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ENERGY AND ECONOMIC ANALYSES OF COMPARATIVE SUSTAINABILITY IN LOW-INPUT AND CONVENTIONAL FARMING SYSTEMS

By

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ABSTRACT

ENERGY AND ECONOMIC ANALYSES OF COMPARATIVE SUSTAINABILITY IN LOW-INPUT AND CONVENTIONAL FARMING SYSTEMS

By

Tiang-Hong Chou

The sustainability of two low-input (LIP) cropping systems and one conventional system, all from the Rodale Farming Systems Trial, is compared from 1981 to 1992 using energy and economic indicators. The low-input animal system (LIP-A) spread manure, while the low-input cash grain system (LIP-CG) grew green manure crops for nutrients. The conventional system (CONV) used commercial fertilizers and pesticides.

Results of these analyses show that both LIP systems required only 50% of CONV nonrenewable energy consumption. Food and biomass energy production was highest for LIP-A. Although LIP-CG generated about 75% of CONV food energy production, it was the most stable system from energy and profitability viewpoints. LIP systems were less profitable than CONV under current policy and economic circumstances. The results demonstrate that LIP are more energy sustainable than CONV. Adjustments to social and economic settings are proposed that could make LIP operations as profitable and economically sustainable as CONV.

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Last but not least, I want to thank my family for their endless support and love which are the ultimate source of my energy. I would like to dedicate this thesis to them and to show my commitment to the environment and agriculture in Taiwan in order to make them more sustainable for our future families.

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CHAPTER 1

INTRODUCTION

Background

After decades of development of conventional agriculture, farmers and researchers are seeking new paradigms of food production which are sustainable over a long period. Since the 1940s, U.S. agriculture has constantly innovated and adapted farming techniques. This contributed to dramatic increases in per acre yield and overall agricultural production, and led to the wide use of machinery, mono-cultural practices, irrigation, and synthetic fertilizers and pesticides in the United States and many other countries (National Research Council, 1989: 25). It is estimated that American farmers' expenditures for petroleum fuel rose five-fold from 1940 to 1974. During the same period, fertilizer and pesticide inputs increased by more than twelve-fold in the U.S. (Stout, 1984: 13).

Risks to conventional agriculture. This energy-intensive agricultural system has experienced at least four problems. First, in the long term, the conventional system is not sustainable because of the **foreseeable uncertainty of fossil fuel supplies** (Lockeretz, 1984: 78). Most recent world estimates show that there are about 1500 billion barrels of recoverable petroleum remaining. These will last about 60-65 years at current rates of consumption (See Cutter et al., 1991: 357-358; Edens and Haynes, 1982: 364). It is speculated that the decrease in petroleum supplies will cause substantial increases in oil prices in the foreseeable future.

Second, due to high dependence on fossil energy, current **farms are sensitive to external forces**. An increase in the price of a raw material or commodity may cause major economic difficulty for farmers, especially those small operators who lack sufficient capital. The impact of the 1973 OPEC oil embargo on agriculture reflected the sensitivity of conventional production systems to its external forces. From 1973 to 1978, major farm inputs showed the following price increases: land, 167%; farm machinery, 137%; fertilizers, 65%; and fuel and oil, 234% (Stout, 1984: 13). Total farm debt rose from $52.8 billion in 1970 to $206.5 billion in 1983 (National Research Council, 1989: 91).

The impact has been felt not only at the farm level but at the societal level as well. Studies estimated that in the late 1970s, American farmers invested $3 billion in pesticides in order to save $12 billion in U.S. crops, and the entire country spent at least $1 billion to cover environmental and health costs associated with pesticides each year (Pimentel et al., 1986). A similar assessment carried out in 1992 concluded that the environmental and social costs of pesticides alone had increased four-fold, to $5 billion dollars, while direct pesticide costs remained unchanged, and the value of crops saved increased only 33% to $16 billion (Pimentel et al., 1992). Although the assessment was thought to underestimate the social and environmental costs because the data was not complete, it is fairly evident that society may be even more sensitive than the farm to the use of pesticides.

Third, public concern about the **stress of agriculture on the environment** has been rising rapidly. Numerous studies have linked conventional farming to degradation of agricultural ecosystems, such as erosion and salinization of soils, underground and surface water contamination, and the reduction of wildlife and natural enemies of agricultural pests (National Research Council, 1989: 97-130). Conventional practices have also resulted indirectly in pollution problems like climatic warming, destruction of the ozone layer, acid rain, and others (Conway, 1990).

Finally, because of the reduction of farming ecosystem linkages, the conventional **production system is losing its internal stability**. For instance, the increasing reliance on chemicals for pest control has resulted in rising resistance to pesticides and the decline of natural pest control mechanisms. These changes have ultimately increased the susceptibility of the systems to insects and diseases (Edens and Koenig, 1980: 697). In Southern and Southeastern Asia, "hopperburn" (a severe rice damage caused by Brown Planthopper) in rice fields has occurred more frequently since the 1960s, when high yielding varieties and relating cropping patterns were introduced into the region (Dyck et al., 1979).

Additional options for agriculture and agricultural research. Actually, these problems are related to each other. The situation common to these problems is the structural dependence of farming systems on fossil energy. Therefore, many have suggested that **future innovations should be based on reducing nonrenewable energy resources in agriculture** (Pimentel et al., 1973: 446; Edens and Koenig, 1980: 697; Harwood, 1985: 64). In Francis and King's words, to achieve more sustainable farming systems in the future, the farming paradigm should be shifted from a "reliance on external resources" to an "utilization of internal farm-derived, renewable resources" (1988: 67).

Two major approaches are leading farmers and agricultural researchers toward alternative agriculture. The first approach focuses mostly on <u>traditional farming philosophy and methods</u>. In this country, studies have been conducted to examine energy saving, soil conservation, and the sustainability of Amish agriculture (Jonson et al., 1977; Jackson, 1988; Stinner et al., 1989). In addition, farming systems research increasingly emphasizes the exploration of indigenous farming knowledge in many parts of the world (Chambers, 1992).

Although valuable, the traditional practices are seen as subject more to their particular cultures and religions. In the case of Amish farming, for example, it was pointed out that most of the energy savings resulted from the frugal lifestyles of the Amish, and not from their farming practices (Kaffka, 1984: 15). Also, Edens and Haynes (1982: 388) argued that "system structures are not reversible in any literal sense...future adjustments must be understood in the context of our current state and the forces most influential in directing future changes." Therefore, knowledge of only traditional farming has limitations in helping us to define the "paradigm transformation."

The second approach enlightens agricultural specialists and operators to <u>design, test, and manage alternative farming systems</u> using current ecological and agronomic knowledge. The term "Agroecosystem Integrated Management" (AIM) by Edens and Koenig (1980) provides an useful concept for describing this approach. The AIM perspective looks at a farming system, not only at production, or any particular subsystem, but at all its components, and the relationships between these components in the context of the system. It focuses on rational design and management of a farming system while recognizing the natural constraints of the agroecosystem. It tries to overcome the constraints through its designed mechanisms, using on-farm renewable resources instead of depending on external nonrenewable resources. AIM seeks the long-term stability of a cropping system and the maintenance of balance between human activities and the agroecosystem in a closed-loop farming structure with feedback. **Organic farming** and **low-input/sustainable agriculture (LISA) program** are two typical examples in this area.

A United States Department of Agriculture (USDA) research team on organic farming (USDA, 1980: 9) defines organic farming as:

> Organic farming is a production system which avoids or largely excludes the use of synthetically compounded fertilizers, pesticides, growth regulators, and livestock feed additives. To the maximum extent feasible, organic farming systems rely upon crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes, mechanical cultivation, mineral-bearing rocks, and aspects of biological pest control to maintain soil productivity and tilth, to supply plant nutrients, and to control insects, weeds, and other pests.

Also, Harwood (1984: 3) provides a brief description for organic farming:

> An organic system is one which is structured to minimize the need for off-farm soil or plant-focused inputs. Because of lack of information on the

disruptive effect of synthetic inputs, none are used. "Natural" sources of inputs are used with discretion.

Although the term "organic farming" has been widely accepted among researchers and operators, some have suggested other terms for the farming philosophy and practice, such as regenerative (Rodale, 1983), ecological (Luo and Han, 1990; Soule and Piper, 1992), biodynamic (Pettersson, 1977; Harwood, 1990), low-input farming (Madden and Dobbs, 1990), etc. In this thesis, "**low-input**" farming is used because the term presents objectively the basic feature of the philosophy and operation from the standpoint of nonrenewable energy use.

The Low-Input/Sustainable Agriculture (LISA) program is an education and research program of organic farming developed in the 1987 by the USDA. It has funded many studies, both on-farm and on-station, to design sustainable farm productions systems for various environments and agricultural products (Parr et al., 1990).

Additionally, the approach of design and management of sustainable farming systems has led many researchers and operators to carry out low-input practices in the U.S. and Europe. The processes and results of some of the experiments and implementations are shown in Balfour, 1977; Pettersson, 1977; Eggert, 1977; Harwood, 1984; Kaffka, 1984; Sahs and Lesoing, 1985; National Research Council, 1989; Liebhardt et al., 1989; Peters et al., 1992; Cunningham et al., 1992; and Chou, 1992.

The Study

Among these efforts, researchers in the Rodale Institute Research Center started a farming systems experiment in 1981 to explore the yield performance and other processes of two low-input farming systems and to compare them with a conventional systems from the perspectives of biophysical and environmental sustainability. In addition to the Institute's studies, several economic analyses have been done to evaluate the economic potential of the low-input practices of the Rodale experiment.

Due to the critical role of energy in future agricultural development, and to the fact that energy analysis might be a viable tool in exploring the cropping systems performance, this study is designed to measure and compare the sustainability of both the low-input systems and the conventional system in the Rodale farming systems trial from energy and economic viewpoints. This study will analyze energy budgets and economic balances of the three farming systems for the 12-year period from 1981 to 1992.

The main objective of this study is to test the hypothesis that low-input farming systems in the Rodale farming systems trial are more sustainable in terms of energy and economic inputs than the conventional system. It is hoped that this study will provide a useful and appropriate design for the comparison of agricultural sustainability between various farming systems.

Organization of the Study

This chapter has included an introductory discussion and an overview of the development of low-input farming systems researches and practices. In the following chapter, I will discuss the literature related to agricultural sustainability, energy analysis, and comparative studies of low-input and conventional farming systems, followed by a description of the Rodale farming systems trial. In the third chapter of this thesis, the objective and hypotheses of the study will be fully described. Important concepts like sustainability, productivity, and stability are quantitatively defined in the chapter. Methods and materials used in the analysis and comparison of the systems, and some associated assumptions in the calculation of the energy and economic budgets are presented in the fourth chapter. Chapter five shows the study's main findings followed by a detailed discussion of the results and the validity of the hypotheses. The last chapter contains a summary of the key points presented from chapter two to five. Finally, conclusions and recommendations for the future development of low-input agriculture are addressed based on the findings of the study.

CHAPTER 2

LITERATURE REVIEW AND

DESCRIPTION OF THE RODALE FARMING SYSTEMS TRIAL

Discussion of Agricultural Sustainability

Literature review. Agricultural sustainability (AS) has been discussed increasingly since the 1980s. Most of the discussions focused on the qualitative characteristics of AS. Edens and Haynes (1982: 372) described sustainability as " **long-term stability**" in agricultural production systems. Since stability is somewhat ambiguous and not well defined, they suggested that sustainability might be a more appropriate criterion for evaluating long-term human impacts on renewable resources (p.383).

Another noted description of AS was given by Douglass (1984 and 1985) who stated a sustainable agriculture (SA) includes:

> agricultural methods which will generate **needed levels of production** with the **least amount of damage** to the physical and human communities on which sustainable societies must depend" (1984: 5).

He pointed out that the definition had led to three different approaches to a SA. The food-sufficiency school emphasizes economic scarcity, attempting to expand the food supply by increasing the agricultural resource base and productive efficiency. The stewardship school is concerned about the ecological balance and natural constraints, concentrating on the need for population control, restructuring of agriculture, or cutting down on hazards to sustainable production. For this school, sustainable production means "the average level of output over an indefinitely long period which can be sustained without depleting the renewable resources on which it depends" (1985: 10). The community school focuses on the effects of different production systems on the social organization and culture of rural life, suggesting a socially holistic perspective in addressing the issues of agricultural sustainability, rather than depending only on scientific or technological efforts. Similarly, Crosson defined a sustainable agricultural system as:

> one that can indefinitely meet demands for food and fiber at **socially acceptable economic and environmental costs** (See Harrington, 1992: 565).

According to Harwood (1988), a sustainable agriculture represents:

> 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.

In addition, some authors have had intensive discussions on the relationships of productivity, stability, sustainability, and equitability in agroecosystems (Conway, 1986, 1990; Marten, 1988). Their definitions of the concepts are generally close. The basic concept is productivity, which was defined as "... the net increment in valued product per unit of resource" (Conway, 1986: 23). Then they went further to define stability in terms of the **consistency of productivity** under normal and/or small scale fluctuations in environmental variables, and to identify sustainability as **the ability of a system to maintain a specific level of productivity over the long term**.

Although these properties were mutually defined, the authors argued that there are trade-offs among them. For example, the dramatic increase of labor productivity in agriculture through the wide use of agrichemicals and farm machinery in the past decades has threatened the stability and sustainability of the system now and for the future. Also, in order to stabilize crops yields in the short term, farmers applied large amount of pesticides in pest control which have inversely affected AS in the long term. These arguments are critical because they show the significance of the **time factor and the perspectives** that we use to consider these properties. For instance, because productivity is the foundation on which the definitions of other concepts were developed, it is important to select an appropriate index for productivity.

Lowrance et al. (1986) tried to incorporate different definitions of AS by proposing a hierarchical definition of sustainability. They indicated four levels of AS:

* agronomic sustainability in the field system,
* microeconomic sustainability in the farm system,
* ecological sustainability in the watershed/ landscape system,
* macroeconomic sustainability in the national/regional system.

The importance of their points is that in evaluating AS, we should determine which **levels of sustainability** we wish to address, and we should fully consider the interactions among various hierarchical levels (also see Seetisarn, 1988: 7). These suggestions therefore provide a good scope for the analysis of AS.

In addition to the qualitative definitions of AS, however, there have been few studies associated with quantifying and measuring AS (MacKay, 1989). There is an urgent need to develop **operational definitions of AS** so that more concrete indexes of AS can be formed for evaluating agroecosystems. Farming systems researchers like Charoenwatana and Rambo (1988) have pointed out the lack of comparative analyses focused on identifying common or unique factors in sustainability of various agroecosystems. Comparative analysis of ecosystem sustainability has also been viewed as an important objective of future researches.

Implications for this study. A definition of agricultural sustainability for this study is derived from the discussion above. The definition centers on physical long-term stability (in Edens and Haynes' term), efficiency of nonrenewable energy resource use (in Harwood's definition), economically acceptable production level (in Crosson's words), and sufficient level of food production (in Douglass's definition) of a farming system. In this thesis, five hypotheses are developed to compare the sustainability of the systems. The first studies the nonrenewable energy consumption. The second is associated with relative food energy production for examining the sufficient food production level. The third hypothesis focuses on returns above variable costs for economically acceptable production level. The remaining two examine energy and economic long-term stability of low-input and conventional farming systems, respectively.

