely data intensive, and difficult to apply to complex farming systems. Like the other methods, it doesn't address synergistic effects directly. It also interprets sustainability in terms of efficiency, not system resilience. Methods for measuring sustainability depend on accurate long-term records not just for productivity, but for weather and other potential sources of shocks, such as agricultural markets, pest problems, and many more. It is hardly surprising that few studies of sustainability as resilience have been done, and that techniques for conducting such studies are lacking (Conway 1991; Harrington 1991).

TFP, using energy as the measurement unit, will be combined with directional measurement and direct estimation techniques for which sufficient information is available, to compare the relative sustainability of conventional and organic agroecosystems. Energy analysis and its strengths and weaknesses will be presented in the following section.

The Use of Energy Analysis in the Comparison of Agroecosystems

The agroecosystem hierarchy rests upon its base of biological and ecological processes. These processes require continuous inputs of external energy, and essential nutrients that can come from internal recycling or from external stocks. Our agroecosystems, then, rely on continuous inputs of energy and material nutrient flows and cycles. It follows that analyses of energy use are necessary, though certainly not sufficient, to understand our agroecosystems.

Energy analysis is an excellent tool used in conjunction with moderate reductionism. Agricultural inputs, outputs, and flows and processes both internal and external to a given agroecosystem can all be characterized in energy units. A whole system approach can be used because common units are used, allowing system and subsystem efficiencies at each level to be compared.

Energy efficiency studies consider both direct energy inputs and the amount of fossil fuel embodied in the other inputs as well. This approach owes much to systems theory (Doyle 1990). Use of systems theory has shifted from an emphasis on unique optimization approaches to identifying sets of solutions that are efficient according to particular economic, technical, or social criteria. Considerations of biological efficiency have just as much relevance in evaluating agricultural systems as ones of economic efficiency (Doyle 1990).

In practice, energy studies tend to focus on one of three levels in the agroecosytem hierarchy. They examine either the national and international level, the farm level, or the plant or animal level. A brief summary of literature concentrating on national/international level will be presented, followed by a discusion of farm and organism level studies.

Energy analysis at the national level offers several benefits. It can reveal the energy requirements of each process within complex production systems using a standard accounting procedure. Energy analysis in this sense can be thought of as a form of technology assessment, which also shows us the possibilities for energy conservation (Smil, Nachman, and Long 1983;

Stanhill 1984)). It allows governments and industry to plan for the consequences of different scenarios of energy availability and price (Stout 1990; Stanhill 1984), and it can form an integral part of larger cost-benefit or other economic studies (Smil, Nachman, and Long 1983). It can answer the question of how energy can substitute for or be replaced by other factors of production, and can show what forms of energy can be and are substituted for one another (Stout 1990).

Analyses of the U.S. food system, including all operations from farm fields to kitchen tables, show that it consumes aproximately 16.5% of the country's energy: 2.9% in production, 4.8% for processing, 1.7% for distribution and transportation, and 7.1% for food preparation and rural living (Stout, Butler, and Gavett, 1984). These figures agree well with those reported in Edens and Haynes (1982), and Koenig and Edens (1976). These figures reveal that far from being a relatively small factor in our national energy budget, our total agroecosystem consumes about one-sixth of the U.S. energy pie. To say that the U.S. food system requires "only" three percent of our national energy is akin to saying that we all buy our food at the farm gate. We do not. We depend on our food processing and distribution system to eat, and to feed others, and will continue to do so.

Agriculture produces energy as well, of course, and many agricultural products can be converted into fuels. The increase in oil prices brought about in part by the Organization of Petroleum Exporting Countries (OPEC) oil embargo prompted interest in a variety of projects to transorm agricultural biomass to fuel. Despite initial enthusiasm for such projects, studies have shown that in the U.S. only the production of methanol from wood has the potential to supply significant quantities of liquid fuel for multi-state or national markets without disrupting food, feed, and export markets (Blobaum 1984; Smil, Nachman, and Long 1983; Stout 1990). This is not to denigrate the considerable actual and potential use of biomass for energy production on a local basis, where it can enjoy an energetic and economic advantage over alternatives (Stout

1990). However, barring significant or even radical technological advances in energy production or consumption technologies (e.g. vastly improved energy storage technology, room-temperature superconducters, safe and efficient fusion power), energy conservation has the potential to make by far the most cost-effective contribution to farm and non-farm energy supplies (Stout 1990).

Labor Analysis as a Necessary Component of an Agricultural Energy Analysis

It is necessary to study energy and labor flows jointly, for they are inextricably intertwined in agroecosystems. In the post-Second World War period conventional farmers substituted energy, and capital in the form of equipment, for labor (Buttel and Gertler 1982; Stanhill 1984). Stanhill (1984) says that the longest and most homogenous series of energy statistics available for any national agricultural system is probably that for France. Studies based on this data show that roughly 21,500 Mcal of energy were consumed for every man-year of agricultural labor leaving French farms between 1945 and 1960. This rate more than doubled from 1965 to 1970. The rate of increase slowed between 1970 and 1975, a period of rapidly rising oil costs (Stanhill 1984).

Similar transformations took place in the United States between 1940 and 1970. Over this period the fossil energy to labor substitution ratio was over 63,000 Mcal per man-year (Stanhill 1984).

Most studies have shown that organic farms use more labor per unit of output than conventional farms (Pimentel et al 1983; Klepper et al, 1977; NRC 1989). This is in keeping with economic research, which has found that energy and labor appear to be substitutes, with elasticities ranging from 0.48 to 3.80, depending on the country and the industry (Tietenberg

1988)[4,5]. Thus, as energy inputs such as synthetic fertilizers and pesticides are withdrawn, it is to be expected in most cases that additional labor will be needed to replace that energy. Organic farmers may be substituting labor for fossil fuel inputs.

Conventional farmers may be reluctant to adopt organic or low-external input systems if they cannot supply or obtain any additional labor needed. For these reasons, in addition to those discussed earlier in this chapter, the labor productivity of the organic farm will be compared to that of county farms, to determine if in fact a difference can be found.

Irreversibile Changes

There are significant technical and economic constraints to reversing the undesirable aspects of industrialized agroecosystems at the national and international level. The loss of genetic material due to the displacement of many native open-pollinated crop varieties by a few hybrid crops cannot be reversed if native varieties are not grown or maintained. This represents a technical constraint to reversibility (Edens and Haynes 1982). Investments in expensive and specialized equipment cannot be reversed or prematurely depreciated by producers without suffering unacceptable losses—they are constrained by economic factors (Edens and Haynes

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The elasticity of substitution between two factors of production, X and Y, is defined as the ratio of the percentage change in the factor ratio to the percentage change in their relative prices, P_x and P_y.

$$\sigma = \frac{\Delta \frac{X}{Y} \cdot \Delta \frac{P_Y}{P_X}}{\frac{X}{Y} \cdot \frac{P_Y}{P_X}}$$

In general, elasticities of substitution greater than one indicate that substitution is relatively easy (Tietenberg 1988 p. 293).

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Most production studies have found capital and labor to be strong substitutes as well (Tietenberg 1988).

1982). Similarly, the emigration of workers from rural to urban areas following the Second World War may impose a irreversible economic and social impediment to an expansion of agricultural labor markets. The enormous technical, economic, and social inertia of regional and national agroecosystems means that change requires significant forces to reverse or redirect these systems, acting over time spans of at least one or two decades (Axinn 1988; Edens and Haynes 1982). A lack of planning over periods longer than a decade, in particular systems-level planning, is one more factor impeding rational decision making and resource allocations (Edens and Haynes 1982; Buttel and Gertler 1982).

Farm-Level Energy and Labor Analyses

In most energy and labor analyses conducted at the farm level, energy inputs and outputs into the whole-farm system and subsystems are measured, and the efficiency of farm production, labor use, and energy transformations are reported (Dobbs et al 1988). In these studies the farm and its subsystems are treated somewhat like "black boxes." Theses studies emphasize the relationships between inputs and outputs, and subsystems, and often disregard the physical, chemical, and biological transformations and processes themselves. The studies reported by Klepperet et al 1977; Lockeretz et al 1978; Pimentel et al 1983; and Axinn and Axinn 1983 appear to fall into this group.

Pimentel et al (1983) examined the energy and labor efficiency of organic and conventional farms growing corn, wheat, potatoes, and apples. The study was based on previous field work done in Iowa for other studies, and no primary data were collected. The crops were chosen to represent a range of input needs. The energy production ratio, used to compare the energy efficiency of the two farming methods, was the ratio of the caloric potential energy of the output to kcal of inputs. Labor productivity was defined as kilograms of output per man-hour.

It was assumed there were no effective organic means of controlling insects and plant pathogens of potatoes and apples. This led logically to the result that crop losses would be severe, and to the conclusion that organic methods were ten to ninety percent *less* energy efficient than conventional means for the two crops (Pimentel et al 1983). However, as pointed out by Edens and Haynes (1982), Harwood (1985), and Carruthers et al (1986), there is a great difference between an "organic" farming system created primarily by withdrawing chemical inputs from an agroecosystem and replacing them with additional tillage, and one created by completely restructuring an agroecosystem to replace plant and animal diversity at several levels of the agroecosytem hierarchy over time and space.

Based on the study's asumptions, organic techniques of growing wheat and corn were shown to be twenty-nine to seventy percent *more* energy efficient than conventional methods. Labor productivity was lower for all four crops when using organic methods, ranging from twenty-two to ninety-five percent below conventional methods. The authors stressed that the use of energy, crop yield, and labor data from unrelated studies was a major limitation of the report, and recommended field studies to investigate their results (Pimentel et al 1983).

Klepper et al (1977) studied fourteen matched pairs of organic and conventional Corn Belt farms in 1974 and 1975. The organic farms were large-scale, mechanized farms that differed from the conventional farms in the use of synthetic fertilizers and pesticides. All farms in the study raised both livestock and field crops. The organic farms were selected by word of mouth, and represented a judgement sample of case studies. Conventional farms were matched to the organic farms on the basis of soil types, farm size, and livestock inventories. All the conventional farmers were "top managers", as judged by local Agricultural Stabilization and Conservation Service (ASCS) personnel, to avoid biasing the results towards the organic farmers. The researchers stated that the matching procedure was largely qualitative, with considerable room for differences between matched farms (Klepper et al 1977).

Among the measures used to gauge the relative performance of the farms in Klepper's study were the energy intensity of crop production (measured in British Thermal Units (BTUs) per dollar of crop output, BTUs per acre of cropland, and BTUs per bushel of output), labor requirements per acre and per $1,000 of crop out, and crop yields per acre. The authors stated their results were preliminary and essentially qualitative. Measured both in British Thermal Units (BTUs) per dollar of crop output, or in BTUs used per acre of cropland, the conventional farms were over twice as energy intensive as the organic farms. In addition, corn raised by the conventional group consumed from 2.7 to 2.8 times as much energy per bushel as organic corn (Klepper et al 1977).

For soybeans, one year the conventional group was 1.5 times more energy intensive than the organic group; the next year, because of higher conventional yields, organic soybeans required roughly 1.2 times more energy per bushel than conventional soybeans. In research based on the same data, Lockeretz et al (1978) found no significant differences between organic and conventional soybean and corn yields.

The organic farms in this study required about 3 percent more labor per acre, and aproximately 11 percent more labor per $1,000 of crop output. The difference was greater when expressed in labor input per dollar of crop output because the organic farms had fewer acres in high value crops such as corn and soybeans (Klepper et al 1977).