Conway's definition of stability, the constancy of productivity, can be converted easily into an operational definition if the constancy is measured through the concept of statistical variation. An alternative indicator of productivity from the energy perspective is applied in this study. Energy productivity is defined as the ratio of food energy output to the nonrenewable energy input of a system. The energy productivity could also be considered as the efficiency of nonrenewable energy use in the farming system.

In fact, the approach of this study incorporates the food-efficiency and stewardship schools described in Douglass's article. The system boundaries of this study are at the farm level or microeconomic level of the sustainability hierarchy discussed by Lowrance et al. (1986).

Energy Analysis of Agriculture

Literature review. The evolution of energy analysis (EA) has been related closely to the recognition of the important position of energy in the world's development. Although engineers in process technologies had been traditionally trained to manage energy functions in the process systems, an overall concern for energy economy did not occur until the 1970s, or more exactly, 1973, when OPEC imposed an oil embargo which resulted in a worldwide shortage of petroleum (IFIAS, 1974).

In agriculture, classical economists defined the three elements of production as land, capital, and labor. In the 1970s, research from an energy perspective took place, and new alternatives to traditional approaches were developed. As Doyle has described (1990: 92), some started discussing the resources of agricultural production in terms of **land, energy, and labor**. Traditionally identified inputs, such as machinery, fuels, and chemicals were replaced by a proxy of the fossil energy required to operate and produce them (de Wit, 1979: 281). Moreover, Pimentel and Pimentel (1979: 13) went further and calculated labor in the form of energy. These efforts laid a basis for further development of EA in which units of energy instead of dollars constitute the indicator of production.

Many researchers have pointed out the contributions and the relative benefits of energy rather than money as the relevant unit of account. First of all, Wilson (1974: 7) discussed the risk of reliance on monetary prices in an imperfect market with government interventions, lack of information, and other imperfections. He suggested that **energy might be a more sensitive and concrete indicator in guiding us to better resource allocation.**

According to Wilson, EA could be a **more value-free tool** which could provide valuable additional information for decision making. This argument could be supported by the examples shown in the Edens and Koenig article (1980). The authors strongly criticized the FAO's estimate of "self-sufficiency ratios" by deducing the dollar value of the difference between exports and imports of major agricultural products, and argued that the FAO completely ignored imports of fossil fuel, which should be included in the calculation of self-sufficiency. They also pointed out the fact that the price of energy has failed to reflect its real cost in the national economy.

Third, Axinn and Axinn (1984) found it **difficult and inappropriate to apply cash-dominated economic analysis to a rural area where households and communities are primarily self-sufficient**. Cash flow may not be significant or even exist in a village if the villagers tend to recycle materials rather than to trade products for cash income. They thus developed an energy recycling ratio as an analytical and comparative index for addressing Nepal's farming systems. One point implied in their findings was that a technique of EA such as the recycling ratio might provide better comparisons between systems, especially those with quite different cultures.

Fourth, one powerful function of EA is its ability to **identify the constraints and boundary conditions** of a production system (IFIAS, 1974: 15). Unlike contents of money used in modern economy which are manipulated by humans and could change over time, laws of energy generation, storage, and transformation are natural phenomena and cannot be altered by humans. For instance, humans may overcome an economic crisis but they can never increase world fossil fuel storage. EA could lead researchers and operators to better understanding of the carrying capacity and mechanisms of agroecosystems, and to rationally and sustainably design and manage the systems.

Finally, the authors of the IFIAS's report (1974) identified EA as "**a mean of injecting physical variables**

into economic theory." EA can thus contribute to the integration of agronomists, entomologists, and economists working for the development of sustainable agriculture.

Renborg (1981), Norum (1983), Jones (1989) and others discussed the questions and limitations of the methodology of EA in agriculture. Renborg focused on the problems related to the **exclusion of solar energy and land** in EA. Norum emphasized the **danger associated with the aggregation of energy resources in both input and output sides.** Jones indicated the **distinction between solar energy and support energy**, and suggested different systems boundaries for different levels of analysis.

More significantly, they all pointed out the difficulties and conflicts of EAs in dealing with **human labor**, but came to separate conclusions. Renborg tended to consider the life support system of a farmer in calculating human labor. Norum concluded that labor should be separated from other inputs and expressed by number of hours. Due to the fact of competition and substitution between resources in production, he suggested that energy analysts should clarify their values as a guide to decision making among the alternatives. Jones argued that the decisions in EA depend on the purpose of the analysis; however, he concluded that EA may be able to serve a descriptive function rather than an analytical function.

It is important that energy analysis proponents recognize both the strengths and limits of EA. They should base decisions to use, or not to use, EA on the objectives of the study. In conducting EA, the analyst should make clear the major assumptions and limitations of the analysis, and interpret its results carefully.

Implications for this study. It can be concluded from the literature that energy analysis is an appropriate technique for this study. As mentioned earlier, this study includes an examination of economic profitability and physical constraints in various farming systems, including low-input systems which tend to recycle intensively their internal resources. According to the authors, energy analysis has unique benefits and strength in exploring these phenomena. Also, farming is a human activity that is closely related to the use of natural resource. EA can be highly useful in allocating resources, especially when dealing with nonrenewable resources, because the renewable and nonrenewable characteristics of resources can be distinguished relatively clearly from an energy perspective.

The weakness and limitations of EA described in the previous literature should have only a minor impact on this study. This analysis will emphasize the utilization and constraints of nonrenewable energy in various farming systems. The exploration of interactions between renewable resources like solar, land, water, etc, and the nonrenewable energy is not the object of this analysis. Human labor will be estimated in terms of time (hours) following the suggestion of Norum (1983). Hence, a straightforward EA can be validly carried out to meet the objective of this study. Also, this study will combine energy and economic analyses, which could be complemented by one another, and making the result more comprehensive. Finally, some needed assumptions will be provided and the results will be interpreted carefully to overcome the possible flaw of EA.

Comparative Studies of Low-input and Conventional Farming Systems

Numerous studies have been designed to compare mechanisms of conventional and low-input farming systems. Some were done from the viewpoints of biophysical relations within the systems, such as pest activity (Motyka and Edens, 1984), soil erosion (Reganold et al., 1987; Sahr and Lesoing, 1985), and nutrient flow (Patten, 1982; Eggert and Kahrmann, 1984; Heichel and Barnes, 1984). Economic comparisons have also attracted much attention in seeking information on transitions from conventional to low-input production systems (Berardi, 1978; Lockeretz, 1981; Dabbert, 1986). Berardi concluded that although total costs were higher on the low-input organic farms than on the conventional, the low-input farms had lower operating costs (total costs excludes unpaid family labor) than the conventional group. Also, the low-input farms were economically comparable to the well managed conventional farms in New York because the organic farmers compensated their lower yields by receiving a price premium. Lockeretz et al. found in their study from 1974 to 1977 that low-input organic farms produced less market values as well as lower operating costs than the conventional farms, resulting in an approximately **equal returns** (crop sales minus operating costs) in the groups.

Both the studies of Berardi and Lockeretz et al. were also designed to compare the energy efficiency and productivity of low-input and conventional production systems. The former author pointed out that conventional farms consumed 48% more energy, yet produced only 29% higher yields than did the low-input farms. Lockeretz et al. (1981) concluded that between 1974 and 1978, the energy consumed to produce a dollar's worth of crops on organic farms was about 40% as great as on conventional farms. Kaffka (1984) showed that his study farm, which practiced low-commercial-input farming methods, **used fossil energy more efficiently** per unit of milk and crop production than average New York state dairy farms. Pimentel et al. (1984) found that organic farms in Iowa produced corn and wheat 26-70% more efficiently than did the conventional farms.

Description of the Rodale Farming Systems Trial

Background. The ongoing cropping systems experiment was initiated in 1981 by a group of researchers at Rodale Institute Research Center, located in southeastern Pennsylvania, near Kutztown. The trial, which includes two low-input systems and one conventional system, was initially designed to study the transition from conventional to low-input production methods. In 1986, it was assumed that the low-input systems had reached a new equilibrium after five years of transition and the study was shifted from addressing conversion difficulties to examining long-term systems operations and environmental conditions in the post-transition phase.

During the past twelve years, the trial has generated much information about yield performance, rotation effects, weed impact, nutrient situation, and soil conditions in the farming systems. Hence, it is helpful in understanding holistically the biophysical mechanisms of different systems and their impacts on the environment. Additionally, the data provide good material for an analysis concerning the comparative sustainability of the farming systems.

Field condition. According to a personal communication with Steve Peters (April 29, 1993), the soil of the 13-acre site (3% south-facing slope) is mainly a Berks shaley silty klay loam that is well drained, with lesser amounts of Commly silt loams and Duffield silt loams. Portions of the silt loams, however, may generate a perched water table. The climate provides 180 frost-free days, 3000 growing days (based on 50^0 F), and an average of 42 inches of rainfall which is relatively evenly distributed through out the year.

Prior to the establishment of the trial, the field was farmed mostly in corn and a small portion of wheat with chemical fertilizers and pesticides. After the harvest of winter wheat in the summer of 1980, the site was fallow until all of it was plowed in March, 1981; followed by the start of the experiment. Foxtail was growing widely on the site during the fallow period (Liebhardt et al. 1989: 152).

System designs. The three farming systems are as follows:

1. The Low-Input system with animal (LIP-A) simulated a beef operation by practicing a five-year rotation including red clover/alfalfa hay, oats, winter wheat, corn grain and silage, and soybeans. Nitrogen was provided both by steer manure from a farm adjunct to the research center, and by third-year legume hay crops plowed down just prior to planting corn.

2. The Low-Input/Cash Grain system (LIP-CG) did not include an animal enterprise. It produced a cash grain every year,

such as corn, soybeans, oats, winter wheat, and spring barley. Nitrogen was provided by short-term legume hay and green manure crops. Weed control for corn and soybeans in both low input systems was accomplished mechanically with a rotary hoe and ridge cultivator, and culturally through crop rotation, green manuring and relay cropping.

3. The Conventional Cash Grain system (CONV) was operated through a corn-soybean rotation using commercial fertilizers and synthetic pesticides recommended by Pennsylvania State University.

Conventional tillage, including moldboard plow, disk, harrow, and cultipack, was applied in all three cropping systems. All these jobs were conducted in the spring with the exception of a fall plowing for winter wheat.

Pest control in both low-input systems was accomplished through crop rotation, while insecticides were used on the conventional system, respectively.

It should also be noted that adjustments were made in the system designs during the study. For the LIP-A system, the whole rotation pattern stayed the same but some minor adjustments occurred. **First**, different cover crop species were used for competition with weeds in different period. From 1981 to 1985 and 1989, pure red clover was grown in the LIP-A plots; in 1986 and 1987 red clover was combined with alfalfa hay; and in 1991 red clover and orchardgrass were used. **Second**, since 1991, ryegrass and rye grain were added into the LIP-A system as additional cover crops. For the LIP-CG system, the rotational pattern changed. **First**, prior to 1986, the system used a 5-year rotation. After that a 3 year rotation was practiced. **Second**, from 1986 to 1990, LIP-CG soybeans were grown by relay cropping. In addition, in this period, mono-cultural practices were followed for the production of LIP-CG soybeans. The remaining two changes in the LIP-CG system occurred in 1991 when hairy vetch replaced red clover as the cover crop of the system, and ryegrass was added into the system (Peters, April 29, 1993, personal communication).

Figures 2.1, 2.2, and 2.3 are system diagrams which symbolize LIP-A, LIP-CG, and CONV farming systems in the Rodale FST respectively. The crop rotation schedules are presented in Table 2.1 and Figure 2.4.

Every farming system in the Rodale FST was distributed randomly into 8 of 24 main plots (60 ft * 300 ft) with three subplots (20 ft * 300 ft) within each of the main plots. Every subplot represents one rotational entry point of a farming system. Therefore, in the experiment, there are 9 treatments (3 farming systems * 3 rotational entries), and 8 replications (8 main plots for each system), resulting in a total of 72 plots (Figure 2.5). Grass buffer strips (5 ft wide) were maintained between the main plots to minimize

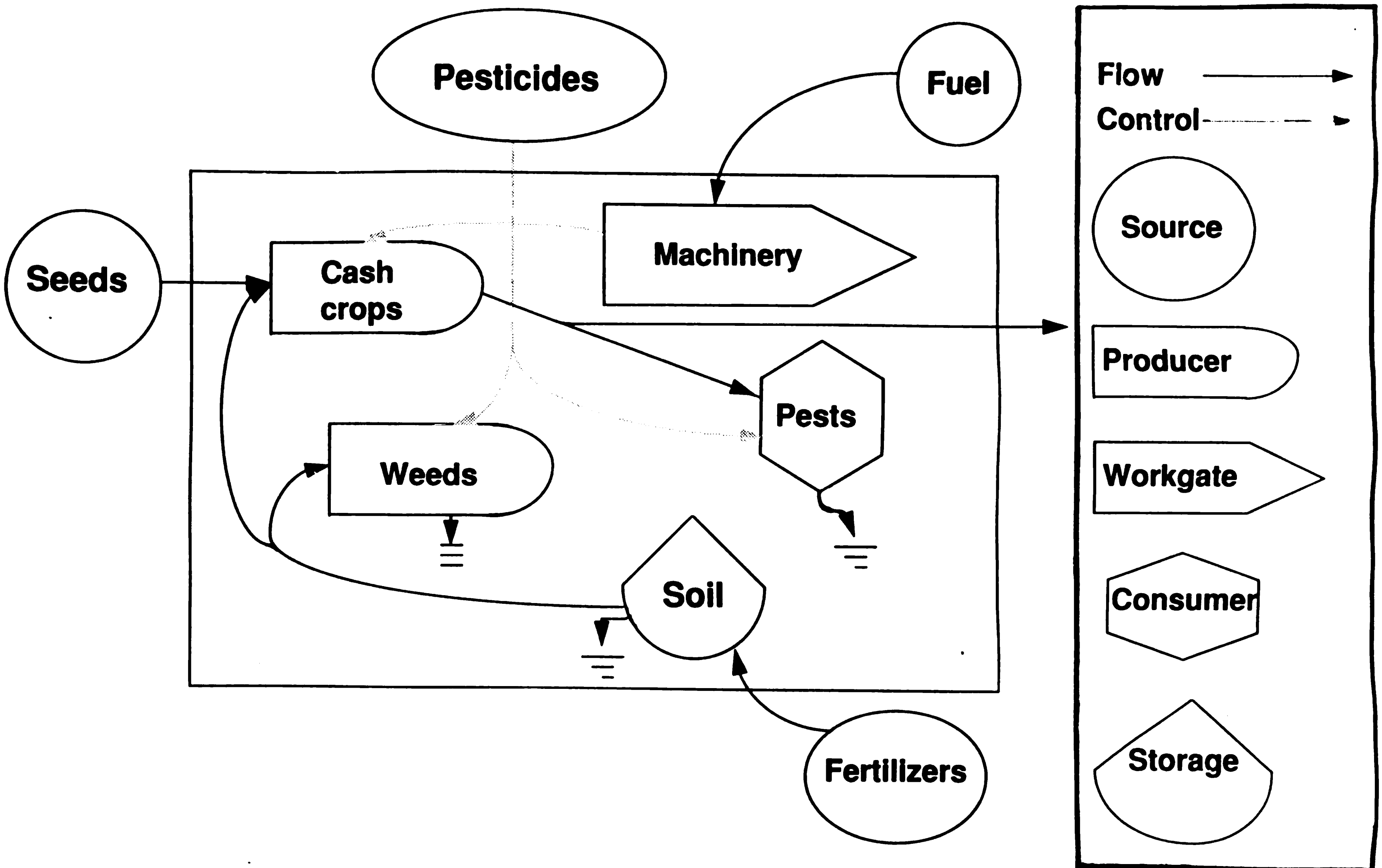


Figure 2.1 System diagram of the conventional system (CONV) in the Rodale Farming Systems Trial.

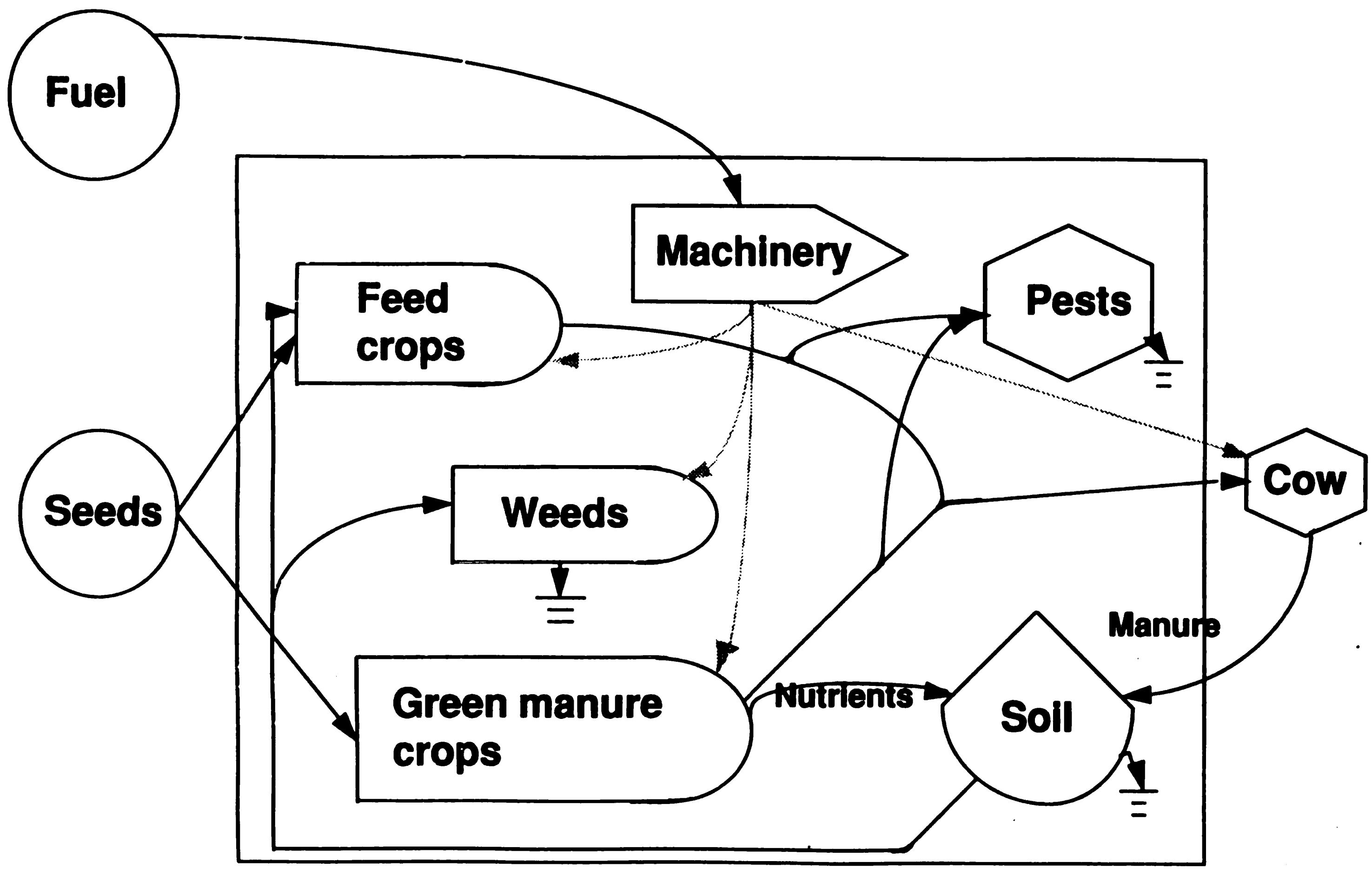


Figure 2.2 System diagram of the low-input with animal cropping system (LIP-A) in the Rodale Farming Systems Trial.

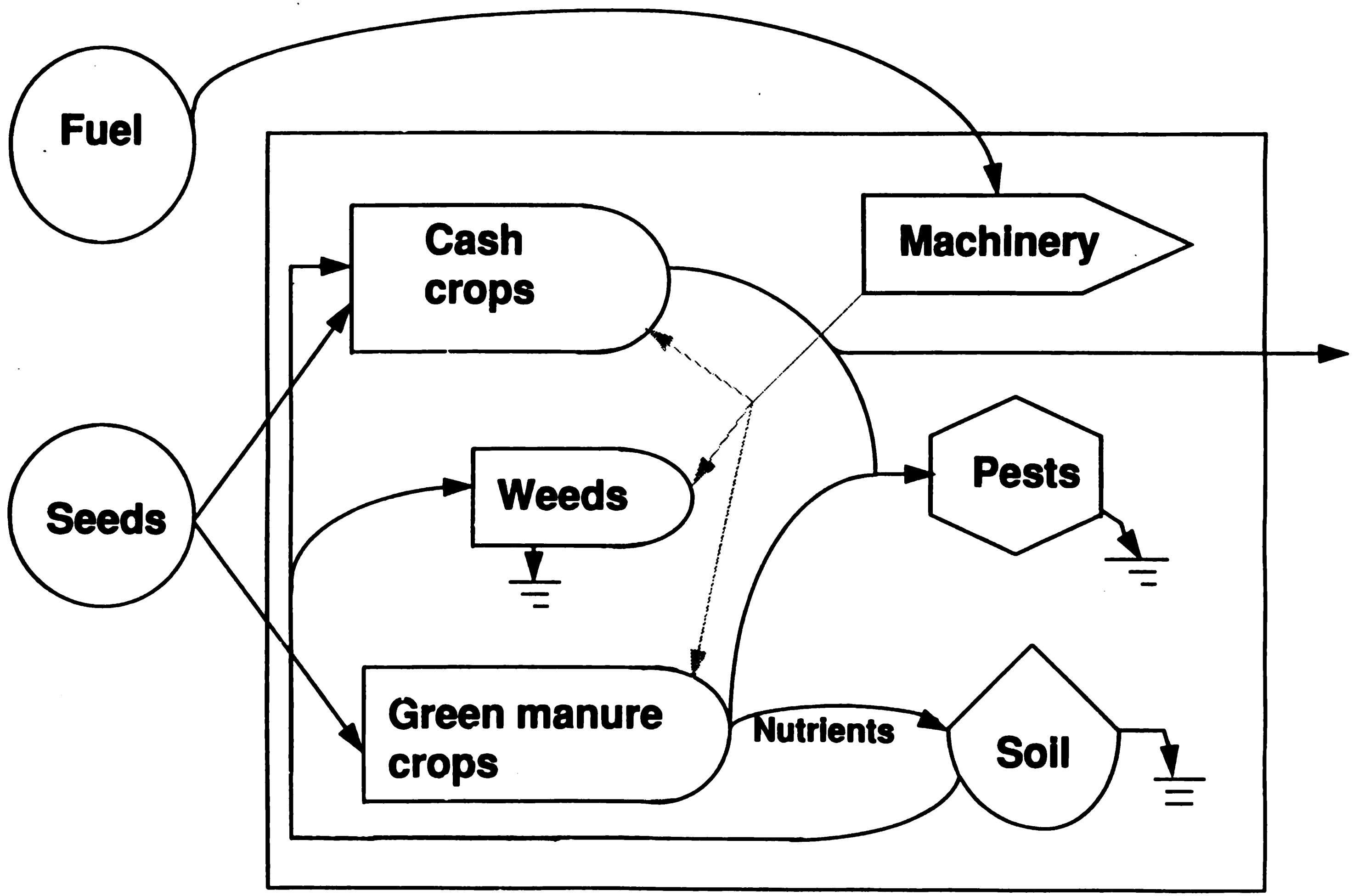


Figure 2.3 System diagram of the low-input cash grain cropping system (LIP-CG) in the Rodale Farming Systems Trial.

Cropping system	Rotation entry pt.	Year 1981	1982	1983	1984	1985
		Crops				
1 Low-input/ livestock	1	oat red clover	red clover (2nd yr)	corn	soybean	corn (silage)
	2	corn	soybean	corn (silage)	wheat red clover	red clover (2nd yr)
	3	corn (silage)	wheat red clover	red clover (2nd yr)	corn	soybean
2 Low-input/cash grain	1	oat red clover	corn	oat red clover	corn	soybean
	2	soybean	oat red clover	corn	wheat hairy vetch	corn
	3	corn	soybean	oat red clover	corn	oat red clover
3 Conventional	1	corn	corn	soybean	corn	soybean
	2	soybean	corn	corn	soybean	corn
	3	corn	soybean	corn	corn	soybean

Table 2.1 Treatment design and rotation schedule of the Rodale Farming Systems Trial, 1981-1985. Source: Liebhardt et al., 1989.

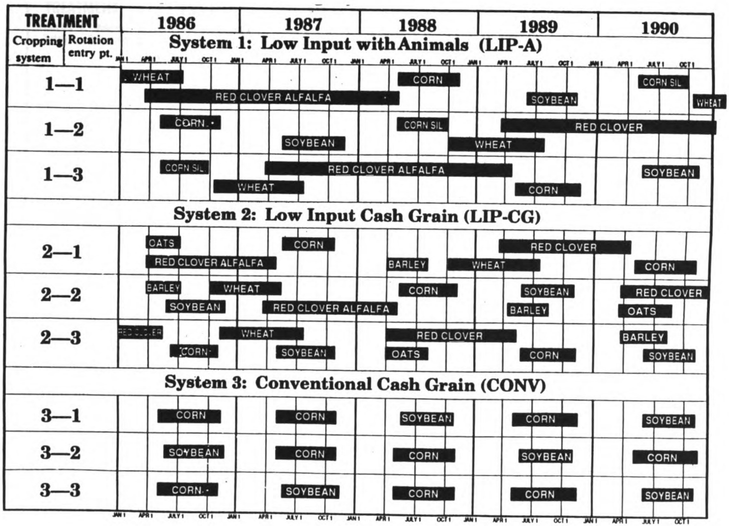


Figure 2.4 Treatment design and rotation schedule of the Rodale Farming Systems Trial, 1986-1992. Source: Rodale Institute Research Center.

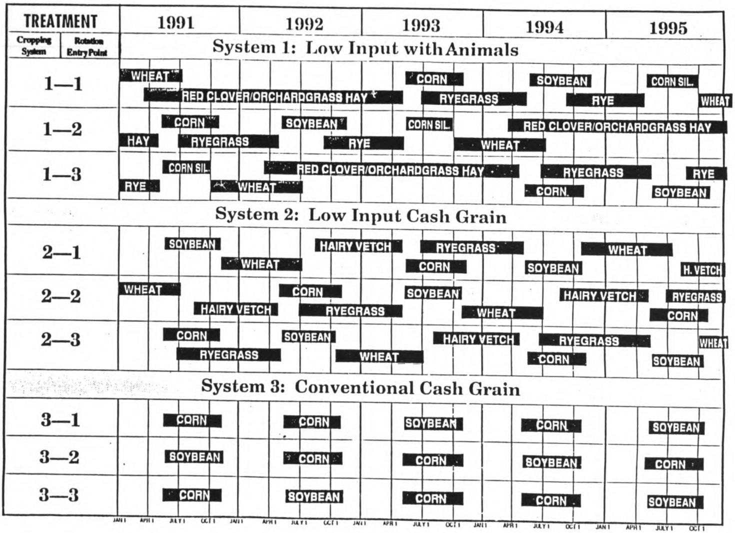
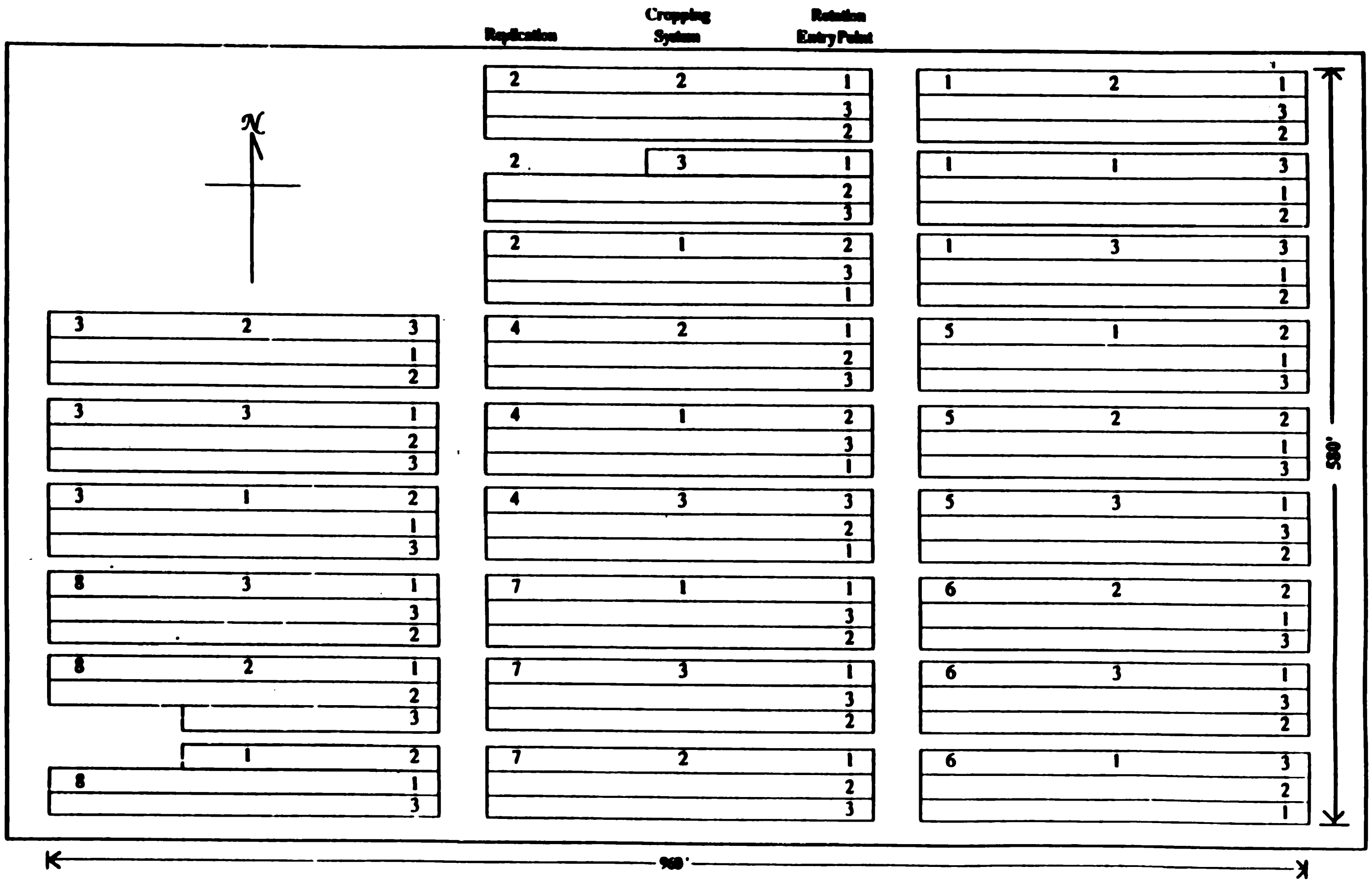


Figure 2.4 (cont'd).