Dobbs et al (1991) compared a conventional and an alternative farms in east-central South Dakota. Most of the alternative farm's cropland qulifies as organic under criteria used in South Dakota and neighboring states.

Corn and soybean yield data and soil samples were collected from random field samples, and yield and soil test data were analyzed statistically by using years as replications. Differences between corn and soybean yields were not statistically significant, ($p > 0.05$). This agrees with Lockeretz et al (1978), which also found no significant differences between organic and conventional corn and soybean yields.

The alternative farm required 58% more labor than the conventional farm (Dobbs et al 1991). No reasons for the higher labor requirements were given.

Conventional farming was more profitable on average for the conventional farmer in this study when organic premiums were ignored, and for a variety of premium scenarios as well. Corn and soybeans averaged 83% of the conventional farmer's land crop, as compared with 49% of the alternative farm's acreage, the primary reason for the income discrepancy (Dobbs et al 1991). Case studies underway for farms in other regions may give different results. A whole-farm economic analysis based on experiment station trials at SDSU's Northeast Experiment Station showed that alternative systems are more competitive than did the case study covered here. Small grains make up a larger proportion of conventional farms' acreage in the experiment station study, and so it appears that under current federal farm programs, the greater the role of small grains in a conventional system, the more economically competitive alternative systems are likely to be (Dobbs et al 1991).

Chou (1993) examined low-input and conventionl farming systems in terms of their energy and economic sustainability. He compared data gathered for the Rodale Farming System Trial from two low-input systems—one cash grain system and one with animals—and one conventional system, which used petrochemical based fertilizers and pesticides. He found that both of the low-input systems required one-half of the nonrenewable energy required by the conventional system. Food and biomass energy production were highest in the low-input animal system, while the low-input cash grain system showed the greatest stability of energy productivity and net income, defined as the inverse of the coefficient of variation of the relevant variable (Chou 1993).

Chou (1993) determined that the energy productivity of the two low-iput systems, measured as calories produced per unit of nonrenewable energy input, was significantly higher than conventional energy productivity. However, net returns above variable costs were significantly higher for the conventional system. This was attributed primarily to the lower fertilization and pest control costs on the conventional system (Chou 1993).

Energy Analyses of Individual Organisms and Soil Ecology

Research on lower levels of the agroecosystem hierarchy focuses on individual plots and organisms, and on soil ecology. This is not to say that such research is intrinsically any less wholistic or systems-based than research on higher levels—soil ecology is no less complex than forest or watershed ecology. Such approaches are in keeping with the philosophy of moderate reductionism advocated by Bunge (1977) and adopted in this paper. Certain emergent properties will only be understood if studied at these levels. Reganold, Elliot, and Unger (1987); Patten (1982); Coleman, Cole, and Elliot (1984); and Hendrix et al (1986) are a few examples of this type of study.

Solar energy is usually not included in energy budgets, or is mentioned briefly, and then set aside. It seems to have most often been treated as a constant or given factor. Research in the physiological ecology of crops suggests a more complicated role. Early studies of photosynthesis tended to be based on the concept of multiple limiting factors, as proposed by F. Blackman in the early 1900s, in which plants respond to increased inputs of only the most limiting factor until another factor becomes limiting (Hall, 1990). More recent studies show that photosynthesis is often limited by multiple and simultaneous plant and environmental factors (Van Caemmerer and Farquhar, 1984; Hall, 1990).

Increases in productivity through plant breeding in many field crops have been achieved by increasing the harvest index—the ratio of seed yield to total biomass—and there has been little or no increase in photosynthetic efficiency (Gifford, 1986; Hall, 1990). In fact, Mitchell (1984) reported that the photosynthetic rate of wheat leaves has fallen during its domestication and breeding. Wild relatives of wheat, sorghum, coton, and pearl millet all have higher maximum light-saturated CO_2 exchange per leaf area than modern cultivars (Mitchell 1984).

Several studies have shown large differences in photosysnthesis between soybean varieties, but only one study related the differences to diferences in yield. Similar results were found for sugarcane yield and photosynthesis. Eagles (1984) writes that this decrease in the photosynthetic rate for wheat has been compensated for by an increase in flag leaf area, so photosynthesis per flag leaf has risen considerably. This indicates an important relationship between yield and leaf size. Studies suggest that total leaf area available for light interception may be a more important determinanat of yield than the photosynthetic activity of the area (Eagles 1984).

The net conversion rates by intensively managed crops of photosynthetically active radiation to chemical energy in the form of carbohydrates falls in a range of 2.1-3.4 percent (Hall, 1990.) Pimentel (1980) states that corn, one of the more efficient plants, converts about 1.2 percent of insolation into biomass, and aproximately .4 percent into grain.

The largest single pathway in terrestrial ecosystems is usually the detritus pathway. That is, more energy is captured and flows through detritus systems than through primary and secondary producers. Its mass is in the same range or larger than plant biomass in virtually all terrestrial ecosystems, if humus is regarded as detritus (Reiners 1983). This means understanding detritus and soil systems is crucial to understanding energy flows in agroecosystems.

Coleman et al (1984) state that a major pulse of CO_2 into the atmosphere, between 1850 and 1890, was recorded by changes in carbon isotope concentrations in bristle-cone pines. This was prior to major outputs from combustion of coal and petroleum, and was almost certainly due to the decomposition of soil organic matter (SOM) as prairie lands were first cleared and plowed around the world. They estimate storage of carbon in SOM at four times that of the living biota or the present CO_2 content of the atmosphere.

Hendrix et al (1986), studying detritus food webs, found that no-tillage appears to increase the importance of fungi relative to bacteria as primary decomposers, and thus as the resource base for the detritus food web. No-till soils are usually physically and chemically stratified, with more nutrients closer to surface.

Plowing creates conditions favorable to bacteria-based food webs, composed of disturbance-adapted organisms with high metabolic rates. This is associated with faster decomposition of organic matter and greater nutrient mobility than in no-tillage systems. There are also distinct seasonal variations in detritus food webs, based on substrate quality and ambient temperature and moisture conditions (Hendrix et al 1986).

Reiners (1983) states that the apportionment of energy flow to different pathways under different disturbance patterrns is a fundamental question. Because of the size of the detritus pathway, the status of detritus following disturbance is therefore one of the most important indices of disturbance severity and recovery potential. In general, he concludes that detritus mass decreases as a function of disturbance frequency. Ecosystem quality can deteriorate, be maintained, or even improve with increasing frequency of disturbance. He cites some humid pasture lands as definitely improving under disturbance (grazing), though he suggests it will maximize at a particular frequency, and decline if disturbed more often Reiners (1983).

Elliot et al (1984) found that the mineralization of N, P, and other nutrients through microbial primary and secondary production and consumption influences energy flow in at least two ways. It controls the influx of energy by regulating primary production through the availability of limiting nutrients, and, it controls decomposition rates as nutrient availability interacts with substrate quality.

Because of the high production efficiencies of some of these forms, especially protozoa, food chains longer than the usual four or five links are possible. The interactions of these life forms has been shown to enhance nutrient uptake and plant yield from 30% to 100% in microcosm experiments.

Some studies have shown that grazers enhanced plant growth more in bacterial than in fungal systems. Considerable quantities of soluble organic carbon are released into soil by plant roots in at least some agroecosystems. Theses inputs may be as high as 20% of total plant dry matter or 40% of carbon translocated to the roots. Carbon losses may occur from lysis of root cell walls rather than actual exudation. Microorganisms usually have higher densities near roots than in root-free soils, clustering for access to the organic compounds resulting from root exudation. This phenomenon has been demonstrated for bacteria, fungi, and protozoa. Microflora compete with primary producers for mineralized nutrients, particularly in the rhizosphere. The authors hypothesize that plant exudates stimulate bacterial production. Producers immobilize N and other nutrients, including sources unavailable to the plant root. The increase in producers stimulates grazing, which increases mineralization, taken up by the plant root. The result is that plants effectively increase their sphere of nutrient uptake compared to regular root activity (Elliot et al 1984).

In early stages of decomposition, particularly if the material has a wide C:N ratio, any exogenous N will be immobilized until enough respiration has occurred to bring ratios down to about 20:1. When N fertilizers are added to crops, photosynthesis and carbon immobilization usually increase, but fertilization can also lead to increased SOM decomposition with concomitant release of CO_2, due to the creation of C:N ratios more favorable for decomposition (Rosswall 1981). Phosphorous cycles in the soil seem to follow immobilization and mineralization processes similar to those discussed for N, though P becomes immobilized in stable and occluded inorganic forms more readily than N.

Studies have shown very different amounts of nitrifiers [NH_4^+ to NO_3^-] and denitrifiers [NO_3^- to N_2 and H_2O] in no-till compared to conventional till. These trends showed a 2 to 20 fold increase in nitrifiers and a 3 to 43 fold increase in denitrifiers in no-till compared to plowed fields. The authors think there may be some long-term benefits in terms of mineral N availability and timing under no-till, possibly as a result of better "management" of microbial populations, in addition to other advantages of no-till, such as maintaining SOM. Improved management of soil microbial populations will lead to more cost-effective, efficient agriculture.

Coleman et al (1984) state that in general there is high variability in the types and amounts of organisms colonizing decomposing material, that is due to a considerable stochastic element that has not been fully appreciated. Rosswall (1981) points out that soil bacteria show very rapid fluctuations in numbers over just a few days, especially after rainfall.

In a study of the long-term effects of organic and conventional farming on soil quality, Reganold et al. (1987) compared a farm managed without inorganic fertilizers since 1909 with a conventional farm that had been using recommended rates of synthetic fertilizers and pesticides since the 1950s. The organically farmed soil had significantly higher organic matter content, thicker topsoil depth, and lower soil erosion than the conventionally farmed soil. The organically farmed soil also had significantly higher microbial biomass, significantly higher polysaccharide content (they serve as active binding agents in soil agregate formation, and help stabilize agregates), and it had a significantly lower modulus of rupture (an index related to surface hardness, and so to seedling emergence). Lockeretz et al (1981) found that that water erosion, based on rotation effects alone, was about two-thirds of the erosion on the conventional farms. Water erosion on the organic farm studied by Reganold et al was almost one-quarter of the conventional rate. Dobbs et al (1991) found that soil organic matter was significantly higher on the organic farm as well.

CHAPTER FOUR
RESEARCH APPROACH

This chapter will describe the research approaches used in this study. The assumptions on which the study rests will be explained, along with data gathering and analysis techniques.

Selection of the Organic Farm

The organic farm was selected from a population of organic farms within a one county radius of Ingham County. Conversations with members of the Michigan Agricultural Stewardship Association, Ingham County Cooperative Extension (CES) personnel, and Michigan State University (MSU) researchers led to a meeting with the organic farmer chosen. At this first meeting the goals of the research study, data and time requirements, and confidentiality of the results were discussed. The organic farmer selected was chosen because his farm is a mixed-enterprise dairy and cash grain operation, the farm is relatively close to the university, the farmer is very knowledgeable about organic farming methods, and perhaps most importantly, he is willing to work with the researcher.

Use of a Composite Conventional Farming System

The decision to compare an actual organic farm with a composite conventional farming system was based on several considerations. It proved difficult to locate a suitable conventional dairy/cash grain farmer willing or able to work within the time constraints of the researcher. It was felt that a composite conventional farming system would allow a closer match to the size and scale of the organic farm. Insofar as the organic farm chosen is representative of a class of organic farms, use of a composite conventional system allows comparison of organic methods with a variety of conventional alternatives by changing the assumptions defining the conventional system.