Cropping System 1 = Low Input Animal (LIP-A)
2 = Low Input Cash Grain (LIP-CG)
3 = Conventional Cash Grain (CONV)

Figure 2.5 Rodale Farming Systems Trial field layout. Source: Peters et al., 1992.

Objectives. The objectives in the first five-year phase of the trial were:

* to define yield-limiting factors that occur during the transition process,
* to identify methods of minimizing yield reductions, and
* to identify physical, chemical, and biological processes that occur during conversion to low-input methods" (Liebhardt et al., 1989: 151).

As the experiment entered its second phase in 1986, it focused on the long term economic reliability, sustainability, and environmental impact of low-input and conventional techniques. Therefore, the study in this phase retained the same concern about yields in different systems, while it differed from the interests of the first phase in that more attention was focused on biological and chemical impacts of the different practices on their ecosystems, especially the soil's condition (Peters et al., 1992).

Major findings. They found that corn grain yields in the low-input systems were 75% of the conventional in 1981 to 1984, largely due to weed competition and insufficient nitrogen in the low-input fields. But in 1985 corn yields increased to the same level as the conventional system. Soybean production was at the same level or greater in the low-input systems than in the conventional system. It was suggested that a favorable transition from input-intensive to low-input systems is feasible if crop rotations are applied with crops that demand less nitrogen and are competitive with weeds (Liebhardt et al., 1989).

The major findings in the second (1986-1990) phase of the study showed that corn yields were nearly the same in all systems from 1986 to 1990. Moreover, in a dry year (1988) corn in a CONV treatment, which had also grown corn in 1987, was outyielded by both low-input systems. However, average LIP-CG soybean yields from 1986 to 1990 were about 85% of those in the other systems, resulting partly from the intercropping with either wheat or barley in the system. Weed levels were generally greater in the LIP systems compared to the CONV, causing yield reduction in two corn treatments and two soybean treatments. Ear leaf nitrogen concentration at corn silking in all treatments usually equalled or exceeded the sufficiency level. Soil nitrate-nitrogen levels in all corn treatments were always higher in the LIP-A system than in the other systems. Water infiltration rates and organic matter levels were higher in the low-input systems than in the CONV system after ten years. Since 1981, soil phosphorus levels had remained high; soil nitrogen levels had increased in LIP-A, unchanged in LIP-CG, and slightly decreased in CONV; but potassium levels had dropped constantly in all systems until the application of potassium fertilizer to all treatments in 1989 (Peters et al., 1992)

According to the results of the study from 1981 to 1990, it has been concluded that low-input farming either with use of animal or green manures could be promising if well-designed crop rotations are applied. Also, low-input systems can provide a favorable soil environment to sustain the growth of healthy crops in the long term.

Results from economic studies. Hanson et al. (1990) carried out a whole-farm study to compare the profitability of the low-input cash grain and conventional systems in the Rodale FST. They considered the influence of various government programs and concluded that the low-input approach is advantageous for risk-averse farmers. They also found that the profit trend was upward for the low-input scenario, but that the economic transitional period was longer than the biological one. They suggested that soil improvement in the low-input fields might have contributed to higher profitability for the low-input operation in the latter years of the study.

Another economic analysis of the FST (Duffy et al., 1989) pointed out that the LIP-A and CONV systems are significantly superior to the LIP-CG system from the farm return point of view. The result of the study reveals that farmers in transition to low-input practices are well advised to avoid row crops, i.e., corn and soybeans. If the crops are to be grown, the authors suggest the use of intermediate levels of commercial fertilizers and pesticides to avoid major loss of profits during the conversion period.

An economic study, conducted by Dunbar (1991) to evaluate the profitability of the Rodale farming systems, showed that returns above variable costs were slightly higher in conventional production than in low-input production. The author concluded that low-input practices are promising due to: 1) lower or no chemical costs, 2) more effective labor use, and 3) more profitable corn production.

Needs for further studies. Some points remain unclear and demand further study:

1. Because the trial was divided into at least two stages with various foci, and currently remains in operation, an overall examination of the twelve-year experiment might help combine the separated parts into one continuous process and make the entire study more comprehensive.

2. The practicality of the low-input systems in the Rodale FST on real farms should be documented because success in research fields does not necessarily guarantee success in a

real farming situation. An assessment should be conducted before the alternative systems and management practices are applied on farms. A whole-farm production analysis and comparison should also be included. For example, in the reports (Peters et al., 1992 and Liebhardt et al., 1989) of the farming systems trials, the corn and soybean yields are compared on the basis of the productivity of the crop-growing plot (i.e., production per acre or per hectare of the corn and soybean-growing plots), not the productivity of the whole cropping system. In a real farm context, the farm incomes are dependent on the productivity of the entire farming system. Therefore, an comparison of the whole system productivity might help farmers make decisions in a more realistic context.

3. Sustainability is an important concept but was not clearly defined in the reports. It could help to develop indices of sustainability which could be used to examine some basic and unanswered questions in the trials, such as " are the low-input systems more sustainable than the conventional one?"

4. Although some fundamental variations between the low-input and conventional farming practices remain, the systems were all operated with identical machinery. Fossil fuel

consumption was reported to be higher in 1981 in the low-input systems, and total energy consumption was higher in the conventional system (Harwood, 1985: 65). No additional evidence is available for characterizing the consumption in other years. The analysis of fuel consumption over all years would help us evaluate the performance of the alternative farming systems.

CHAPTER 3

PROBLEM STATEMENT AND HYPOTHESES

Chapter Introduction

The problem and design of this study is based on the discussion in the last chapter. A main definition of agricultural sustainability, with four associated factors, is developed to analyze the problem. Finally, four quantitative hypotheses are described in the last section of this chapter, providing the research structure of this thesis.

Problem Statement

This study addresses comparative sustainability in each of the three Rodale farming systems through energy and economic analyses of the 12-year experimental data. The major objective of this study is to test <u>the hypothesis that the low-input cropping systems are more sustainable than the conventional systems from the viewpoints of energy use and economic performance.</u>

Definitions and Measurement of Main Variables

> **In this study, a farming system is defined to be more energy sustainable compared to other farming systems if it uses less nonrenewable energy while it maintains or increases productivity on or above an acceptable level over a long period of time.**

Nonrenewable energy. The nonrenewable energy of farming systems is the fossil fuel-based energy embodied in gasoline, diesel, machinery, seeds, commercial fertilizers, and pesticides. It is also assumed that renewable resources such as solar energy, water, green and animal manures and biomass can be regenerated and thus are not exhaustible.

Comparable production level. There are a number of different methods to determine the acceptable production level of a farming system. One approach used in this study examines the biomass and food energy production of a system. If the food energy production levels in the low-input systems are comparable to those of the conventional system, they are acceptable.

The second approach examines the level of net farm return. It is generally noted that low-input practices produce lower crop yields than conventional operations, but low-input practices also cost less because they use few external inputs. If the loss resulting from reduction of yields in a low-input system can be recovered by cost savings, leading to similar net returns for the low-input and conventional systems, then the low-input production level is acceptable.

Long-term stability. Long-term stability is another major criterion for a sustainable production system. In this study, two types of systems stability will be analyzed. One is energy stability, the other is economic stability. A definition of systems stability by Conway (1990: 219) is used. He defined stability as:

> the **constancy of productivity** in the face of small disturbing forces arising from the normal fluctuations and cycles in the surrounding environment.

Among many techniques of statistical analysis, coefficient of variation is mostly commonly used in measures of relative dispersion among several sets of observed values (Stockton and Clark, 1980: 93-94; Thomas, 1983: 15). The coefficient of variation is defined as the ratio of a standard deviation to the mean of the data from which the standard deviation was computed. Comprehensively stated, the coefficient of variation presents a standard deviation as a percentage of the mean of a set of values. It provides a standardized basis for a cross comparison of the variability of various sets of data with different average values.

The concept of constancy is exactly opposite to the concept of variability. In mathematics, this opposite relation can be expressed as a reciprocal one. Therefore, in this thesis, the relative stability of system productivity will be measured by the reciprocal of the coefficient of variation of the twelve productivity values in each system.

In this definition of stability, the concept of productivity is especially important. As Conway (1990: 219) stated:

> **Productivity is the output of valued product per unit of resource input.**

Based on this statement, definitions of energy productivity and economic productivity can be developed and described as:

> **Energy productivity of a farming system is defined to be the ratio of the food energy output to the nonrenewable energy input to the system in a particular period.**

and similarly,

> **Economic productivity of a farming system will be defined in terms of the ratio of the income obtained from valued output to the investment in the system needed to generate the output in the in a particular period.**

Actually, farm management economists use the term <u>profitability index</u> to describe the concept of economic productivity defined in this thesis. Harsh et al. (1981: 247) defined the profitability index to be <u>the ratio of the</u>

present value of an investment to the cost of the investment. Hence, economic stability in this thesis can be appropriately described as the **stability of profitability** of a farming system.

In this study, one year is used as a time unit in calculating productivity and profitability for each cropping system.

Long-term stability is a major concern in this analysis, but the question of "long term" is a subjective judgement. In theory, the longer the period to be studied, the more valid the study is in addressing long-term effects. For this analysis, twelve years is the maximum period for which data are available.

Hypotheses

As discussed earlier, the main hypothesis of the study includes five properties: nonrenewable energy consumption, energy production, returns, energy stability, and economic stability. This study has five specific quantitative hypotheses presented below.

Nonrenewable Energy Consumption. The low-input cropping systems consume less nonrenewable energy embodied in machinery, fuels, seeds, commercial fertilizers, and synthetic pesticides than the conventional system. Formally stated, the hypothesis to be tested is:

H1: The total nonrenewable energy consumption in the low-input cropping systems will be less than that of the conventional system.

Comparable Energy Production Levels. The low-input farming systems are able to produce as much food as conventional systems. Formally stated, the hypothesis to be tested is:

H2: The food energy production per hectare in the low-input farming systems will be greater than or equal to that of the conventional system.

Energy Productivity Stability. The two low-input systems are more stable in terms of food-energy productivity than the conventional system. Formally stated, the hypothesis to be tested is:

H3: The reciprocals of coefficients of variation of energy productivity values (ratios of yearly food energy production to nonrenewable energy input) in both low-input systems are greater those that in the conventional system.

Economically Comparable Production Levels. The dollars saved by reducing energy input in each low-input system compared to the conventional, is greater than or equal to the dollar losses which result from lower yields compared to the conventional in a particular time period. Formally stated, the hypothesis to be tested is:

H4: The returns above variable and amortized equipment costs, measured by the difference between total revenue from valued crops (crop sales) and the costs in each low-input system will be greater than or equal to that of the conventional system.

Economic Stability. The two low-input systems are more stable in terms of profitability than the conventional system during the same time period. Formally stated, the hypothesis to be tested is:

H5: The reciprocals of coefficients of variation of profitability values (ratios of total yearly revenue from crop sales to total variable and amortized equipment costs) in both low-input systems are greater than those in the conventional system.

These hypotheses will be tested for each cropping system in the Rodale Farming Systems Trial on an annual basis, over periods covering the first five years, the last seven years, and the total 12 year period respectively.

CHAPTER 4

RESEARCH APPROACH

Chapter Introduction

The research design of this thesis has been provided through the description of the hypotheses in the last chapter. Energy and economic analyses are two major sectors of this study. The former uses energy as an indicator in the exploration of a system while money is used by the latter. Both are quantitative approaches to a system analysis and cannot be carried out without sufficient quantified data. Additionally, some important assumptions need to be established in conducting the analyses. This information will be fully described in this chapter. All calculations in this study were done using a Lotus 1-2-3 for Windows spreadsheet package.

Sources of Information

Field data. Field data used in this study were provided by the Rodale Institute Research Center, including records of crop yields for every replication in each system, and documents of field inputs such as the date, type, and amount of seed, fertilizer, animal manure, and pesticide applied to the field for each of the three systems. Data on field operations were also collected, including types and number of tillage operations, planting, harvesting, and machinery used. These data were produced and organized on an annual per-acre basis for each of the nine treatments by the project group from 1981 to 1992. The yield data were recorded for each replication plot. Information about the rotational pattern, climate and nutritional content and moisture of manure and crops was provided in two major published reports of the trial, by Liebhardt et al. (1989), and Peters et al. (1992). These two documents also presented detailed data, process, and findings in the first five years and the following five years of the project respectively.

Results of previous studies. As mentioned earlier in the literature chapter, the Rodale cropping systems trial has been studied intensively since 1981 by individuals and research groups not associated with the Rodale Institute. Part of this information has been collected and is available for economic analysis and comparison in this study. These published articles and reports include Dabbert, 1986; Duffy et al., 1989; Hanson et al., 1990; and Dunbar, 1991.

Energy Estimates and Analysis

Conversion ratios. Energy conversion factors of various input materials and output crops were obtained largely from a energy handbook edited by D. Pimentel (1980). This publication is probably the most widely-used data source for energy analysis in agricultural production. Other data needed for energy estimates can be found in other energy handbooks of particular agricultural industries, such as the fertilizer and pesticide sectors. Other conversion factors used in this study are listed in Table 4.1.

Table 4.1 Conversion factors used in the analysis.

1 mile	= 5280 ft
1 inch	= 2.54 cm
1 hectare	= 0.4 acre
1 square feet	= 2.3 E -5 acre
1 gallon	= 3.785 liter
1 pound	= 0.454 kg
1 short ton	= 909 kg
1 bushel of corn grain	= 56 pounds of corn grain
1 bushel of wheat	= 60 pounds of wheat
1 bushel of soybeans	= 60 pounds of soybeans
1 bushel of oats	= 32 pounds of oats
1 bushel of barley	= 48 pounds of barley
1 bushel of rye	= 60 pounds of rye*
1 kcal	= 4186 joules

* Assuming the same as wheat.

Estimates in the literature of the energy embodied in particular products or inputs are generally average values which were derived under various assumptions. As Kaffka (1984: 37) pointed out, the energy embodied in synthetic fertilizer may differ depending on the type of fertilizer, its manufacturing process, efficiency of the factory, and other factors. Therefore, efforts have been made to choose values carefully based on the criterion of consistency among several authors. The details of energy calculations are discussed later in this chapter.