System Boundaries

The organic farm's legal boundaries are defined as the boundaries of the physical agroecosystem. Flows of energy and materials across these boundaries are considered as imports or exports of the organic farm agroecosystem.

The physical components of the farming system are divided into subsystems. Energy, labor, and material inputs and outputs are allocated to subsystems. The organic farm is defined as having a crop subsystem, an animal subsystem, a pasture subsystem, and a natural environment subsystem. Transfers between subsystems are traced to analyze labor and energy sources, flows, and sinks, in order to compare them to corresponding flows on conventional farms. See Figure 2.X in Chapter 2 for a representation of the organic farm agroecosystem.

The crop subsystem consists of those farm areas on which the farmer grows crops for sale off-farm, for animal feed, or for nutrient capture and cycling purposes. Inputs of interest to the crop subsystem include the farmer's labor, manure, seed, farm machinery, and diesel fuel.

The animal subsystem is composed of all animals raised on the farm for commercial purposes—dairy cows and replacements. Approximately 60 chickens are also raised for egg production, but were not included in the study. The animal subsystem includes the farm buildings and machinery dedicated to the animals, and inputs to and outputs from the animals. Feed, electricity, and machinery and equipment are principal inputs to the animal subsystem.

The pasture subsystem is made up of the farm areas used for permanent pasture systems, and **does not include cropland** used to graze dairy cattle or to raise fodder.

The natural environment subsystem contains the areas of the farm populated by non-commercial trees, shrubs, forbs, and grasses, as well as the areas populated by natural means, and not by direct human intervention. It includes vegetated fence rows, tree corridors, the creek flowing through the property and the area bordering it, and other areas populated as described above.

The farm household subsystem encompasses the farm family, the farmhouse, and the barns and storage areas, which are located within approximately 100 meters of the farmhouse.

Data Collection Methods

Data describing the organic farm were collected from a number of sources. Published soil surveys and topographical maps (SCS 1979, USGS 1979) were consulted for information on the farm's soils and topography. Much of the remaining information was collected from personal interviews with the farmer and his wife during farm visits.

Farm visits and interviews provided detailed information about crop rotations, input levels, crop and animal production levels, and management methods. The farmer also recorded information on crop and animal inputs and outputs on prepared forms, and reviewed these forms with the researcher, at which time additional information was gathered and clarifications were made. Data were gathered at the field and farm levels, and then converted on a per-hectare basis.

The organic farmer has conducted on-farm research projects and comparisons under the auspices of a program of the American Farmland Trust and the Michigan Agricultural Stewardship Association (AFT 1992; AFT 1991). Data from these studies were analyzed and also served to verify information collected during this study.

Information about conventional dairy and cash grain farms in Ingham County was gathered from county, state, and national records. Crop and milk production data were collected from Michigan Agricultural Statistics, the U.S. Census of Agriculture, and the Dairy Herd Improvement Association (DHIA). The Sycamore Creek Watershed Plan provided data on typical farming practices and rotations in the county. The Ingham County Cooperative Extension Service (CES) provided data on dairy farming practices in the county as well.

Calculation of direct and indirect energy inputs and outputs

Inputs to farms and farm subsystems were converted to units of kilocalories using formulas and values from a variety of publications (Pimental, 1980; Smil, Nachman, and Long II, 1983; Lockeretz, 1977; Stout, 1990; Stanhill, 1984; Gillespie and Klemme, 1991; Nott et al, 1991; and others as cited). The energy values of different materials cited in the literature are usually average values that depend on assumptions about variables such as the extraction, manufacturing, transportation, and application methods used. The primary criteria used to select values for this study were that the values are representative of south-central Michigan, and consistent between authors.

The general approach taken, consistent with the literature, was to include the average direct and primary indirect energy costs of producing and transporting an input onto a farm. The direct energy costs of anhydrous ammonia, for example, include the energy consumed during the manufacture, storage, and transportation of anhydrous ammonia (direct costs), as well as the energy costs for the extraction and production of the feedstocks for the manufacturing process, and the costs of generating the energy needed for the fertilizer production process (primary indirect costs). Secondary indirect costs, such as the costs of producing the energy extraction and generation equipment, were not included. Energy consumed by the farm family to maintain their home, including personal transportation, was not included in this analysis.

Internal and External Energy Resources

All inputs to farm enterprises are considered as coming from either external or internal sources. The farm system boundaries discussed earlier in the chapter are used to make this determination. The principal internal resources for the organic and conventional farming systems are animal manure and seeds. The seed for wheat production on conventional systems is assumed to come from internal sources, so as to avoid biasing the comparison against conventional systems. For this reason, conventional wheat producers relying on off-farm seed could have lower energy output to input ratios than given in this study.

Fertilizers and Manure

The embodied energy of commercial fertilizers was calculated from values in the literature, and includes the energy needed to process raw material feedstocks, and to manufacture and transport the finished product. An embodied energy value for dairy manure was calculated on the basis of data and assumptions concerning its nutrient content, and by assigning an energy content equivalent to that of a comparable mix of synthetic fertilizers (after Smil, Nachman, and Long, 1983; Stout, 1990). The values for the nutrient content of dairy manure were derived from the literature (Stout, 1990) and county dairy manure analyses (CES, 1993). (Table). Values were determined for fresh manure because the 1988 Northern U.S. Dairy Farm Survey found that daily hauling of manure to fields was the most common method of manure handling in Michigan (MSU-AES 1990). The calculation for the energy content of the fresh dairy manure agrees very closely with the average energy of dairy manure calculated in Stout (1990), taking into account assumptions on the amount of nitrogen in fresh manure.

Table 4.1 The Nutrient Content and Embodied Energy of Dairy Manure as a Fertilizer

NUTRIENT	MANURE, FRESH (23% DRY MATTER)	ENERGY VALUE OF DAIRY MANURE AS A FERTILIZER (KCAL/KG OF FRESH MANURE
Nitrogen, Total	0.90%	
Nitrogen, Available	0.30%	53
Phosphorous (P205), Total	0.29%	
Phosphorous (P205), Available	0.16%	19
Potassium (K20), Total	0.92%	
Potassium (K20), Available	0.69%	22
TOTAL ENERGY CONTENT (KCAL/KG of Fresh Manure)		57

Table 4.2 The Embodied Energy of Commercial Fertilizers (from Lockeretz, 1980)

FERTILIZERS	Kilocalories per Kilogram Actual Nutrient (Kcal/Kg)
Anhydrous Ammonia	12000
Urea	14300
Ammonium Nitrate	14700
Superphosphate	2300
Triple Superphosphate	3000
Potassium Sulfate	1600

One-half of the energy "cost" of manure spread on fields was allocated to the respective cropping systems. The entire value was not allocated, because the organic farmer does not rely completely on manure for nutrient inputs, nor would he import comparable quantities of manure or synthetic fertilizers if he sold his dairy herd. In a similar fashion, one-half on the energy cost of spreading manure was allocated to the appropriate crop systems, and the other half was considered to be a cost of operating a dairy herd. These method were chosen after discussing them with the farmer, and reflect most accurately how and why he uses manure.

The fertilizing practices of at least some conventional dairy farmers in the county also support this method. Having calibrated their manure spreaders and tested their manure, these dairy farmers first apply manure, and then applyd synthetic fertilizers to bring their nutrient applications up to the levels recommended in their soil tests (CES, 1993). The chief value of the manure was its nutrient content, and without it they would have applied an equivalent amount of synthetic fertilizers. At the same time, they are obligated to dispose of their dairy manure in one manner or another.

Pesticides

The organic farmer used no synthetic or naturally derived pesticides during the four years studied. Conventional farmers in the county used a number of different herbicides during the same period (CES 1992). Because the embodied energy values of all the individual pesticides used are not available, average values for the production, formulation, packaging, and transportation of herbicides were used (Pimental 1980).

Table 4.3 The Embodied Energy of Selected Herbicides (Pimental, 1980)

HERBICIDES	Kilocalories per Kilogram Actual Ingredient (Kcal/Kg)
Fonofos	99910
Metolachlor	99910
Cyanizine + Atrazine	88150
Dimethoate	99910
Chlorpyrifos	99910

Fuel

All traction on the organic farm is supplied by diesel fuel consuming equipment. Fuel consumption was calculated from consumption rates given in extension and university enterprise budgets and energy audits (Helsel and Oguntunde, 1981; Griffith and Parsons, 1983; Siemens, Griffith, and Parsons 1985). The fuel consumption for conventional farms was based on these same values, and on standard and typical tillage and cultivation practices for the crop in question as described in the Sycamore Creek Watershed Plan and the aforementioned enterprise budgets.

Table 4.4 Fuel Consumption for Conventional Farms (Lockeretz, p.128; Stout, p.223)

FUEL	UNITS	KCAL/UNIT	PRODUCTION INPUTS	TOTAL
Diesel	Liters	9235	2179	11414
Electricity	Kilowatt Hours (kwh)	859	2004	2863

Farm Machinery

The energy embodied in farm machinery and its consumption by different crop systems was determined in the following manner. The average amount of energy per kilogram required to manufacture and maintain a farm machine was taken from the literature (Chou, 1993; Doering, 1980). The kilograms of farm machinery consumed per hectare was estimated from the weight of the machinery needed for the operation, the average useful life of the machinery, and the time required for a given operation.

The organic farmer gave the size and type of machinery used in his operations during interviews, and values for a similar conventional operation were derived from Wisconsin enterprise budgets for four-row crop enterprises and other literature sources (Chou, 1993; Gillespie and Klemme, 1991a and 1991b; Scott and Krummel, 1980; Fuller et al, 1992). A list of machinery used, their weights, useful lifetimes, and the time required for a given field operation are given in Table 4.5.

Seeds

The value of seeds is directly related to their ability to produce a future crop of a certain quality. Their importance to a farming system far exceeds their embodied energy. They are better considered as triggering devices, for which a small energy input can lead to energy outputs several orders of magnitude higher. For this reason the energy value of seeds is best determined from the energy needed to produce seed crops, rather than from the enthalpy of the seed itself. Unfortunately, this data is not always available.

Various sources were used to arrive at values for the embodied energy content of seeds used in crop production (Table 4.6). Heichel (1980, in Pimental, 1980), is one of the few sources of information on the energy required to produce, process, and distribute crop seeds. However, the embodied energy values he gives for some small grain seeds were equal to or less than values given for the output energy or enthalpy of the grain in other papers in the handbook, which makes no sense. For this study the seed energy of these small grains was estimated as the enthalpy of the grain plus ten percent.

The embodied energy content of hairy vetch seed was taken from values determined for alfalfa seed in Heichel, (1980, p. 31). He presents data linking seed costs with embodied energy content, and as the market costs of hairy vetch and alfalfa seed are roughly comparable, the alfalfa seed value was used.

Table 4.5 Machine Embodied Energy

MACHINES	OPERATIONS	OPERATIONS (Hrs./ha)	MACHINE WEIGHT (Kg)	EQUIPMENT LIFE (hours)	KG/HA	KCAL/HA
130 hp 6-cylinder diesel Tractor	Moldboard plow, Disk, Field Cultivate, Apply Anhydrous Ammonia (NH3), Apply other fertilizers, Roller harrow, Rotary hoe, Bale, Haul Alfalfa		5100	10000		
70 hp 4 cylinder diesel Tractor	Spread manure (5 ton), Rotary hoe,Row cultivate, Drill grain, Broadcast plant, Apply herbicides, Mow/Condition, Rake, Haul grain		2250	10000		
4 Row Combine	Harvest corn grain, Harvest soybean, Harvest small grains		7720	2000		
Pick-up truck	Haul alfalfa, Haul grain		2000	10000		
6 bottom Moldboard Plow	Moldboard plow	0.25	1125	2000	0.662	11926
Tandem Disk 14 ft.	Disk	0.13	1950	2000	0.460	8256
Field Cultivator 20 ft.	Field cultivation	0.25	2000	2000	0.934	16790
Manure Spreader	Spread manure	0.83	753	1200	1.750	31597
Anhydrous Ammonia Applicator	Apply Anhydrous Ammonia	0.11	2000	1200	0.598	10757
40 ft.Fertilizer Spreader	Apply other fertilizers	0.03	4000	1200	0.284	5128

Table 4.5, (cont'd).

Roller Harrow (15 ft.)	Roller harrow	0.13	1750	2000	0.427	7700
15 ft.Rotary Hoe	Rotary hoe	0.10	600	2000	0.166	2969
24 Wide Row Cultivators	Row cultivate	0.13	800	2000	0.193	3475
4 row planter	Row plant	0.17	100	1200	0.126	2286
21 hole, 7.5 inch grain drill	Drill grain	0.13	870	1200	0.294	5282
Broadcast seeder	Broadcast plant	0.05	150	1200	0.044	778
30 ft. Sprayer	Apply herbicides	0.08	3000	1200	0.561	10100
9 ft. Mow/Condition	Mow/Condition	0.25	980	2000	0.442	7950
2 hay rakes	Rake	0.17	300	2000	0.156	2780
Baler with ejector	Bale	0.04	1650	2000	1.320	23751
4 Row Combine	Harvest corn grain and soybeans	0.28	7720	2000	2.664	47956
4 Row Combine	Harvest small grain	0.25	7720	2000	2.385	42921
Hay wagon	Haul alfalfa	0.20	500	10000	0.188	3380
Gravity Boxes	Haul grain	0.20	500	2000	0.222	4003
Elevator/ Conveyor	Store alfalfa	0.25	500	1200	0.257	4633

Table 4.6 The Embodied Energy Content of Seeds Used in Crop Production (Heichel 1980)

SEED	KILOCALORIES PER KILOGRAM (KCAL/KG)
Corn	24806
Soybeans	7584
Winter Wheat	3630
Alfalfa	43620
Rye	3340
Hairy Vetch	43620
Oats	4108

The organic farmer supplied much of the seed he needed for grain and cover crops from previous harvests. For these crops the seed energy was treated as an energy cost for the enterprise, generated from internal resources.

Labor Inputs

Labor inputs for the organic farming system were calculated from information obtained in interviews with the farmer, and are presented in the following chapter on results. One hour per acre of labor overhead was allocated to each organic crop enterprise to allow for a direct comparison with labor values from Wisconsin crop enterprise budgets.

Several different values for labor inputs to conventional crop and dairy systems were calculated for comparative purposes. Michigan crop and livestock enterprise budgets values were used to calculate one value (Nott et al, 1992; Nott, 1991). Crop and dairy enterprise regression formulas for Michigan farms were used to generate another value (Nott et al, 1992; Nott, 1991). Wisconsin crop enterprise budget figures were used to determine a third value for crop enterprises (Gillespie and Klemme, 1991a and 1991b). Michigan Telefarm project data was used to generate a value for labor inputs to the animal portion of a dairy system (Nott, 1991).

Farm Outputs

Crop yields for the organic farm are the farmer's estimates, based on his recollection, farm records, and the records of on-farm research studies (AFT, 1992; AFT, 1991) Figures for milk production on the organic farm are from dairy cooperative records. Yields for conventional farms were taken from Michigan Agricultural Statistics for the years studied. The caloric content or enthalpy of the outputs was calculated from crop and dairy yields and the average energy content of the output studied.

Table 4.7 Average Energy Contents of Farm Outputs

ENERGY OUTPUTS	KCAL/KG	SOURCE
Corn grain	3550	(Odum, 1984 in Stanhill, pp.24-51)
Soybeans	4021	(Pimental, 1980)
Wheat	3300	(Pimental, 1980)
Alfalfa Hay	2713	(Pimental, 1980)
Milk, Fluid	.703	(Kaffka, 1984, for 3.5% Holstein milk)

Standardizing Yields for Soil Types

A common problem faced by agricultural researchers is the comparison of productivity data for crops grown on soils of varying fertility. It is suggested that crop yields can be presented as a percentage of the potential yield of the soil, thus allowing a direct comparison of relative crop production. For the purposes of this study the potential yield or productivity of a particular soil type is defined as the yield of a given crop possible on a particular soil type under a high level of management, as listed in the SCS soil survey of Ingham County (SCS 1979).

Using this method, for example, we find that the potential yield for corn grain grown on Adrian muck (Ad) is 95 bushels/acre. The potential corn grain yield on Aubbeenaubbee-Capac sandy loam, 0 to 3 percent slope, (AnA) is 145 bushels/acre. A yield of 90 bu/acre on Ad soil thus represents 95 percent of the potential yield of the soil, while a yield of 120 bu/acre on AnA soil represents 83 percent of the potential yield of the soil. It is argued that higher percentages of the potential yield of a soil represent more intensive management of the soil resource.

This method can be applied in any situation where the soil types and the potential yield for the necessary crops are known, and allows at least a first order comparison between qualitatively distinct soils. It can also be used on a patchwork of soils, such as a farm, if the relative proportion of each soil type in the area of interest is known. This method will be used to compare the organic farm and Ingham County crop yields in the following chapter.

CHAPTER FIVE
RESULTS

The results of comparisons of crop and dairy yields, energy inputs and outputs, and labor flows are presented in this chapter. The results will be discussed and interpretations will be presented. Crop and dairy yields will be considered first, followed by results of the energy flow analyses. Labor flows will be the third and final area of the study examined.

Crop and Dairy Yields

The average crop yields and milk production data for the organic farm, together with Michigan and Ingham County average yields, are given in Table 5.1. The same information is presented in graphical form by individual enterprises in Figures 5.1-5.5.

The table and figures show that the organic farm crop yields were lower than state and county averages for corn, soybeans, and winter wheat. While perhaps not readily apparent from the figure, organic alfalfa yields were also lower than the Michigan average.

Two reasons are advanced to explain some of the difference between soybean yields on the organic farm, and state and county average yields. The organic soybeans are grown for soymilk and tofu production, and the variety grown for this purpose has been demonstrated to yield less than soybeans grown for feed and oil (anonymous, 1993). The second reason for lower soybean yields on the organic farm is that they are grown in 38-inch rows for greater ease of mechanical cultivation, compared to the more typical 30-inch rows on conventional farms, resulting in lower plant populations and production.

A Student's t-test statistical comparison of the organic yields with the state and county averages showed that, for **all** the crops studied, the organic yields were **not** equal to the state or

Table 5.1. Selected Crop Yields for Organic and Conventional Farming Systems from 1989-1992.

Crop Yields, in kg/ha and as a percent of potential yield					
CORN	**ORGANIC kg/ha**	**ORGANIC % of Potential Yield**	**MICHIGAN kg/ha**	**INGHAM COUNTY kg/ha**	**INGHAM COUNTY % of Potential Yield**
1989	5166	65%	7093	7582	110%
1990	5136	69%	7218	7564	110%
1991	4712	59%	6904	7338	107%
1992	5649	83%	6591	6534	95%
SOY	**ORGANIC kg/ha**	**ORGANIC % of Potential Yield**	**MICHIGAN kg/ha**	**INGHAM COUNTY kg/ha**	**INGHAM COUNTY % of Potential Yield**
1989	1681	64%	2421	2892	130%
1990	1749	70%	2556	2697	122%
1991	2421	106%	2556	3141	142%
1992	1076	43%	2219	2522	114%
WINTER WHEAT	**ORGANIC kg/ha**	**ORGANIC % of Potential Yield**	**MICHIGAN kg/ha**	**INGHAM COUNTY KG/HA**	**INGHAM % of Potential Yield**
1989	2354	70%	3565	3443	97%
1990	0	-	3699	3975	111%
1991	0	-	2892	2609	73%
1992	3363	66%	3766	3739	105%
ALFALFA	**ORGANIC kg/ha**	**ORGANIC % of Potential Yield**	**MICHIGAN kg/ha**		
1989	3965	75%	3660		
1990	3558	90%	3965		
1991	3965	101%	3965		
1992	3558	95%	4066		
MILK	**ORGANIC kg/cow**	**Not available**	**MICHIGAN kg/cow**	**INGHAM COUNTY kg/cow**	
1989	6777	-	6801	6777	-
1990	7748	-	6900	6858	-
1991	6669	-	6991	6967	-
1992	6740	-	7088	7058	-

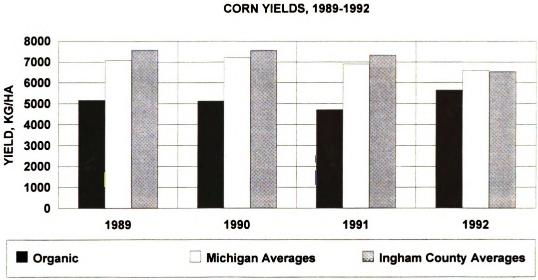

Figure 5.1 Corn Yields From 1989 to 1992 for Organic and Conventional Farming Systems

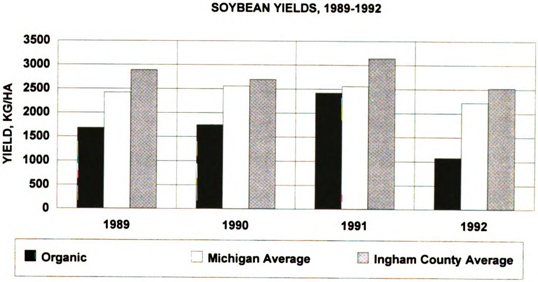

Figure 5.2 Soybean Yields form 1989 to 1992 for Organic and Conventional Farming Systems

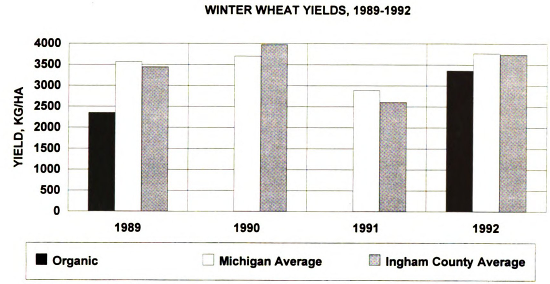

Figure 5.3 Winter Wheat Yields from 1989 to 1992 for Organic and Conventional Farming Systems

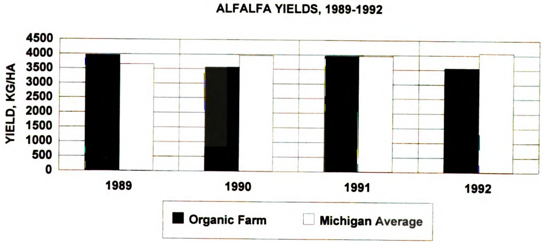

Figure 5.4 Alfalfa Yields from 1989 to 1992 for Organic and Conventional Farming Systems

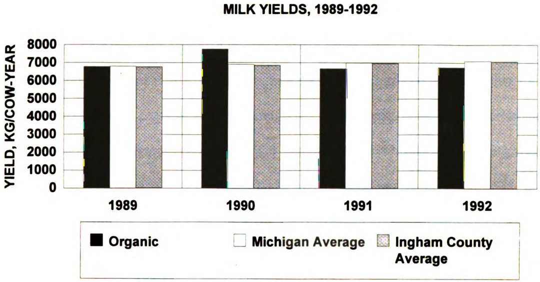

Figure 5.5 Milk Yields from 1989 to 1992 for Organic and Conventional Farming Systems

county averages, but were in fact lower ($p < .05$). A potentially significant limitation of this test is that the data used to calculate Michigan and Ingham County averages were not available, and so the actual variance and standard deviations of the county and state samples were unavailable. Instead, the variance and standard deviation of the state and county **averages** were used, leading to much lower values for both statistics. It could be that alfalfa yields on the organic farm would be found to be equal to the state average if the true sample variance and standard deviation were available. There is little doubt that corn, wheat, and soybean yields on the organic farm were significantly lower than the state and county averages.