Basis for the calculation and comparison. All the process and results of energy estimates in this study are shown by mean values in units of kilo-calories (kcal) per hectare per year for a cropping system. As mentioned in the description of the Rodale Farming Systems Trial (Rodale FST) in Chapter Two, there are three rotation entry points in each of the systems, resulting in nine treatments in the trial. This study will focus on the analysis of the whole system, and comparisons between systems, instead of treatments. This is because the level of sustainability that this thesis examines is the farm/microeconomic level. This study is most concerned about the practicality of low-input practices in a real farm situation. On a real organic farm, a farmer may not operate by using only one rotational entry point, or by growing only one crop at a time.

Another reason for not considering the effect of rotation entry points in this study is provided. Although it is recognized that the overall energy production in the low-input systems was lower for the treatments started with corn than the others, no consistent and significant difference in energy production between treatments with different rotation entry points was noted for the low-input systems (See Table 4.2). For example, a comparison of energy production between treatments shows that in the low-input with animal system, although the second treatment which started its rotation with corn produced less energy than the first treatment started with oats and clover, the third treatment started with corn silage had equal energy output of the first treatment in the first five years. In the low-input cash grain system, the third treatment started with corn averaged higher energy production than one of the other two treatments started without corn in the meantime. The difference between treatments seemed more obvious in the comparison of corn leaf tissue nitrogen concentration as discussed in the literature of Liebhardt et al. (1989), but not in yields. Stated another way, energy analysis based on yield data might have difficulties to examine the micro difference between treatments with distinct rotation entry points. Therefore, the field data for both inputs and crop yields of the three subsystems within a system are first summed and then converted into mean values, giving a system basis for comparison.

Table 4.2 Average energy production of the low-input treatments in Rodale Farming Systems Trial, 1981-1985. Source: Rodale Institute Research Center.

Cropping system	Entry point	Energy production (million kcals/ha/yr)	Initial crop
LIP-A	1	21.40	oat, clover
LIP-A	2	13.43	corn
LIP-A	3	21.40	corn (silage)
LIP-CG	1	19.20	oat, clover
LIP-CG	2	13.61	soybean
LIP-CG	3	15.03	corn

There are at least four types of soil (Peters, November 13, 1992, personal communication) which vary in productive ability and which might result in different levels of productivity from one system to another. Nevertheless, the effect of this uncontrolled variable is assumed to be minimized by random distribution of a system into eight mainplots (replications) before the trial was initiated.

Inputs excluded from energy calculation. Some researchers have pointed out that low-input practices may use human labor, manure, or information more intensively than do conventional practices (Francis and King, 1988). Nevertheless, human labor, animal manure, and information will not be included in energy calculations. This decision was based on two considerations. First, labor and manure are considered to be renewable from a physical perspective, thus they are treated like other renewable resources as water, solar energy, etc. Second, although creating information (largely through research) may involve consumption of much nonrenewable energy, once the information is generated, it can be repeatedly applied on indefinite number of times. Calculus suggests that the nonrenewable energy consumed to generate one information application approaches zero as the number of applications of the information increases.

Additionally, transportation of manure from the beef farm for the low-input with animal system is neglected in this analysis because of the short distance (about one mile) between the farm and the experimental site.

Some indirect inputs such as buildings, and hardware are not included in this study, largely due to lack of information and partly because of the variation of these inputs farm one farm to another. Therefore, this analysis will focus only on the estimates of direct inputs.

Energy embodied in machinery. This energy input is calculated by multiplying the amount of machinery consumed per hectare (in terms of kg) by a conversion factor, 18000 kcal/kg (Table 4.3), which represents the average energy

Table 4.3 Energy embodied in diesel fuel and machinery.

	Unit	Kcal/unit	Source
Diesel*	liter	11414	Cervinka, 1980: 15
Machinery	kg	18000	Pimentel and Pimentel, 1979

* Diesel fuel consumption is assumed to be 0.053 gallon of diesel fuel per drawbar HP hour (Fuller et al., 1992: 1).

embodied in a kilogram of farm machinery. The amount of machinery consumed in an operation is estimated from the operation, and the size, weight, and life of the machinery used for the operation. For example, the machinery consumed in a moldboard plow (MP) carried out by a 8-16" moldboard plow of 1400 kg and a 160-hp tractor of 5789 kg with 2000 and 10000 hours of life respectively is calculated as following:

According to the data provided in "Minnesota farm machinery economic cost estimates for 1992", work performed by a 8-16" MP is approximately 4.65 acre per hour. One hectare is 2.5 acres. It thus requires 2.5 * 1/4.65, i.e., 0.54 hour, to moldboard plow a one-hectare field. The average machinery consumed per hour for equipment is calculated by dividing its weight by its life hours, resulting in 0.7 and 0.58 kg for the MP equipment and the tractor respectively. Therefore, it will consume (0.7 + 0.58)* 0.54 which is approximately 0.69 kg of machinery to plow a hectare with a moldboard plow.

Due to the fact that machinery utilization varies greatly from farm to farm, farms of significantly different size may use different machinery. Some have argued that it may not be reasonable to estimate the energy consumed in machinery by using the machinery information from the Rodale FST because the equipment was mainly for experimental purposes (Peters, November 13, 1992; and Harwood, January 1991, personal communication). To tackle this problem, this study will conduct one calculation and analysis according to the machinery used in the Rodale FST. Another calculation will be carried out assuming that the operation in each of systems of the trial is practiced on a standardized 500-acre farm with commonly-used machinery, because some organic farms of that size have been reported (USDA, 1980). This decision was also based upon the hope that the information provided by the trial and the analysis could be useful to operators in a more realistic situation.

For the sake of the comparison between the three systems, it is also assumed in this study that all systems were operated on farms of the same size and with the same machinery. The machinery designs and associated information for Rodale FST and the standardized farm are shown in Table 4.4 and Table 4.5 respectively.

Table 4.4 Machinery used in the Rodale Farming Systems Trial.

Machine	Size	Operation	Weight (kg)	***Total costs /hour	++Life (hour)	Work Perform (acre/hr)
Tractor JD 2840	80 hp	M.P., Chisel	3950		10000	
Tractor JD 2640	70 hp	Disk, Harrow, Field Cultivate Spread manure Cut hay/silage	2238		10000	
Tractor JD 2040	40 hp	Plant corn/sybn Drill, Spray Herbicide	1945		10000	
Tractor IH 584	50 hp	Cultivate, Rotary hoe Rotary mower cultipack	2318		10000	
Tractor IH 140	30 hp	Sidedress	1376		10000	
Tractor Oliver 1750	80 hp	Bale, Rake, Ted	4915		10000	
Combine JD 6620	small	Combine	7718	74.11	2000	3.58
Moldboard plow	3-18	Moldboard plow	*750	+29.5	2000	1.96
Tandem disk	10ft	Disk, Harrow, Field cultivate	+1250	24.14	2000	4.85
Chisel plow	10ft	Chisel plow	**800	27.48	2000	4.36
Planter JD 71 Flex	4-30	Plant corn/soybean	92	+35.92	1200	3.28
Drill JD 7100	12ft	Drill small grain	864	37.81	1200	4.78
Cultivator	4-30	Cultivate	**400	+20.59	2000	3.88
Rotary hoe JD 415	6-30	Rotary hoe	599	+26.82	2000	+10.18
Manure spreader	150bu	Spread manure	753	+29.17	1200	3.49
Fertilizer spreader	20ft	Sidedress	**300	+38.02	1200	19.4
Lime truck	2 tons	Spread lime	**3700	+27.81	10000	+14.6
Sprayer	20ft	Spray Herbicide	**200	+25.24	1500	9.45
Forage harvester NH 717	8ft, 2R	Cut hay/corn silage	726	+48.02	2000	+1.5
Rotary mower Wd's M84p	7ft, 2-30	Rtry mow, cultipack	563	+25.64	2000	3.19
Baler Case Int'l 8420		Bale hay/straw	1444	+33.63	2000	3.78

Source: RIRC; NAEDA Offical Guide, spring 1992; Fuller et al., 1992.

+ Estimates
++ American Society of Agricultural Engineers Standards, 1991.
* John Deer Co. Catalog
** Scott and Krummel, 1980: 120
*** Includes depreciation, interest, insurance, housing, repairs, fuel, labor, and lubricants.

Table 4.5 Machinery used on a 500-acre standardized farm.

Machine	Size	Operation	Weight (kg)	***Total costs /hour	++Life (hour)	Work Perform (acre/hr)
Tractor JD 8050	160hp	M.P., Chisel Disk, Harrow, Field Cultivate	5789		10000	
Tractor JD 2840	80hp	Spread manure Cut hay/silage Plant, Drill, Cultivate Rotary mower, Rake Sidedress, Bale Ted, Cultipack	3950		10000	
Tractor JD 2040	40 hp	Rotary hoe Spray Herbicide	1945		10000	
Combine Massey-Ferguson 8	Med. 20 ft	Combine	8626	88.64	2000	4.14
Moldboard plow	8-16	Moldboard plow	+1500	58.26	2000	4.65
Tandem disk	32ft	Disk, Harrow, Field cultivate	+3000	61.66	2000	15.52
Chisel plow	20ft	Chisel plow	+1500	46.73	2000	8.73
Planter JD 7000	8-30	Plant corn/soybean	1791	62.08	1200	6.55
Drill JD 7100	20ft, 8-30	Drill small grain	1352	56.88	1200	7.96
Cultivator	8-30	Cultivate	550	30.46	2000	7.76
Rotary hoe	16ft	Rotary hoe	550	26.38	2000	10.86
Manure spreader Case Int'l 53	150bu	Spread manure	753	29.17	1200	3.49
Fertilizer spreader	40ft, 4 ton	Sidedress	400	+64.67	1200	38.79
Lime truck	2 tons	Spread lime	*3700	27.81	10000	+14.6
Sprayer	30ft	Spray Herbicide	+350	27.72	1500	14.18
Forage harvester NH 717	8ft, 2R	Cut hay/corn silage	726	+48.02	2000	+1.5
Rotary mower BH 3108-01	9ft	Rtry mow, cultipack	977	+41.65	2000	4.64
Baler Case Int'l 8420	14*18"	Bale hay/straw	1823	+34.95	2000	4.64

Source: RIRC; NAEDA Offical Guide, spring 1992; and Fuller et al., 1992; with knowledgable assistance of Dr. G. Schwab.

\+ Estimates

++ American Society of Agricultural Engineers Standards, 1991: 299.

* Scott and Krummel, 1980: 120

** Includes depreciation, interest, insurance, housing, repairs, fuel, labor, and lubricants.

Fuel. In this study, all powered equipment is assumed to consume diesel fuel. Diesel fuel consumption is calculated by 0.053 gallons of diesel fuel per drawbar HP hour (Fuller et al., 1992). For instance, a 50-hp tractor consumes 50*0.053 gallons of diesel fuel in one hour of operation. The energy embodied in a liter of diesel fuel is 11414 kcal (Table 4.3) which has been used in many energy analyses.

Fossil energy embodied in seeds. Seeds are one of the major inputs in agriculture. In a modern seed industry, a large amount of fossil energy is consumed to produce seeds. In this study, the energy embodied in seeds includes the energy needed in the production, processing, and distribution of seeds. The amount of seed energy varies from crop to crop. Table 4.6 is a list of the values for various seeds used in the Rodale FST.

Table 4.6 Estimated fossil energy costs of field seed production, processing and distribution.

Crop	Kcal/kg	Source
Seed oats	4108	Heichel (1980: 32)
Clover, Red	37604	Heichel (1980)
Seed corn, hybrid	24806	Heichel (1980)
Soybean seed	7584	Heichel (1980)
Seed wheat, spring	3002	Heichel (1980)
Seed barley	3318	Heichel (1980)
Ryegrass	12166	Heichel (1980)
Orchardgrass	21646	Heichel (1980)
Rye seed	3340	Reeves (1980: 100)
Hairy vetch	14421*	

* Estimates.

Energy embodied in commercial fertilizers. Table 4.7 shows the energy embodied in various types of commercial fertilizer. Each number listed in the table is an average value and includes the energy needed to manufacture, transport, and distribute the final product.

Table 4.7 Energy inputs for chemical fertilizers.

Fertilizers	Kcal/kg	Source
Urea	14300	Lockeretz (1980: 24)
Ammonium nitrate	14700	Lockeretz (1980)
Liquid N (UAN)*	14700	
Crushed limestone	315	Terhune (1980: 26)
Starter fertilizer	272	Mudahar and Hignett (1987: 52)
Potassium sulfate	1600	Lockeretz (1980)

* Assuming the same as ammonium nitrate.

Energy embodied in synthetic pesticides. Rodale FST has used various herbicides and one insecticide recommended by Pennsylvania State University in the conventional cropping system. Information on the energy embodied in different products is not available. In this study, average values of energy inputs, including the energy in the production, formulation, packaging, and transportation of herbicides and insecticides were used. For the purpose of calculation, the herbicide and insecticide purchased for Rodale FST were assumed to be in the forms of miscible oil and granules, respectively. The energy values for the pesticides are shown in Table 4.8.

Table 4.8 Energy inputs (production, formulation, packaging, transport) for various pesticides. Source: Pimentel, 1980: 47.

Pesticides	Kcal/kg
Herbicide	
Miscible oil	99910*
Wettable powder	62770
Granules	86600
Insecticide	
Miscible oil	86910
Wettable powder	61470
Granules	74300*
Dust	74300

* Used for this analysis.

Energy contained in crops. Some studies have been done by separating nutritional content and caloric content in calculating energy contained in crops (Burnett, 1978). This is especially necessary for a production system with high-protein products like milk and meat. In Rodale FST, the products of the systems are crops, thus only the caloric content is considered in this study. Table 4.9 shows the energy contained in the crops produced in Rodale FST.

It should be noted that feed crops like corn silage produced in the low-input with animal system, and hay and straw in both low-input systems in Rodale FST will be included in the energy calculation. Although these products are not consumed directly by human, resulting in lower economic values than those of food grains like corn and wheat, the energetic content in the feed crops might not be distinct from that in the food crops from physical point of view.

Table 4.9 Food energy in various cash crops.

Crop	Kcal/kg	Source
Corn grain	3550	Burnett (1978: 145-148)
Soybean	4030	Burnett (1978)
Wheat	3300	Burnett (1978)
Barley	3480	Burnett (1978)
Oats	3900	Burnett (1978)
Rye	3340	Burnett (1978)
Corn silage	1085*	Pimentel (1984: 9)
Hay	2713**	Pimentel (1984: 9)

* for corn silage with 65% moisture.
** includes alfalfa, straw, and hay.

Human labor. As mentioned earlier in Chapter 2, human labor estimates will not be included in the energy calculation. The human labor needed in the three cropping systems is measured and discussed in terms of hours.