These results do not support Hypothesis 2, which stated that the organic farm crop yields would equal Michigan averages. They instead support an alternative hypothesis that organic crop yields are lower than both Michigan and Ingham County averages. It is illuminating at this point to examine the yield results as a percent of potential yield.

Table 5.1 shows crop yields as a percent of potential yield for Ingham County and the organic farm. Potential yield figures are unavailable for the state as a whole. The results indicate that county average yields for corn grain between 1989 to 1990 were near or above 100 percent of the potential yield, implying intensive management of the soil. An alternative explanation is that farmers in Ingham County plant corn preferentially on higher quality soils, meaning that the county potential yield for corn, based on all county soils, is an underestimate. County potential yield figures are based on SCS data from 1979 and earlier, which means as well that figures for the estimated yields possible under high levels of management, on which the potential yield figures are based, cannot take into account yield increases due to crop varieties developed after 1979.

Ingham County average soybean yields, expressed as a percent of the potential yield, were even higher. They ranged from a low of 114 percent of the potential county average yield in 1992 to a high of 142 percent in 1991. The author suggests that these figures represent indirect evidence for the preferential planting of soybean crops on better quality soils, and/or the use of higher-yielding soybean varieties compared to those available in 1979.

Because figures on hay production are not collected at the county level, data on alfalfa hay yields for 1991 and 1992 from three conventional Ingham County dairy farms were gathered from the county extension office for the purposes of discussion. All three farms participate in the Sycamore Creek Watershed Project, and from the researcher's point of view were selected essentially at random. A county agricultural agent characterized farm management for all three as above average or better (Jack Knoreck, personal communication). Actual yields ranged from

4 to 6 tons/acre. Alfalfa hay yields as a percent of the potential yield for their soils ranged from 56 to 86 percent, averaging 71 percent. Organic alfalfa yields as percent of potential yield for the particular soils for the same two years were 101 percent and 95 percent, respectively. The organic farm alfalfa yields as a percent of potential yield were higher than the respective values for corn, soybeans, or wheat, suggesting the organic farming system may enjoy a competitive advantage for alfalfa relative to other crops.

Milk production per cow on the organic farm was found to be equal to the state and county averages. It was not expected that milk yields on the organic farm would differ from those on conventional farms, and this appears to be the case. This supports Hypotheses 3, which proposed that milk yields from organic farms will equal Michigan averages.

Energy Inputs, Outputs, and Flows

In this section external and internal inputs to individual organic and conventional crop systems and rotations are compared, as are their outputs and the ratio of crop outputs to inputs. The share of energy inputs coming from specific categories is examined, and differences between the two farming systems are presented and interpreted. The flow of crop outputs on the organic farm is also discussed briefly.

Solar Energy Inputs

Modern, input-intensive agriculture is still a process of collecting and concentrating solar energy. Insolation, or incoming solar radiation, to both cropping systems was estimated at 8.34E+09 kcal/ha for corn and soybeans (1 May-31 Oct)[6], 9.97E+09 kcal/ha for winter wheat (1 Oct-31 July) and at a yearly total of 1.26E+10 kcal/ha for alfalfa (after Stout, 1990; Smil, Nachman, and Long, 1983). These figures are based on radiation incident on a horizontal

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Although the growing season in south-central Michigan does not extend to the end of October, farmers nonetheless rely on solar energy to dry corn and soybean crops in the field, and may leave crops in the field much later than October 31.

collecting surface, and so are almost certainly underestimates.[7] This input is well over 1000 times all other energy required by conventional corn, the most energy demanding crop in this study. Seen in this light, human-controlled energy inputs to cropping systems take on the appearance of control inputs, relatively small yet influential inputs, meant to assist in the management of much larger flows.

Energy Inputs and Outputs for Individual Crops

Non-solar energy inputs to conventional corn crops were approximately 4.5 million kcal per hectare, 80 percent greater than inputs to organic corn of 2.5 million kcal per hectare. Tables 5.2 and 5.3 shows energy inputs and outputs for the conventional and organic farming systems. Figures 5.6 and 5.7 show energy inputs, external inputs, and outputs to individual crop enterprises, as well as the ratio of crop energy outputs to inputs.

Inputs to organic corn would be even lower, but energy costs of growing a rye/hairy vetch cover crop prior to corn were allocated as a fertilization cost to the organic corn crop. Given that the organic farmer does not grow corn without having plowed down a legume to supply nitrogen (evinced by his decision not to plant corn following a failed hairy vetch crop), it was felt that the cost of growing the corn must include the costs of supplying the necessary nitrogen as well. The organic farmer does plant corn following alfalfa plowdowns, but the alfalfa is raised for forage, and is typically grown as a four year stand. The farmer takes advantage of the nitrogen fixed by alfalfa, but he relies on hairy vetch to supply nutrients for corn on an annual basis.

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This is because the maximum amount of solar energy is captured by collecting surfaces (such as leaves) perpendicular to the angle of incidence of solar radiation. Leaves, by hanging at a variety of angles, can maximize solar energy capture for a greater part of the day.

Table 5.2. Energy Inputs and Outputs by Enterprise on a Conventional Versus an Organic Farm for Corn and Soybeans

ENERGY	CORN ORGANIC	CORN CONVENTIONAL	SOYBEAN ORGANIC	SOYBEAN CONVENTIONAL
INPUTS (kcal/ha)	**kcal/ha**	**kcal/ha**	**kcal/ha**	**kcal/ha**
Insolation	8.34E+09	8.34E+09	8.34E+09	8.34E+09
Machinery	105,360	138,157	113,616	93,908
Fuel (diesel)	769,936	1,049,800	809,374	614,224
Natural Gas	0	0	0	
Fertilizer	30,213	2,057,863	0	289,627
Pesticides	0	887,989	0	223,967
Seeds	417,055	417,055	510,030	510,030
Other	0	0	0	0
Postharvest	0	0	0	0
Subsidy from Other Crops	1,183,292	0		0
All External Energy Inputs	1,426,865	4,004,874	1,433,020	1,731,756
All Internal Energy Inputs	1,079,992	545,990	0	0
All Inputs minus Insolation	2,505,857	4,550,864	1,433,020	1,731,756
OUTPUTS				
Crop Yields (kcal/ha)	18,066,578	24,633,411	7,201,157	9,774,573
OUTPUT/ INPUT	7.21	5.41	5.03	5.64
OUTPUT/ EXTERNAL INPUT	12.66	6.15	5.03	5.64

Table 5.3. Energy Inputs and Outputs by Enterprise on a Conventional Versus an Organic Farm for Alfalfa and Winter Wheat

ENERGY	ALFALFA ORGANIC	ALFALFA CONVENTIONAL	WINTER WHEAT ORGANIC	WINTER WHEAT CONVENTIONAL
INPUTS	**kcal/ha**	**kcal/ha**	**kcal/ha**	**kcal/ha**
Insolation	1.26E+10	1.26E+10	9.97E+09	9.97E+09
Machinery	49,659	64,888	95,886	118,121
Fuel	330,315	397,498	760,338	854,714
Natural Gas	0	0	0	
Fertilization	0	26,900	547,866	1,492,231
Pesticides	0	503,927	0	0
Seeds	183,342	183,342	610,300	406,867
Other	0	0	0	0
Postharvest	0	0	0	0
Subsidy from Other Crops	0	0	0	0
All External Energy Inputs	563,317	1,176,555	856,224	1,904,263
All Internal Energy	0	0	1,158,166	967,670
All Inputs minus Insolation	563,317	1,176,555	2,014,390	2,871,933
OUTPUTS				
Crop Yields (kcal/ha)	22,740,574	23,372,188	8,411,050	11,572,053
OUTPUT/ INPUT RATIO	40.37	19.86	4.18	4.03
OUTPUT/ EXTERNAL INPUT RATIO	40.37	19.86	9.82	6.08

Due to the costs of the rye/hairy vetch cover crop, the distribution of input costs among machinery, diesel fuel, fertilization, and seed costs are similar for the organic and conventional corn crops. Figures 5.8 and 5.9 display the distribution of energy inputs by categories for selected crops for the two farming systems. Pesticide costs for the conventional corn made up almost 20 percent of the energy input, an input avoided in the organic system, while fertilization costs for the conventional corn system were almost 70 percent higher than for the organic corn crop. Interestingly, diesel fuel and machinery energy inputs were 36 percent and 31 percent higher for the conventional system compared to the organic inputs. This was due to the costs of spreading manure from the conventional dairy operation on the corn acreage. Mechanical weed control increased the machinery and fuel inputs to the organic corn, a technique not needed by the conventional system.

The ratio of corn energy output to all non-solar inputs was 7.21 (to 1) for organic corn compared to 5.41 for conventional corn. If the ratio of energy outputs to external energy inputs is considered, the ratio of 12.66 for organic corn is more than double that for conventional corn, 6.15. Internal sources supplied 43 percent of the organic corn inputs (including internal energy from the rye/hairy vetch cover crop), but made up only 12 percent of the inputs to conventional corn.

An unexpected result of this study is that under the study's assumptions conventional soybean crops produced more output energy per unit of energy input, 5.64, than the corresponding organic soybean crops, at 5.03. Over the four years covered in the study soybean yields and energy outputs for the conventional soybeans were nearly 36 percent higher than the organic soybean outputs, more than compensating for the extra inputs of fertilizer and herbicides the conventional soybeans required. The organic soybeans required inputs of approximately 1.4 million kcal; the conventional soybeans had 1.7 million kcal of inputs, 21 percent higher than the organic soybeans. No internal inputs were applied to soybeans under either of the farming

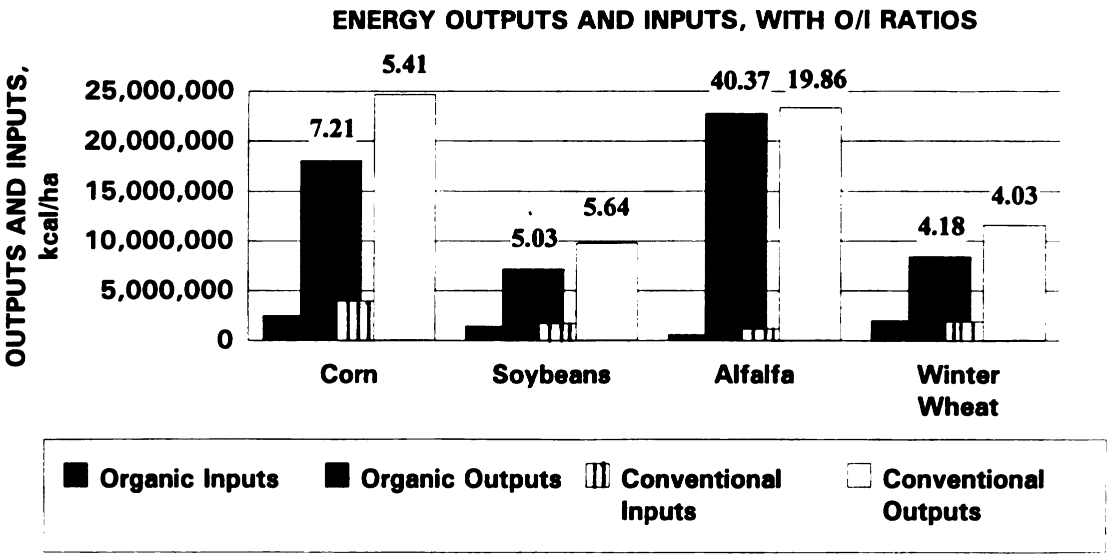

Figure 5.6 Energy Outputs and Inputs, with Output/Input Ratios, for Organic and Conventional Farming Systems.

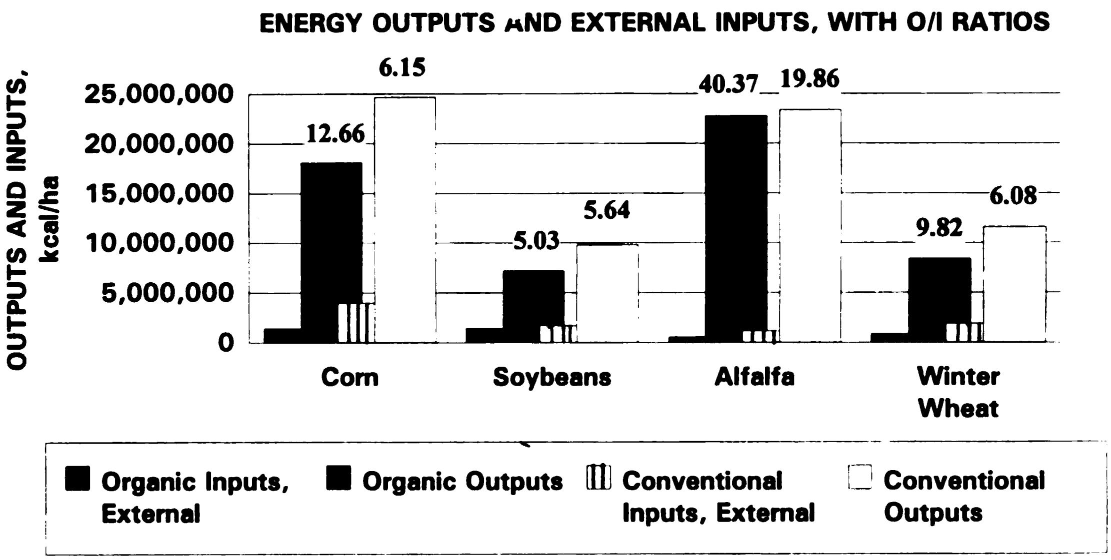

Figure 5.7 Energy Outputs and External Inputs, with Output/External Input Ratios, for Organic and Conventional Farming Systems.

systems, so the ratio of soybean energy outputs to external energy inputs is the same as the ratio of soybean outputs to all inputs.

The organic soybeans required almost 32 percent more diesel fuel energy, for mechanical cultivation. The conventional soybeans needed modest amounts of synthetic fertilizers and herbicides (0.51 million kcal), equal to the energy requirements of the seed. Winter wheat grown on the organic farm consumed just over 2 million kcal in inputs. Winter wheat grown under the assumptions of the composite conventional system required 2.9 million kcal of inputs, almost 43 percent more than organically grown wheat. Diesel fuel and seed inputs were the largest inputs for the organic wheat. The seeding rate for organic wheat was 50 percent higher than it was for conventional wheat. Because conventional wheat yields were almost 38 percent higher than the organic yields, winter wheat output energy per unit of input was virtually identical for the two systems—4.03 for the conventional wheat as opposed to 4.18 for organic wheat. The ratio of wheat energy outputs to external energy inputs favored the organic system. At 9.82, the ratio is almost 63 percent higher than the value of 6.08 for conventional wheat. It is important to note that these figures are based on the assumption that conventional farmers supply wheat seed from their own crops. If this is not the case, energy output per unit of external energy for the conventional system would drop by 20 percent.

The principal inputs to the organic wheat were diesel fuel, seeds, and fertilizer in the form of manure. The conventional wheat required both manure and synthetic fertilizer, diesel fuel, seeds, and pesticides as primary inputs. Over 57 percent of the organic wheat inputs came from internal sources, including seed and manure. The corresponding figure for conventional wheat was just under 34 percent, also in the form of manure and seed.

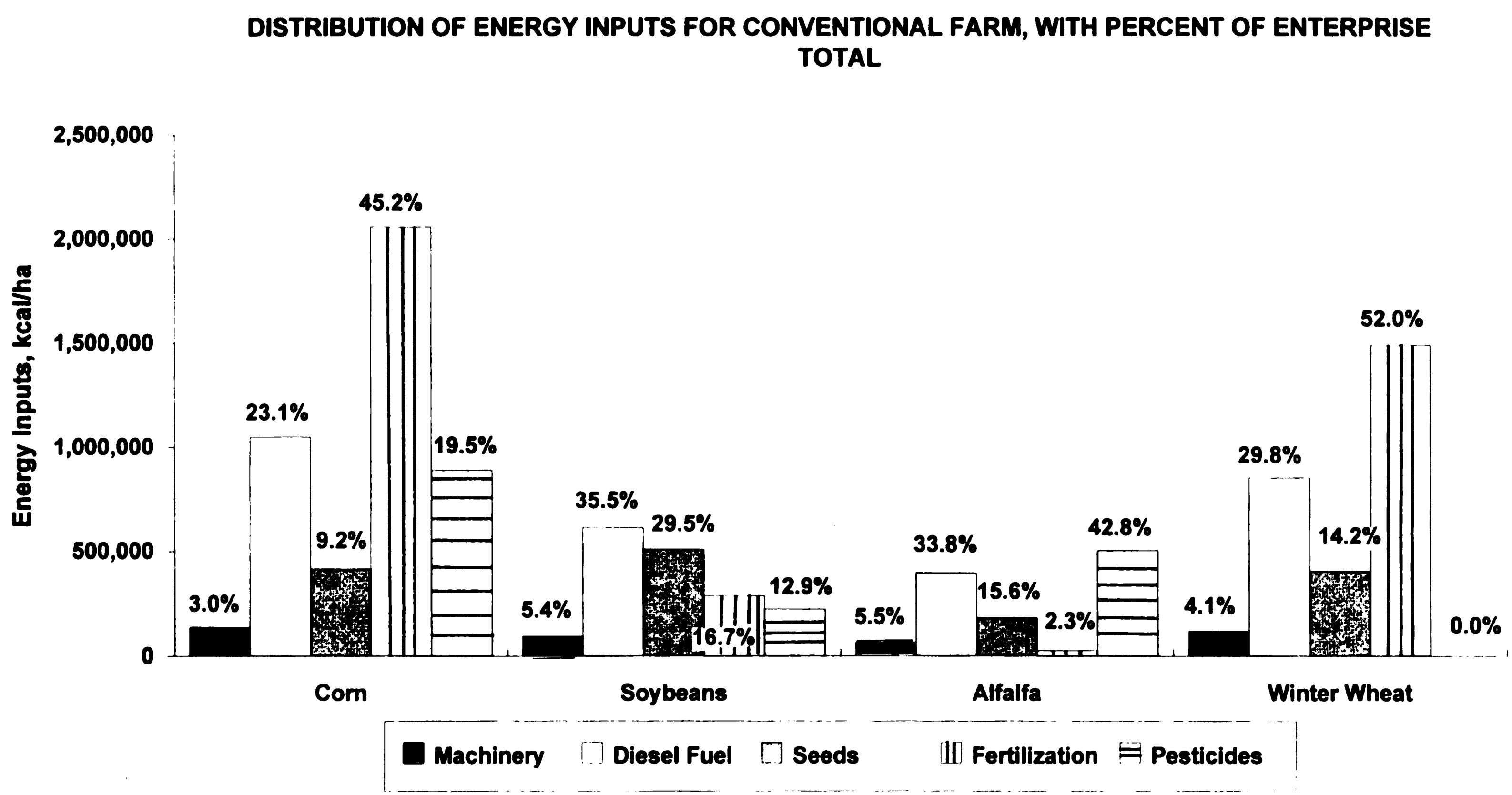

Figure 5.8 Distribution of Energy Inputs to Conventional Farming Systems by Input Categories

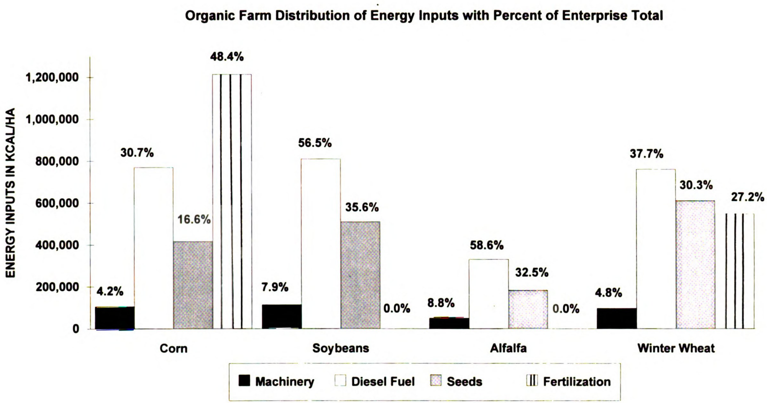

Figure 5.9 Distribution of Energy Inputs to Organic Farming Systems by Input Categories

Organically grown alfalfa consumed less than half the energy inputs of conventional alfalfa, 0.56 million kcal compared to 1.18 million kcal. Though no internal energy inputs were used to grow alfalfa, it was the most energy frugal crop for both farming systems. Because of this, and because alfalfa produces high levels of plant matter, the output to input ratios were quite high. It was estimated that the organic system produced just over 40 kcal of energy output for each kcal of input. The corresponding figure for conventionally grown alfalfa was 19.86. Diesel fuel for harvesting alfalfa hay was the largest input for the organic farm (59 percent), and pesticides were the largest energy input to conventional alfalfa (43 percent).

For the four individual crops studied, energy inputs per hectare were higher for conventionally grown crops, ranging from 20 percent over the organic inputs for soybeans to almost 110 percent over inputs to organic alfalfa. Conventional outputs were also higher for each of the four crops. Conventional alfalfa outputs were not quite 3 percent greater than organic alfalfa outputs. The differences between energy outputs for the other three crops were quite similar, with organic outputs between 37 and 35 percent less than conventional yields. The ratio of energy outputs to all non-solar inputs, and to external inputs, provide some measure of which farming system produces the most energy per unit of input. Organic alfalfa was the most productive by far, with an output to input ratio of over 40 to 1. Conventional alfalfa was next, at almost 20 to 1. Organic corn returned over 7 kcal for every kcal of inputs, and produced over 12.5 kcals for every kcal of external energy inputs. Output to input ratios for the conventional crops not yet mentioned were in a range of 4 to 1 up to 6 to 1. Conventional soybeans were **more** energy productive than were organic soybeans, while organic and conventional winter wheat total energy productivity were quite close at just over 4 to 1. For corn, alfalfa, and wheat, the ratios of organic energy outputs to **external** energy inputs were 61 to more than 100 percent higher than the respective conventional ratios.