Economic analysis

Agricultural prices. Information about the prices of inputs and products of Rodale FST in the past twelve were obtained primarily from various issues of "Agricultural Prices" published by USDA. Prices in either March, April, or May were collected depending on the availability of the data. The prices of seeds, diesel fuel, commercial fertilizers, and pesticides were average prices paid by farmers in the U.S.; the crop prices were the average prices received by U.S. farmers. Various herbicides and starter fertilizers were used in the Rodale conventional system, and not all of these agrichemicals could be found in the statistical document. Therefore, an average value was derived for total herbicide use in a year, and for starter fertilizer. It was found that the prices of Lasso and 13-13-13 can reasonably represent the average prices of herbicide and starter fertilizer, respectively. Hence, prices of the two products were used for herbicides and starter fertilizers in this thesis.

The information about prices of manure, rye seed, hairy vetch seed, corn silage, and straw was not available in the USDA documents. Other sources were used to determine these prices. The total price data needed in this study and their sources are shown in Table 4.10.

Estimates of operation costs. Operation costs in this study include the costs of human labor, machinery, and fuel. These costs will be calculated together rather than individually, because they are all machinery-related costs. Stated another way, the cost of operating machinery for one hour includes not only the costs of the machinery itself,

Table 4.10 Prices of various agricultural commodities, 1981-1992.

Year		1981	1982	1983	1984	1985	1986
Commodity	Unit	Prices $/unit	Prices $/unit	Prices $/unit	Prices $/unit	Prices $/unit	Prices $/unit
Diesel	gallon	1.16	1.11	0.98	1.00	0.97	0.70
Manure+	ton	11.00	12.00	12.00	12.00	12.00	12.00
SEEDS							
corn	bu	60.00	63.70	64.60	70.20	67.30	65.60
soybeans	bu	14.00	10.70	10.10	13.40	11.90	11.80
wheat	bu	7.22	6.89	6.89	6.37	6.10	5.94
oats	bu	4.42	4.51	4.37	4.52	4.18	3.63
barley	bu	5.95	5.60	5.22	5.31	5.10	4.82
rye++	bu						7.25
ryegrass	100 lbs	37.80	37.20	39.20	39.00	37.30	36.10
orchardgrass	100 lbs	98.00	101.00	96.10	94.70	80.90	86.90
clover, red	100 lbs	117.00	126.00	160.00	145.00	121.00	133.00
hairy vetch+++	100 lbs	57.20	58.40	58.40	62.60	63.40	61.30
FERTILIZERS							
Urea	ton	237.00	240.00	213.00	227.00	217.00	174.00
A. nitrate	ton	185.00	195.00	184.00	198.00	189.00	171.00
UAN	ton	150.00	158.00	148.00	153.00	146.00	132.00
limestone	ton	14.60	15.50	16.00	16.30	16.00	15.90
N-P-K*	ton	188.00	191.00	184.00	187.00	187.00	165.00
K sulfate	ton	152.00	155.00	143.00	147.00	128.00	111.00
PESTICIDES							
Insecticides	50 lbs	43.40	46.80	51.20	72.10	78.30	77.00
Herbicides**	5 gals	85.10	93.10	99.12	105.00	105.00	101.92
CROPS							
Corn	bu	3.16	2.41	3.03	3.36	2.70	2.25
Soybeans	bu	7.10	5.88	6.06	8.24	5.88	5.13
Wheat	bu	3.93	3.60	3.75	3.59	3.43	3.16
Oats	bu	2.03	1.96	1.54	1.88	1.68	1.07
Barley	bu	2.97	2.36	2.37	2.60	2.16	1.86
Corn silage***	ton	26.96	22.46	26.18	28.16	24.20	21.50
Baled hay	ton	71.60	70.90	83.90	84.90	72.50	69.20
Straw****	ton	71.60	70.90	83.90	84.90	72.50	69.20
Indexes of prices							
Prices received by farmers for all crops	1977=100	134	121	128	138	120	107
Prices paid by farmers for commodities & services, interest, taxes, & wage rates	1977=100	150	159	161	164	162	159

Source: Agricultural Prices, 1981-1992. All prices are US average prices of March, April , or May for each year except for the indicated.

\+ Culik et al., 1983: 53, and estimate
++ Debbert, 1986: 108
+++ Agicultural Prices, 1972 Annual Summary, and estimate.
* Price of 13-13-13
** Price of Lasso
*** Price of corn grain * 6 + 8 Robbins, 1986
**** Assuming the same as hay

Table 4.10 (cont'd).

Year		1987	1988	1989	1990	1991	1992
Commodity	Unit	Prices $/unit	Prices $/unit	Prices $/unit	Prices $/unit	Prices $/unit	Prices $/unit
Diesel	gallon	0.70	0.75	0.80	0.81	0.82	0.79
Manure+	ton	12.00	13.00	13.00	14.00	14.00	14.00
SEEDS							
corn	bu	64.90	64.20	71.40	69.90	70.20	71.80
soybeans	bu	11.30	11.90	14.70	12.50	12.80	12.40
wheat	bu	5.56	5.89	6.71	6.05	4.72	6.06
oats	bu	3.99	4.37	5.89	4.19	3.71	4.26
barley	bu	4.47	4.58	5.91	5.25	4.55	5.10
rye++	bu						9.00
ryegrass	100 lbs	45.10	47.90	54.30	50.50	46.80	43.80
orchardgrass	100 lbs	115.00	116.00	117.00	102.00	101.00	100.00
clover, red	100 lbs	160.00	143.00	143.00	145.00	134.00	122.00
hairy vetch+++	100 lbs	61.30	62.20	68.40	68.40	67.50	67.50
FERTILIZERS							
Urea	ton	161.00	183.00	212.00	184.00	212.00	198.00
A. nitrate	ton	157.00	166.00	189.00	180.00	184.00	178.00
UAN	ton	109.00	135.00	147.00	134.00	139.00	137.00
limestone	ton	16.30	15.90	15.80	16.40	18.00	17.70
N-P-K*	ton	162.00	181.00	187.00	181.00	184.00	180.00
K sulfate	ton	115.00	157.00	163.00	155.00	156.00	150.00
PESTICIDES							
Insecticides	50 lbs	71.80	70.20	71.30	73.30	77.90	81.30
Herbicides**	5 gals	96.88	101.92	108.08	113.96	122.92	127.12
CROPS							
Corn	bu	1.52	1.85	2.56	2.52	2.42	2.43
Soybeans	bu	4.90	6.36	7.29	5.62	5.77	5.61
Wheat	bu	2.63	2.81	4.03	3.51	2.60	3.66
Oats	bu	1.50	1.66	2.24	1.37	1.16	1.39
Barley	bu	1.69	1.58	2.73	2.17	2.10	2.08
Corn silage***	ton	17.12	19.10	23.36	23.12	22.52	22.58
Baled hay	ton	64.10	72.90	101.00	91.60	87.30	73.00
Straw****	ton	64.10	72.90	101.00	91.60	87.30	73.00
Indexes of prices							
Prices received by farmers for all crops	1977=100	106	126	134	128	131	131
Prices paid by farmers for commodities & services, interest, taxes, & wage rates	1977=100	162	170	178	184	188	190

but also the costs of the human labor and fuel needed to operate the machine for an hour. Additionally, the three costs are all proportional to the use of machinery; thus, they can be estimated together. The operation costs per hour for various types of machinery are listed in Table 4.4 and Table 4.5, and were obtained or derived from the data provided in "Minnesota farm machinery economic cost estimated for 1992." Because information for estimating operation costs in other years is not available, the costs were all estimated according to the prices in 1992. In order to construct a basis for calculation and comparison of the prices and costs, the adjustment of all other prices to 1992 is necessary. Two series of price indexes will be use to make the adjustment. First, the price indexes of all crops from 1981 to 1991 were used for the price adjustment of the crops produced in the Rodale FST. Second, the indexes of prices paid by farmers for commodities and services, interest, taxes, and wage rates in the same period were used for making the adjustment for all inputs in the Rodale FST. The data were obtained from "Agricultural Prices" and are listed in Table 4.11.

Basis for economic comparison. Although it was mentioned in the description of the Rodale FST that the low-input with animal system was design to simulate beef production, this economic comparison was conducted assuming that all three

Table 4.11 Indexes of prices received and paid by farmers, United States, 1981-1992 (1977=100). Source: Agricultural Prices, USDA.

Index	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	92
Prices received: All crops	134	121	128	138	120	107	106	126	134	128	131	131
Prices paid: all commodities, taxes, services, interest, & wage rates	150	159	161	164	162	159	162	170	178	184	188	190

farming systems are commercial cash-crop farms. There are two reasons for this assumption. First of all, actually the low-input with animal system is a cropping system without a cattle sector within it. The focus of the Rodale experiment was also the crop performance and the systems environments. More significantly, the assumption provides a simple basis for the comparison of the economic performance between the three systems using available data. If the calculations of low-input with animal system are operated based on a beef operation, additional variables such as animal protein conversion factors, and equipment and operations for cattle must be added into the analysis. However,these data are not available; thus, an economic assessment of the low-input with animal system using the beef operation cannot be accomplished in this study.

Under the assumption of commercial cash-crop operation for all systems, manure spread in the low-input with animal system is considered to be purchased from external markets and was included in costs. All crops produced in Rodale FST, including corn silage, hay, and straw in low-input systems were marketed to generate income.

In the economic analysis and comparison, the conventional system is selected to be the base farm. The profitability of the low-input systems is judged on the basis of their economic performance compared to that of the conventional system.

Similar to the method used in calculating and presenting the energy budgets, the economic estimates and analyses will be conducted on an annual per-hectare basis within a whole system.

CHAPTER 5

RESULT AND DISCUSSION

Chapter Introduction

Results of energy and economic calculations of this study are presented in this chapter, followed by discussions of the findings. Similarity or difference between the results of this study and those of previous studies are also addressed. The presentation and analysis of the results will be first organized for the energy analysis, then for the economic analysis.

Energy Analysis

Energy input and test of hypothesis 1. Tables 5.1, 5.2, and 5.3 show the results of energy calculations for the low-input with animal farming system (LIP-A), the low-input cash grain farming system (LIP-CG), and the conventional farming system (CONV) in the Rodale Farming Systems Trial (Rodale FST), respectively. It can be seen from Figure 5.1 that CONV nonrenewable energy consumption in each year was considerably higher than those in both low-input (LIP)

Table 5.1 Energy budget in LIP-A system, million kcals per hectare.

Rodale Farming Systems Trial													
Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Average
INPUTS													
Machinery	0.10	0.11	0.11	0.11	0.12	0.11	0.11	0.12	0.13	0.10	0.13	0.14	0.12
Diesel	0.90	0.95	1.04	0.91	1.27	1.04	1.00	1.15	1.13	1.07	1.22	1.16	1.07
Seed	0.47	0.46	0.32	0.68	0.49	0.65	0.58	0.33	0.85	0.47	0.96	0.54	0.57
Fertilizer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.43	0.00	0.00	0.00	0.12
Pesticide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total input	1.47	1.52	1.47	1.70	1.88	1.80	1.69	1.60	3.54	1.64	2.31	1.84	1.87
Human labor * hr/ha	6.0	5.9	7.1	6.0	8.5	7.3	6.3	7.5	7.4	6.8	8.2	7.3	7.0
OUTPUT													
Corn	1.88	0.00	6.62	10.45	0.00	12.94	0.00	8.27	9.33	0.00	8.66	0.00	4.85
Soybeans	0.00	4.48	0.00	4.85	4.67	0.00	4.03	0.00	3.93	4.30	0.00	4.20	2.54
Wheat	0.00	2.85	0.00	2.62	0.00	3.37	3.67	0.00	3.37	0.00	3.49	4.65	2.00
Oats	2.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24
Barley	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn silage	9.86	0.00	8.96	0.00	14.63	18.33	0.00	13.56	0.00	17.75	15.72	0.00	8.23
Hay	2.30	10.56	4.89	2.24	6.62	4.93	10.56	2.97	2.57	8.45	1.89	8.57	5.55
Straw	0.00	0.00	0.00	0.00	0.00	1.19	3.47	0.00	1.20	0.00	0.67	1.11	0.64
Total output	16.87	17.89	20.47	20.16	25.92	40.76	21.73	24.80	20.40	30.50	30.43	18.53	24.04
Energy productivity **	11.48	11.77	13.93	11.86	13.79	22.64	12.86	15.50	5.76	18.60	13.17	10.07	13.45
500-acre Standardized Farm													
INPUTS													
Machinery	0.09	0.11	0.10	0.11	0.12	0.11	0.11	0.12	0.13	0.11	0.13	0.13	0.11
Diesel	0.83	0.89	0.96	0.89	1.19	1.00	0.99	1.08	1.05	1.04	1.17	1.09	1.02
Seed	0.47	0.46	0.32	0.68	0.49	0.65	0.58	0.33	0.85	0.47	0.96	0.54	0.57
Fertilizer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.43	0.00	0.00	0.00	0.12
Pesticide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total input	1.39	1.46	1.38	1.68	1.80	1.76	1.68	1.53	3.46	1.62	2.26	1.76	1.82
Total output	16.87	17.89	20.47	20.16	25.92	40.76	21.73	24.80	20.40	30.50	30.43	18.53	24.04
Energy productivity **	12.14	12.25	14.83	12.00	14.40	23.16	12.93	16.21	5.90	18.83	13.46	10.53	13.89

* These ratios are shown to provide a time series perspective on human labor intensity. They are not included in the energy budget calculation.
** Energy productivity is calculated by the ratio of total energy output to energy input.

Table 5.2 Energy budget in LIP-CG system, million kcals per hectare.

Rodale Farming Systems Trial													
Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Average
INPUTS													
Machinery	0.09	0.12	0.12	0.12	0.11	0.13	0.10	0.13	0.12	0.12	0.13	0.15	0.12
Diesel	0.69	1.01	0.99	1.10	0.90	0.93	0.64	1.04	0.90	0.81	1.08	1.13	0.94
Seed	0.53	0.56	0.59	0.66	0.76	0.81	0.92	0.80	1.08	0.86	1.07	0.94	0.80
Fertilizer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.43	0.00	0.00	0.00	0.12
Pesticide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total input	1.31	1.69	1.70	1.88	1.77	1.87	1.66	1.97	3.53	1.79	2.28	2.22	1.97
Human labor * hr/ha	4.5	6.7	6.6	7.4	6.3	6.3	4.1	7.1	6.0	5.1	7.5	7.4	6.3
OUTPUT													
Corn	1.65	6.54	5.49	15.27	11.43	10.31	10.83	8.20	8.35	11.21	6.08	10.25	8.80
Soybeans	2.38	4.48	0.00	0.00	4.85	4.39	4.03	0.00	3.02	2.65	4.53	4.28	2.88
Wheat	0.00	0.00	0.00	2.40	0.00	0.00	6.07	0.00	3.30	0.00	4.70	4.72	1.77
Oats	3.12	1.46	7.22	0.00	4.72	3.54	0.00	5.00	0.00	5.10	0.00	0.00	2.51
Barley	0.00	0.00	0.00	0.00	0.00	1.83	0.00	3.79	0.00	2.40	0.00	0.00	0.67
Corn silage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hay	2.28	1.29	4.73	0.00	1.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.84
Straw	0.00	0.00	0.00	0.00	0.00	1.02	3.47	4.67	2.47	1.79	0.84	1.97	1.35
Total output	9.43	13.77	17.44	17.67	22.73	21.09	24.40	21.66	17.14	23.15	16.15	21.22	18.82
Energy productivity **	7.20	8.15	10.26	9.40	12.84	11.28	14.70	10.99	4.86	12.93	7.08	9.56	9.94
500-acre Standardized Farm													
INPUTS													
Machinery	0.09	0.11	0.12	0.12	0.11	0.12	0.10	0.13	0.12	0.11	0.12	0.14	0.12
Diesel	0.63	0.92	0.96	1.03	0.85	0.87	0.63	0.98	0.85	0.75	0.99	1.03	0.87
Seed	0.53	0.56	0.59	0.66	0.76	0.81	0.92	0.80	1.08	0.86	1.07	0.94	0.80
Fertilizer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.43	0.00	0.00	0.00	0.12
Pesticide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total input	1.25	1.59	1.67	1.81	1.72	1.80	1.65	1.91	3.48	1.72	2.18	2.11	1.91
Total output	9.43	13.77	17.44	17.67	22.73	21.09	24.40	21.66	17.14	23.15	16.15	21.22	18.82
Energy productivity **	7.54	8.66	10.44	9.76	13.22	11.72	14.79	11.34	4.93	13.46	7.41	10.06	10.28

* These ratios are shown to provide a time series perspective on human labor intensity. They are not included in the energy budget calculation.
** Energy productivity is calculated by the ratio of total energy output to energy input.