While it seems clear that several organically grown crops may produce more energy per unit of energy input than their conventional counterparts, the exceptions cast doubt on Hypothesis 1, that organic farms produce more energy outputs per unit of energy inputs than conventional farming systems. An examination of several organic crop rotations with a typical conventional rotation provide a clearer picture.

According to the Sycamore Creek Watershed Plan, a five year rotation of corn-corn-corn-soybeans-winter wheat is both common and typical for conventional farmers in the watershed (SCS 1992). Three organic rotations, typical of the organic farmer studied, were compared to the conventional rotation. The rotations and their inputs and outputs are shown Table 5.4. The figures shown are five year totals.

It can be seen from an inspection of Figure 5.10 that the three organic rotations are virtually identical in the relative distribution of energy inputs by category. Machinery and fertilization costs are within a few percentage points of each other for each rotation. Seed inputs make up the largest input for each rotation, and are close to 50 percent for each organic rotation. If the embodied energy of hairy vetch seed could be shown to be lower, the relative size of inputs from seed in the organic rotations would drop significantly. Fuel costs across the rotations are within a percentage point of each other, and are all about 38 percent of the total inputs.

The distribution of energy inputs for the conventional system are qualitatively different from the organic rotations. They are similar only in that machinery is a relatively small part of inputs. In contrast to organic systems, fertilization inputs including manure and synthetic fertilizers make up the largest single input, just under 44 percent. Diesel fuel is a relatively smaller portion of the conventional energy budget, accounting for 25 percent of inputs. Pesticides and seed costs make up the balance of the conventional inputs.

Table 5.4 Five Year Totals for Energy Input On Organic and Conventional Farm

INPUTS, kcal/ha	ROTATION 1 ORGANIC	ROTATION 2 ORGANIC	ROTATION 3 ORGANIC	ROTATION 4 CONVEN-TIONAL
	Corn-Soy-Rye & Hairy Vetch	Soy-Winter Wheat-Rye & Hairy Vetch-Corn-Oat-Rye & Hairy Vetch-Corn	Soy-Rye-Rye & Hairy Vetch-Corn	Corn-Corn-Corn-Soy-Wheat
Machinery	680,036	625,327	612,285	626,501
Fuel	4,568,473	4,212,336	4,112,332	4,618,338
Natural Gas	0	0	0	0
Electricity	0	0	0	0
Fertilization	465,363	946,805	807,756	7,955,446
Pesticides	0	0	0	2887934
Seeds	5,669,514	5,397,679	4,798,956	2,168,062
Other	0	0	0	0
Postharvest	0	0	0	0
Transport	0	0	0	0
Subtotal - Insolation	11,777,423	11,182,147	10,331,329	18,256,281
External Energy Subtotal	7,725,218	6,450,830	6,493,948	15,650,641
OUTPUTS, kcal/ha				
Crop Yields	74,632,948	69,946,103	62,563,841	95,246,859
Output/ Input	6.34	6.26	6.06	5.22
Output/ External Input	9.66	10.84	9.63	6.09

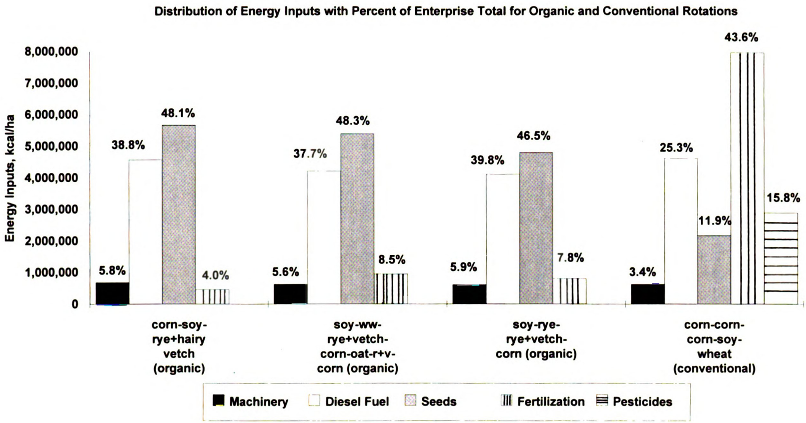

Figure 5.10 Distribution of Energy Inputs to Organic and Conventional Crop Rotations by Input Categories

Over a five year period the conventional rotation produces from 28 to 52 percent more energy output than do the organic rotations, despite the fact that the organic soy-winter wheat-rye+hairy vetch-corn-oats-rye+hairy vetch-corn includes four of the five crops grown in the conventional rotation. These figures are consistent with the output results from the individual crops.

The three organic rotations all have energy output to input ratios between 6.06 and 6.34 to 1. The conventional rotation has a ratio of 5.22 to 1, about 18 percent less than the organic rotations. The difference is more pronounced when energy output per input unit of **external** energy is considered. Two of the organic rotations are almost identical, at about 9.6 to 1. The third is 10.8 to 1. The corresponding value for the conventional system is 6.09 to 1. The organic rotations produce significantly more energy per input of external energy, and appear to produce almost 20 percent more energy per kcal of energy input than the conventional rotation. These figures support Hypothesis 1. It appears that organic crop systems do produce more energy per input unit than the conventional system.

Energy Flows

Flows of energy and materials in the form of farm machinery, diesel fuel, seeds, and synthetic fertilizers are the principal off-farm inputs for the cropping systems studied. These flows, including their size, have been discussed for particular crops and crop rotations earlier in this chapter.

Flows of energy off-farm for the systems studied are in the form of milk and farm products. Although the organic farmer grows more than enough corn to feed his dairy cattle, beginning in 1990, organic corn is fed to the herd for about five or six months over the winter, while as much corn as possible is sold for organic premiums. Commercial corn is then used for the dairy ration. In 1990 about two-thirds of the organic corn was sold off-farm. The remainder was fed to the dairy herd, providing about 80 percent of the corn they consumed.

Approximately one-quarter of the 1991 corn harvest was used for feed, which supplied the dairy herd from mid-November 1991 to mid-May 1992. The remainder was sold. A similar pattern was followed in 1992.

The organic famer followed a similar pattern with soybeans. He fed the dairy herd soybean meal made from beans culled during processing, sold his soybeans for an organic premium, and bought commercial soy meal for feed. The dairy ration includes about 12 percent oats, all of which is provided from farm crops. The balance is sold off-farm. He also sells hairy vetch and rye/hairy vetch mix seed to other farmers for use as cover crops, along with some rye grain.

All alfalfa hay grown on the farm was fed to the dairy herd, and a very minor three percent in additional forage was purchased. Forage and roughage contribute about 58 percent of the total feed calories needed by dairy cattle (Oltenacu and Allen, 1980). Together with the feed grains grown on the organic farm, approximately 80 to 90 percent of the calories consumed by the dairy herd were grown on the organic farm.

Though similar data were unavailable for conventional dairies, farms with dairy herds smaller than 65 cows had an average internal feed crop transfer (from crop systems to dairy herds) of $39,731. They spent an average of $19,281 to purchase feed (Nott, 1990). This means that 67 percent of the cost of dairy feed was met from on-farm resources. It seems likely that the percentage of calories fed from conventional on-farm resources was at least slightly higher, as typical purchased feed additives such as minerals, vitamins, and molasses do not provide many calories.

Both the organic and conventional farming systems depend on the flow of nutrients from manure back to the soil to help maintain soil fertility. Assuming a dairy cow and a replacement together generate 45 kg/day of manure, a dairy cow with replacement produces about 1 million kcal per year of manure, using an embodied energy value based on fertilizer replacement for fresh manure discussed in Chapter 4. This is equivalent to each cow with replacement returning approximately 60 kg of actual available nitrogen, 27 kg actual available phosphate, and 113 kg of actual available potash each year.

The third significant internal transfer of energy is the use of home-grown seed on the organic farm. The organic farmer provides his own seed for wheat, oats, rye, hairy vetch, and barley crops. Seed is a significant portion of the embodied energy inputs to these crops, ranging from 30 to 70 percent of the total inputs of the crop. Data on the use of home-grown seed by conventional farms in the area were unavailable.

Labor Inputs

Table 5.5 shows the results of the comparison of energy outputs per hour of labor input. Figure 5.11 illustrates this information. It is apparent from the table and figure that the closest match to the actual labor figures for organic corn is the data from the Wisconsin Livestock and Cash Crop Enterprise Budgets. The Michigan labor budget and regression figures agree well with the actual organic output to labor input figures for soybeans, though all three are some 50 percent smaller than the Wisconsin labor budget figure. For winter wheat the Michigan labor regression figure and the Wisconsin labor budget match. For alfalfa, the ratio of outputs to labor for the Wisconsin labor budget figure agrees with the organic farmer's ratio, and both are three times greater than the figures suggested by Michigan budget and regression formulas.

Michigan Telefarm data for hours of labor per dairy cow for dairy farms with less than 65 dairy cows is identical to the organic farmer's estimate of 67 hours per cow per year. This figures are slightly larger than those estimated from the Michigan budget and regression figures for a herd of 100 cows, but less than the estimate the Michigan regression formula gives for a herd of his size.

Table 5.5. Ratio of Energy Outputs to Labor Inputs for Organic and Conventional Farming Systems

OUTPUT/HOUR, in kcal	CORN	SOY	ALFALFA	WINTER WHEAT
OUTPUT/HOUR, ORGANIC	2,480,000	1,040,000	3,980,000	1,140,000
OUTPUT/HOUR, MI BUDGET	1,630,000	1,060,000	909,000	1,230,000
OUTPUT/HOUR, MI REGRESSION	1,670,000	1,010,000	803,000	1,580,000
OUTPUT/WI BUDGET	3,730,000	1,520,000	2,890,000	1,510,000

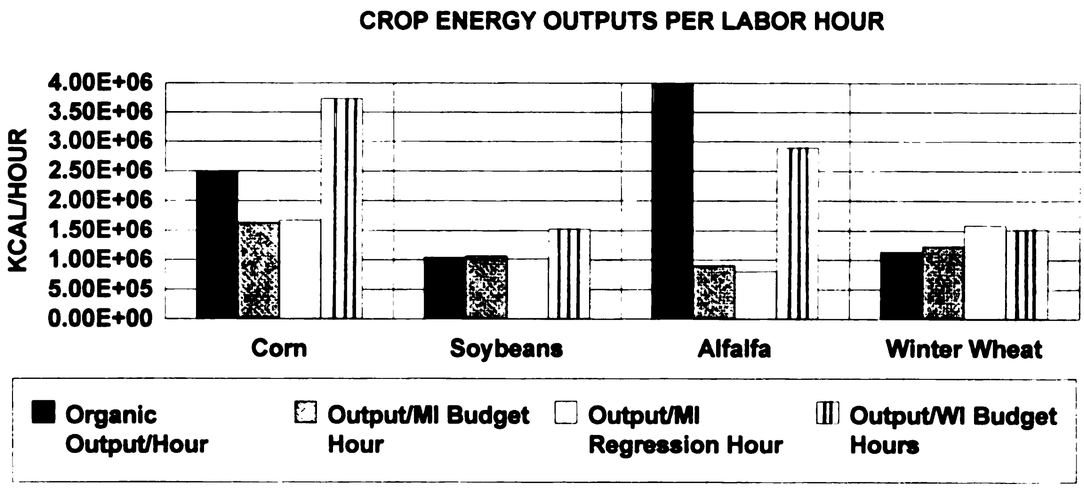

Figure 5.11 Crop Energy Outputs per Labor Hour for an Organic and Several Conventional Farm Labor Budgets

These data do not support Hypotheses 4, which states the organic farm would require more labor per unit of output than the conventional Michigan farm average. The measure employed to test this hypothesis was energy output per unit of labor, a measure of labor productivity. Higher values of labor productivity equal lower labor inputs per unit of energy output. Energy output per unit of labor for corn and alfalfa was much higher for the organic farm than for either of the Michigan calculations. Energy output per unit of labor for soybeans were quite close for the three Michigan examples. For winter wheat the output of energy per labor hour from the organic farm was lower than the other two Michigan cases. Data from Wisconsin were used to provide another point of comparison.

These data do not provide sufficient evidence to support Hypothesis 4. In several instances the organic farm yielded more energy per unit of labor than the two Michigan conventional examples.

Summary

The analysis of results does not support Hypothesis 1, which stated that organic farm crop yields would equal or exceed Michigan averages. Hypothesis 2 was supported by the results, which showed that milk yields from the organic farm were comparable to Michigan averages. Hypothesis 3 was supported by data that showed that organic rotations produced more energy per unit of energy input. Hypothesis 4 is not supported by the results. Energy output from the organic farm per unit of labor input was greater than or equal to the corresponding values from the Michigan conventional examples for several crops.

These results, their meaning, and conclusions will be discussed in the following chapter, and suggestions for further research will be presented.

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

A central premise of this study is that the sustainability of an agroecosystem is inversely related to its degree of openness; that is, the more open an agroecosystem, the less sustainable it will tend to be. This study characterized an organic farm as a relatively closed agroecosystem, and a composite conventional farming system as a relatively open agroecosystem. Sustainability was represented by the variables of *yield per unit of land and cow*, *energy input per unit of crop output*, and *labor inputs per unit of crop and cow*.

An energy analysis was conducted on the two agroecosystems. Agricultural inputs, outputs, and flows and processes internal and external to the agroecosystems were characterized in energy units. Because common units were used, system and subsystem efficiencies at different levels of the farm agroecosystem could be compared. This approach is grounded in systems theory (Doyle 1990).

Two hypotheses address the relative sustainability of the two agroecosystems based on their yields. The ratio of energy outputs to energy inputs forms the basis for another hypothesis. The relationship between farming systems and labor productivity provide the final hypothesis.

Hypothesis 1 and Conclusions

Hypothesis 1, which states that the organic farm would require less energy per unit of output than the Michigan average, was supported by the results. All the organic crops studied were produced with lower direct and indirect energy inputs. Due to the higher yields of the conventional farming system, the ratio of energy outputs to inputs were closer for the individual crops studied. For corn, alfalfa, and wheat the ratio of energy output to all non-solar inputs for the organic crops was greater than the ratio for conventional crops, ranging from more than double the conventional ratio to just under four percent higher. Unexpectedly, conventional soybean crops produced **more** output energy per unit of energy input, 5.64, than the corresponding organic soybean crops, at 5.03. This was a result of higher conventional yields and only slightly lower energy inputs for the organic soybeans.

However, a comparison of organic and conventional rotations reveled that organic cropping systems do produce more energy per unit of energy input than do conventional systems. The organic system energy output/total energy input ratio was almost 20 percent higher than that of the conventional rotation. The organic rotations studied all yield over 50 percent more energy output per unit of **external** energy input as compared to the conventional rotation.

This is due to several factors. The organic rotations all include cover crops, which demand fewer inputs than cash crops. Fertilization in the conventional rotation consumed more energy than the entire external energy demands of each of the organic rotations. The higher yields of the conventional rotation were not enough to offset the higher energy requirements. This study shows that for three of the four crops, conventional methods required more machinery inputs. In the case of corn and wheat, this was because the conventional system applied both manure and fertilizer to the crops. In the case of alfalfa, machinery was required to spread fertilizers and pesticides that were not used on the organic farm. Organic soybeans demanded more machinery than their counterparts due to the need for multiple cultivations.

Hypothesis 2 and Conclusions

Hypothesis 2, which states that organic farm crop yields would be equivalent to Michigan averages, was not supported by the study results. Instead, the data suggest that conventional crop yields are higher than those of the organic farm studied.

Organic corn, soybean, and winter wheat yields averaged very close to 70 percent of those considered possible by the SCS on the organic farm soils under high levels of management. The corresponding averages for the conventional yields were close to or over 100 percent. There are at least two possible reasons for this difference. First, the conventional figures are evidence of preferential planting of these cash crops on the best available soils, meaning that the county potential yield figures, based on all county soils, are underestimates. Alternatively, the difference may be due to the fact that county potential yield figures are based on SCS data from 1979 and earlier. This means that figures for the estimated yields possible under high levels of management do not account for yield increases due to crop varieties developed after 1979. It is quite possible that both of these factors play a role in the "overyield" phenomenon observed for the conventional crop averages.

The organic farm demonstrates several of the transition effects noted by Dabbert and Madden (1986a, 1986b), and Harwood (1985). The organic farmer studied, who undoubtedly knows his farm better than anyone, estimates his yields using organic methods are 85 or 90 percent of those he could expect using conventional techniques. This reduction in yields caused by the switch to an organic system is a biological transition effect. The reduction in yields may also be due in part to a learning or knowledge effect. Lockeretz and Madden (1987) found that organic farmers often claim the lack of information on organic methods hampers greater adoption, as did the organic farmer who cooperated in this study. It is possible that this may reflect the comparatively small amount of research and extension devoted to organic farming, rather than the complexity of organic systems (Lockeretz 1991).

Hypothesis 3 and Conclusions

Hypothesis 3 states that organic farm milk production would be equal to Michigan averages. This was supported by the results. There was no significant difference between milk yields per cow on the organic farm and average yields per cow at the county and state level.

This is not surprising. Milk production is a function of genetic makeup and diet. The organic dairy herd's diet is similar to that used elsewhere in the county and state. The organic farmer buys breeding stock and insemination services from local suppliers, so there is no reason to doubt that his cows are genetically similar in terms of quality to other county herds.

This hypothesis served as a "check" upon the animal systems. If milk yields had proved dissimilar, the result would have warranted further study. Differences between the organic and conventional herds, such as differences in herd health, may exist, but are beyond the scope of this study.

Hypothesis 4 and Conclusions

Hypothesis 4 stated that the organic farm would require more labor per unit of output than the Michigan average. This hypothesis was not supported by the results. The data suggest there is no difference in the amount of labor required per unit of output between the organic farm studied and estimates provided by three different conventional labor budgets.

Energy output for organic corn and alfalfa per labor hour were much higher than the figures predicted by the Michigan labor budget and regression studies. Output per labor hour for organic alfalfa was over four times the figures suggested by the Michigan studies, and a third higher than the figure predicted from data in the Wisconsin farm crop budgets. Output per labor hour for organic corn was fifty percent higher than that predicted by the Michigan studies, and fifty percent lower than the ratio predicted by the Wisconsin farm crop budgets.

Output per labor hour for organic soybeans was within a few percentage points of the figures based on Michigan enterprise budgets, but was almost fifty percent lower than the ratio in the Wisconsin budgets. Organic winter wheat energy output per labor hour was 8 to 39 percent lower than the figures predicted by the three conventional enterprise budgets.

It is difficult to determine the areas where differences in labor demands arose, because the conventional labor enterprise budgets did not disaggregate labor requirements by categories such as tillage, planting, and harvesting.

This result is quite intriguing, as a number of previous comparative studies have shown that organic farming systems demand more labor, as farmers substitute labor in the form of cultivation and tillage for chemical inputs. These results suggest that at least in some circumstances low external input or chemical-free farming does not necessarily mean more labor intensive farming.

General Conclusions

The organic farming system did prove to be a more closed system. Direct and indirect energy inputs to the organic agroecosystem were far lower than energy inputs to conventional farming systems. Does this mean that the organic farming system is more sustainable; that is, can the organic farming system maintain productivity in the face of significant disturbance better than the conventional agroecosystems studied? The answer depends on the nature of the disturbance.

In the transition to an organic agroecosystem, internal nutrient and energy cycles have been reestablished that free the farm from reliance on external fertilizer and pesticide inputs. If there is a major disturbance to input supplies or availability, including regulation or taxation, the organic agroecosystem seems far better prepared to deal with it than the conventional farming systems. The data also suggest that the organic agroecosystem is no more vulnerable to disruptions of labor markets than are conventional systems. Although yields from the organic system are lower than the conventional yields, it remains to be seen what the effects of the disturbance of pre-existing soil ecologies by chemical inputs will be. It may be that organic systems are able to maintain production over time far better than petrochemical-based agroecosystems.

In short, the organic agroecosystem is more sustainable than the conventional farming systems studied in terms of energy efficiency and independence. It is as sustainable as the conventional systems in terms of labor efficiency. It may or not be as sustainable in terms of crop production as the conventional systems.

Implications

Despite predictions of soaring energy prices, made at the height of the Organization of Petroleum Exporting Countries (OPEC) oil embargo, and their dire consequences on agriculture, petroleum prices adjusted for inflation are lower than they were prior to the start of the embargo. Corrected for inflation the price of fertilizer nitrogen was at an all-time low in the European Community in 1990 (de Wit 1990), and fertilizer nitrogen prices have not increased since then. It may well be that the availability of agrichemicals will depend less on petroleum markets than on government-imposed regulations and taxes.

Though current oil prices demonstrate the difficulty of predicting future trends based on past and present information, it seems likely that present trends in the regulation and taxation of farm chemicals will continue and increase. These trends are driven by forces such as public and personal health concerns and the desire to address point and non-point source pollution problems, among others. The Michigan Groundwater and Freshwater Protection Act, recently signed into law, imposes fertilizer taxes and increases pesticide regulation fees. It is only one of the latest in a series of state and federal actions aimed at reducing agricultural externalities.

Such trends will encourage more efficient use of on and off-farm resources, including chemicals. Because farmers tend to be price takers, they cannot pass input price increases along to consumers. This means they must cut costs to create or maintain profit margins. If these trends continue, yields per unit input, including energy and labor efficiency, will become an increasingly important, albeit incomplete, measure of agricultural sustainability.

Recommendations for Future Research

A number of information needs exist at different levels of the agroecosystem hierarchy. At the farm level, transition effects, including biological and learning effects, are poorly understood, and yet have significant repercussions on agroecosystems. It is suggested that research into these effects be expanded. Some possible questions are the information needed when an organic or alternative system is being developed. Is more information required to adopt a new system, or for its continued use? Does handling the information needed for an alternative or organic system require more time, or does it also demand more management skill? Studying farm operators' skill is quite difficult, and has been neglected.

The extent of environmental externalities related to agrichemical use needs to be determined and quantified, so that more efficient economic and social policies can be determined.

As stated earlier in this study, a sustainable agriculture necessarily must address the sustainability of social, economic, and physical systems making up an agroecosystem. Information on the impact of different farming systems on the sustainability of rural communities and regions is needed before the continued dis-integration of rural societies and economies becomes irreversible, and the question becomes tragically moot.

Finally, further work is needed in the measurement and comparative analysis of sustainability. An adequate method of measuring sustainability should be able to distinguish between yield changes due to changes in inputs (movement along a production function), yield changes due to technological change, and changes in yield due to changes in resource quality (after Harrington 1991). The sustainability of our agroecosystems is a matter of increasing importance in a world with a growing appetite for food and fiber, and little stomach for the problems caused by conventional agriculture.

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