Table 5.3 Energy budget in CONV system, million kcals per hectare.

Rodale Farming Systems Trial													
Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Average
INPUTS													
Machinery	0.08	0.09	0.10	0.10	0.09	0.08	0.09	0.05	0.09	0.09	0.09	0.09	0.09
Diesel	0.58	0.72	0.78	0.90	0.74	0.70	0.66	0.54	0.70	0.66	0.72	0.76	0.71
Seed	0.44	0.50	0.49	0.49	0.51	0.56	0.61	0.58	0.64	0.74	0.66	0.70	0.58
Fertilizer	3.63	2.86	6.63	3.89	1.94	2.35	2.35	2.35	2.62	1.17	2.35	2.35	2.86
Pesticide	0.33	0.27	0.22	0.19	0.25	0.38	0.37	0.25	0.63	0.27	0.37	0.21	0.31
Total input	5.06	4.24	8.22	5.57	3.53	4.07	4.08	3.77	4.68	2.93	4.19	4.11	4.54
Human labor * hr/ha	3.7	5.0	5.1	6.1	5.0	4.9	4.4	3.8	4.7	4.3	4.9	5.3	4.8
OUTPUT													
Corn	5.86	21.74	14.67	22.79	10.23	25.12	20.23	14.21	18.50	11.88	18.04	23.97	17.27
Soybeans	2.38	3.93	3.84	4.76	9.33	3.84	4.85	4.48	4.21	7.41	4.53	4.28	4.82
Wheat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oats	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Barley	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn silage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hay	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Straw	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total output	8.24	25.67	18.51	27.55	19.56	28.96	25.08	18.69	22.71	19.29	22.57	28.25	22.09
Energy productivity **	1.63	6.05	2.25	4.95	5.54	7.12	6.15	4.96	4.85	6.58	5.39	6.87	5.19
500-acre Standardized Farm													
INPUTS													
Machinery	0.08	0.09	0.10	0.11	0.10	0.08	0.09	0.06	0.09	0.09	0.09	0.10	0.09
Diesel	0.53	0.67	0.70	0.88	0.68	0.65	0.62	0.49	0.65	0.61	0.68	0.72	0.66
Seed	0.44	0.50	0.49	0.49	0.51	0.56	0.61	0.58	0.64	0.74	0.66	0.70	0.58
Fertilizer	3.63	2.86	6.63	3.89	1.94	2.35	2.35	2.35	2.62	1.17	2.35	2.35	2.86
Pesticide	0.33	0.27	0.22	0.19	0.25	0.38	0.37	0.25	0.63	0.27	0.37	0.21	0.31
Total input	5.01	4.19	8.14	5.56	3.48	4.02	4.04	3.73	4.63	2.88	4.15	4.08	4.49
Total output	8.24	25.67	18.51	27.55	19.56	28.96	25.08	18.69	22.71	19.29	22.57	28.25	22.09
Energy productivity **	1.64	6.13	2.27	4.98	5.62	7.20	6.21	5.01	4.90	6.70	5.44	6.92	5.25

* These ratios are shown to provide a time series perspective on human labor intensity. They are not included in the energy budget calculation.

** Energy productivity is calculated by the ratio of total energy output to energy input.

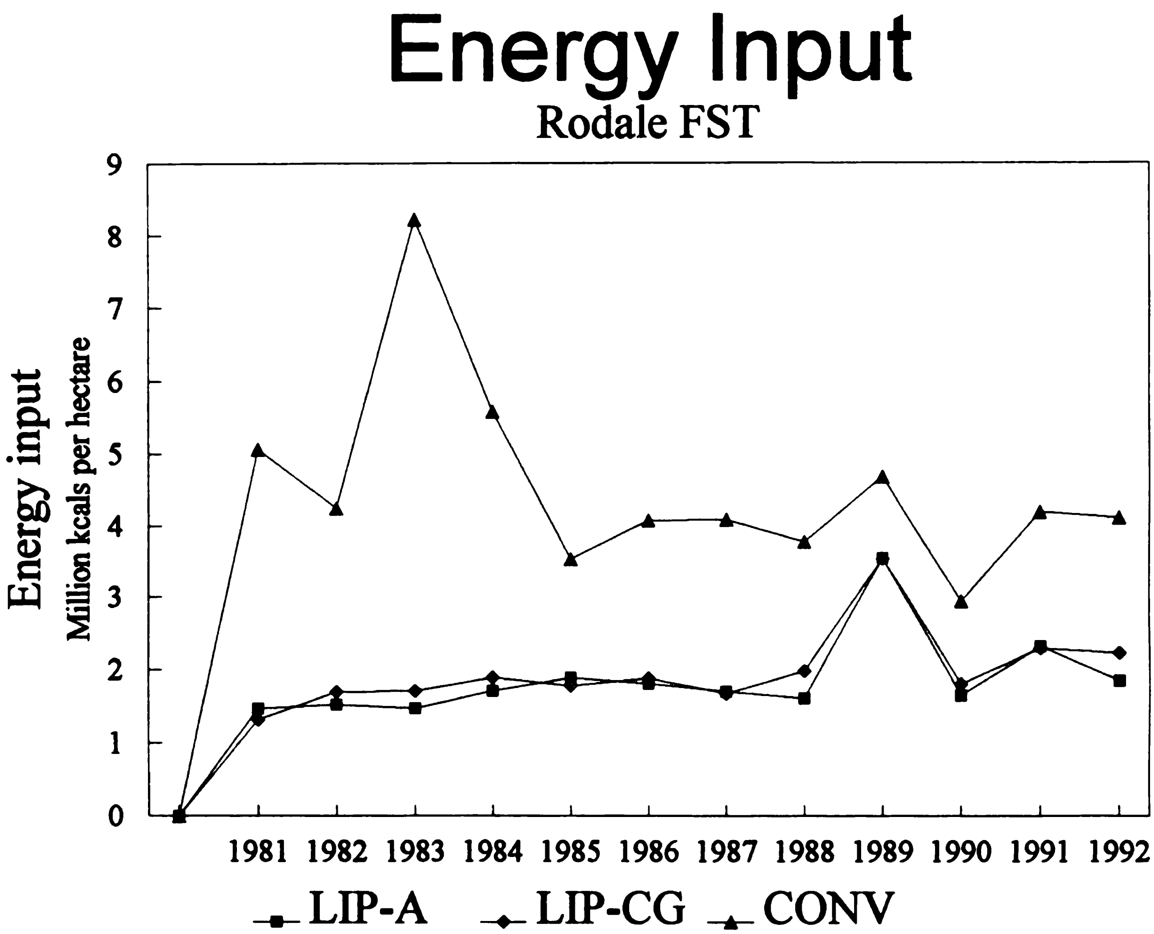


Figure 5.1 Total nonrenewable energy consumption in the Rodale Farming Systems Trial.

systems. On average, CONV consumed more than 4.5 million kcals of nonrenewable energy per hectare per year, which was more than double that of each LIP system.

<u>One could conclude from the comparison that the CONV used substantially more nonrenewable energy than the LIP systems from 1981 to 1992</u>. In the LIP systems, LIP-CG consumed approximately 2 million kcals and LIP-A accounted for 1.9 million kcals of energy consumption. The difference in energy consumption between LIP-A and LIP-CG is not significant. If manure were considered, LIP-A has consumed more off-farm energy than LIP-CG.

Fertilizer utilization in CONV accounted for its high energy consumption. Without the fertilizer input (about 2.9 million kcals/hectare/year), only 1.7 million kcals of energy per hectare annually was consumed by CONV. The energy input of fertilizer alone in CONV exceeded the total energy input of each LIP system.

The share of total energy consumption in the LIP and CONV systems by different inputs was different. In CONV, the following percentages are shown: fertilizer 63%; diesel fuel, 15%; seed, 13%; pesticides, 7%; and machinery, 2%. The patterns in LIP-A and LIP-CG were similar. Diesel fuel accounted for the greatest part of energy consumption, followed by seed, machinery, and fertilizer (Figure 5.2). The combination of diesel fuel and seed in LIP systems

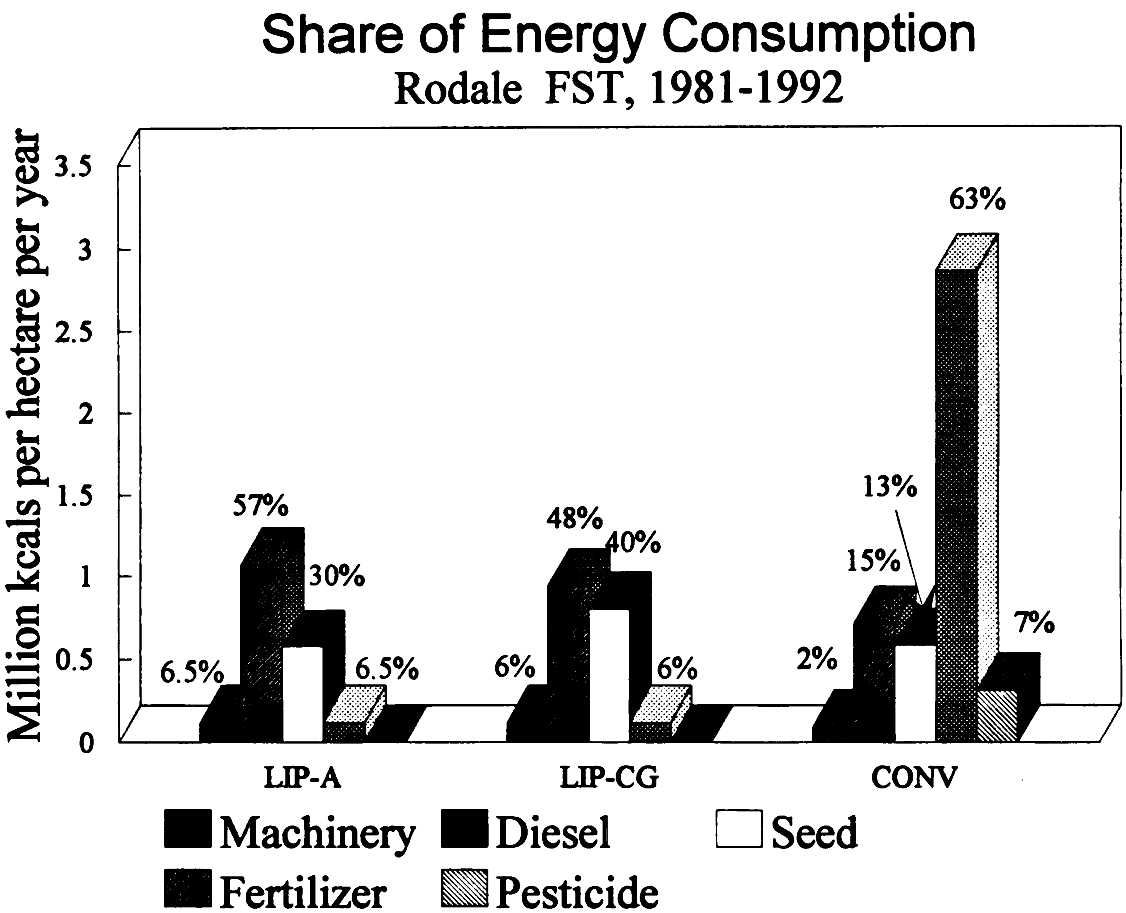


Figure 5.2 Share of nonrenewable energy consumption in the Rodale Farming Systems Trial, 1981-1992.

represented roughly 90% of their total nonrenewable energy input, while fertilizer in CONV accounted for more than 60% of its energy consumption.

There were minor differences among the systems in the consumption of machinery, fuel, and seed. First, measured by energy use per hectare per year, machinery consumption is the largest in LIP-CG, about 120 million cals, was slightly more than LIP-A's 115 million cals, followed by CONV's 87 million cals.

Second, LIP-A used the greatest amount of diesel fuel energy (1070 million cals), followed by 940 million cals for LIP-CG, and 710 million cals for CONV. The higher level of machinery and fuel utilization in LIP systems could result partly from the additional operations of manure spreading in LIP-A, cultivation and hay cutting and processing in both LIP systems.

Finally, energy consumed through the use of seeds was the greatest in LIP-CG, about 800 million cals, followed by 580 million in CONV, and 570 million in LIP-A. This relation could be explained by the fact that LIP-CG relied exclusively on the nutrients from the green manure crops grown in its field. Thus, the system needed sufficient green manure crops seed.

Comparison of energy inputs over time shows that total energy input in LIP-A increased by 28% from the first five-year period to the last 7-year period (Table 5.4). During

Table 5.4 Summary of energy budgets, 1981-1992.

System	Period I 1981-1985	Period II 1986-1992	12-year Period 1981-1992
Rodale Farming Systems Trial			
Nonrenewable energy input*			
LIP-A	1.61	2.06	1.87
LIP-CG	1.67	2.19	1.97
CONV	5.32	3.98	4.54
Energy output*			
LIP-A	20.26	26.74	24.04
LIP-CG	16.21	20.68	18.82
CONV	19.91	23.65	22.09
Energy productivity**			
LIP-A	12.6	14.1	13.5
LIP-CG	9.6	10.2	9.9
CONV	4.1	6.0	5.2
500-acre Standardized Farm			
Nonrenewable energy input*			
LIP-A	1.54	2.0	1.82
LIP-CG	1.61	2.12	1.91
CONV	5.28	3.93	4.49
Energy output (Same as Rodale FST)			
Energy productivity**			
LIP-A	13.1	14.3	13.9
LIP-CG	9.9	10.5	10.3
CONV	4.1	6.1	5.3

* Energy output and input are shown in million kcals per hectare per year.

** Energy productivity index is calculated by the ratio of energy output to nonrenewable energy input.

the same period, total energy consumption in LIP-CG increased by 31%. These increases were largely due to the dramatic increase in seed applied in the LIP fields in 1989 and 1991, and to the application of fertilizer in LIP systems in 1989. In contrast, total energy input in CONV decreased by 25% over the period studied, mostly because of the less amount of fertilizer inputs in the second period.

A comparison of energy inputs between Rodale FST and a 500-acre standardized farm shown in Table 5.4 suggests that <u>the standardized farm tends to consume slightly less nonrenewable energy overall than Rodale FST</u>. The savings of the standardized farm are due to its lower machinery and fuel consumption per hectare. A larger farm is considered to be more efficient in machinery and fuel consumption per unit of land than a smaller farm. However, these savings of the standardized farm are not significant enough to change the total energy consumption pattern[1].

Energy output and test of hypothesis 2. As shown in Table 5.4, annual average food energy output was approximately 24 million kcals per hectare in LIP-A, 22 million kcals in CONV, and 19 million kcals in LIP-CG. This indicates that a low-input operation does not necessarily result in lower production than a conventional operation from an energy

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Compare Figure 5.3 with Figure 5.1.

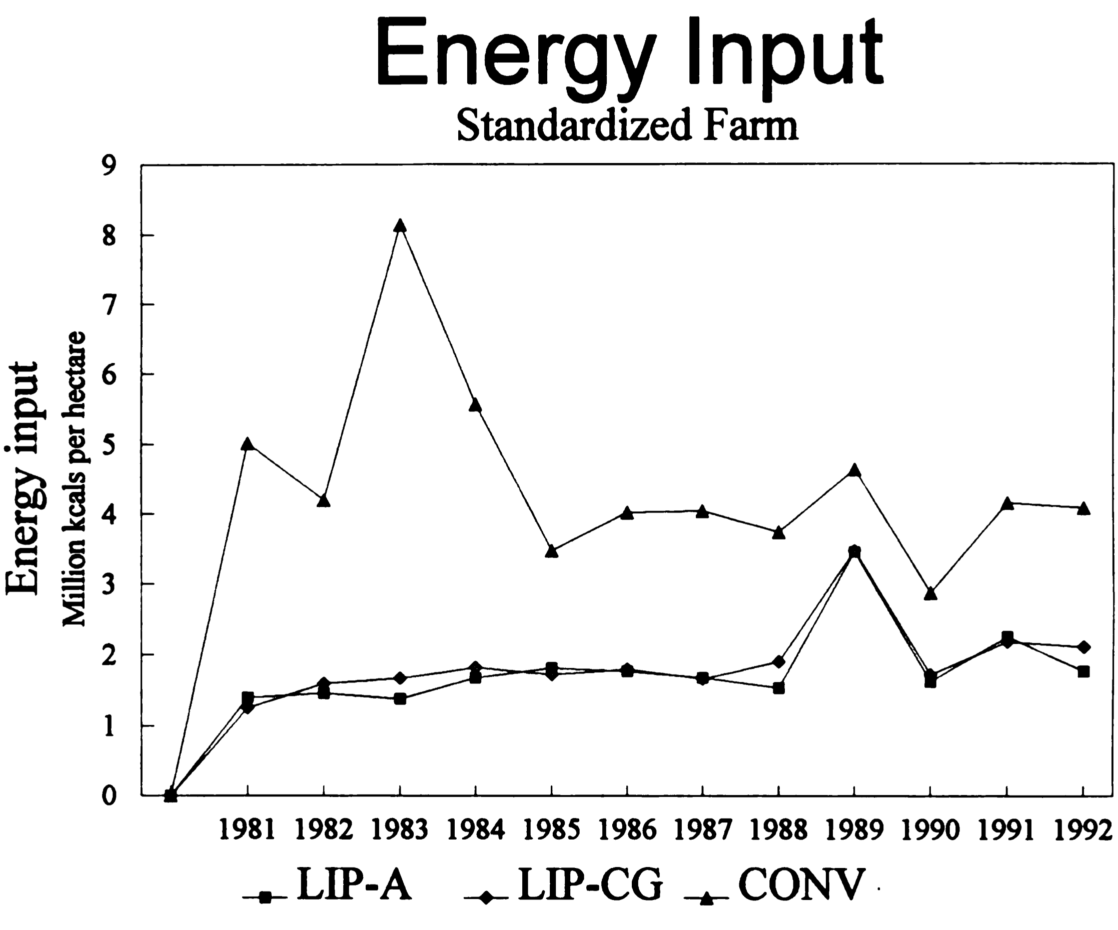

Figure 5.3 Total nonrenewable energy consumption on a 500-acre standardized farm.

point of view. Actually, LIP operations like LIP-A in Rodale FST has produced more energy overall than CONV in the twelve years of study. However, LIP-CG produced less energy than CONV during the same period. The relationship of energy production among systems was similar during different periods of time, i.e., 1981-1985 and 1986-1992. The test of the first hypothesis that LIP energy production is greater than or equal to that of CONV has revealed that the hypothesis is supported for LIP-A but not for LIP-CG.

If only food grains, (i.e., corn, soybeans, wheat, barley, oats, and rye) were considered, and corn silage in LIP-A and hay and straw in both LIP systems were excluded from the calculation, the energy output would remain unchanged for CONV, and would decrease to 17 million kcals in LIP-CG, and to 10 million kcals in LIP-A. Because LIP-A was originally designed to be a beef operation, a comparison of energy production in only food grains between systems might be biased against LIP-A because the system also produces feed grains, e.g., corn silage and hay, for cattle. Nevertheless, it should be appropriate to compare LIP-CG with CONV on a commercial cash grain farm basis. The comparison shows that LIP-CG produced about 75% as much food energy as CONV.

The difference in average energy production between the two different time periods of the study demonstrates the transition effect, which caused lower output in LIP systems during the conversion period from 1981 to 1985. Total energy production in LIP-A rose from 20.26 million kcals per hectare per year in the conversion period to 26.74 million kcals between 1986 and 1992, resulting in a 32% increase in total energy output (Table 5.4). Meanwhile, LIP-CG had a similar increase of 28%. CONV also raised its energy production during the same period by 19%, considerably less than the LIP systems. If these trends remain unchanged, LIP-CG food energy production might be comparable to that of CONV in the near future.

This lower production for LIP systems, especially LIP-CG, during the conversion period was primarily due to insufficient nitrogen provided by green manure crops in the LIP-CG fields and excessive weed problems in LIP-A (Liebhardt et al., 1989).

An analysis of the energy output year by year shows that LIP-A produced more energy than CONV in 1981, 1983, 1985, 1986, 1988, 1990, and 1991, due largely to LIP-A corn silage production in these years. LIP-CG had more energy production than CONV in 1981, 1985, 1988, and 1990; and did not differ significantly in 1983 and 1987. In the twelve years, LIP-A produced more energy than LIP-CG except for 1987 and 1992. In 1981, 1985, 1988, and 1990, both LIP systems outyielded CONV (Figure 5.4).

Dry weather seemed to affected LIP systems less than CONV. Weather in 1981, 1983, and 1988 was dry compared to

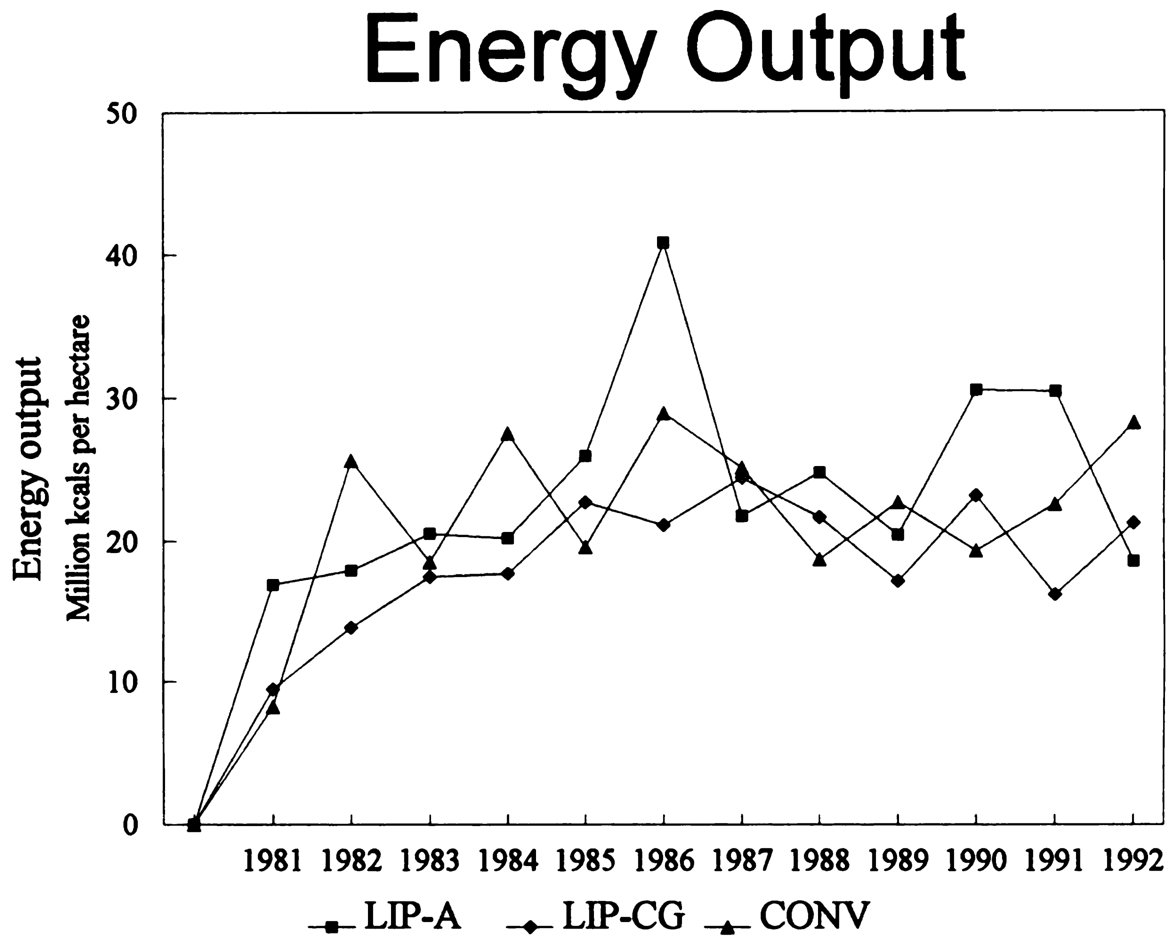

Figure 5.4 Total energy output in Rodale Farming Systems Trial.

that in the other study years[2]. In these dry years, LIP systems, particularly LIP-A, generally had higher energy output than CONV. Two explanations of this phenomena are provided based on the literature of Liebhardt et al. (1989). First, it was noted by the authors that corn dry matter production was less affected by dry conditions in 1981 and 1983 than corn grain yield in Rodale FST. This factor is favorable to LIP-A in which corn silage was produced. Second, they mentioned that dry weather conditions allowed better timing of weed control. Thus, dry weather could resulted in an improved condition and production in LIP systems because weed problems were more dominant in LIP-CG, especially in LIP-A.

Additionally, as shown on the CONV energy output curve in Figure 5.4, there are energy production valleys in 1981, 1983, 1985, 1988, and 1990. In 1985 and 1990 soybeans were grown in two-thirds of the CONV fields, thus producing less energy. In addition, 1981, 1983, and 1988 have been observed to be dry years (Peters, April 29, 1993, personal communication). For LIP curves, no such trends were noted. It is thus evident that CONV production was more sensitive to dry weather than were LIP systems. One major reason for this is that there were more diverse crops in LIP than in CONV systems which, in turn, were unlikely to all be

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See Liebhardt et al., 1989; and Peters et al., 1992.

adversely effected by unfavorable weather conditions. Also, Peters et al. (1992) pointed out that soil in LIP-CG was much more friable and "spongy" than that in CONV, and concluded soil in LIP systems had better structure. The improved soil in LIP treatments could result in better plant growth than CONV treatments during unfavorable weather conditions.

It is worth noting that 1986 was a special year for LIP-A production. Yields of corn and corn silage in the system were particularly high. In the same year, corn yield in CONV was also the highest during the twelve-year period. This higher corn production was a result of the even distribution of rainfall through the growing seasons in 1986 (Peters et al., 1992). However, LIP-CG corn production in the same year did not perform the same way. This was because a short-season variety was grown, resulting in a lower corn production in the LIP-CG system.

Energy production on the standardized farm was assumed to be the same as that of Rodale FST. Thus, no difference of energy output would be shown between Rodale FST and the standardized farm.

Energy productivity. Overall, energy productivity[3] in Rodale FST is the highest, about 13.5 in LIP-A, followed by

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Energy productivity was measured by the ratio of energy output to nonrenewable energy input as defined in chapter 3.

10 for LIP-CG, and 5.2 for CONV. <u>LIP systems are thus considered to be more productive/efficient in terms of nonrenewable energy use than CONV.</u> If only energy output of food grains were taken into account (i.e., omitting corn silage, hay, and straw), the ratios of energy productivity would be 8.4 in LIP-CG, 5.2 in CONV, and 5.1 in LIP-A. This shows that LIP-CG energy productivity was still significantly greater than that of CONV; the former is about 62% more productive than the latter. This result corresponds to the conclusions of some previous comparative studies described in the literature, and to the finding of Pimentel et al. (1984), who concluded that the energy productivity of corn and wheat produced on organic farms was 26-70% greater than that of conventional farms.

As shown in Table 5.4, although CONV had lower energy productivity than the other two systems, its increase rate (46%) of energy productivity from the 1981-1985 period to the 1986-1992 period was significantly higher than those of LIP-A and LIP-CG, which were 12% and 6%, respectively. The increase of energy production in each system accounted for the overall rise of the energy productivity. The decrease of fertilizer used in CONV additionally contributed to its dramatic increase in energy productivity.

On the contrary, the application of fertilizer in 1989, and higher consumption of seeds in LIP systems in 1989 and 1991 not only resulted in a smaller increase, but also caused the two major drops in energy productivity in the systems (Figure 5.5). The combination of these two effects has caused the LIP energy productivity to drop close to the CONV value in 1989. Longer-term analyses are needed to study whether this phenomenon is a long-term trend or it occurs only temporarily.

Generally, the curves of energy productivity in LIP-A and LIP-CG followed the same pattern except for 1986, 1987, and 1991. As mentioned earlier, in 1986 LIP-A corn and corn silage yields were particularly high, which resulted in the 1986 peak on the curve of energy productivity in LIP-A. In 1987, high production of wheat and wheat straw in LIP-CG raised its productivity over LIP-A. In 1991, corn yield in LIP-CG dropped significantly, to a valley on the curve of energy productivity besides that in 1989.

All values of energy productivity have been slightly increased from the Rodale experiment to a standardized 500-acre farm due to the lower energy consumption on the standardized farm than in Rodale FST. The energy productivity increases by 3% in LIP systems and 2% in CONV. Because these changes are limited, the curves of energy productivity of Rodale FST and the standardized farm shown in Figure 5.5 and 5.6 are relatively similar.

Energy stability and test of hypothesis 3. The comparison of stability of energy productivity in Rodale FST is shown

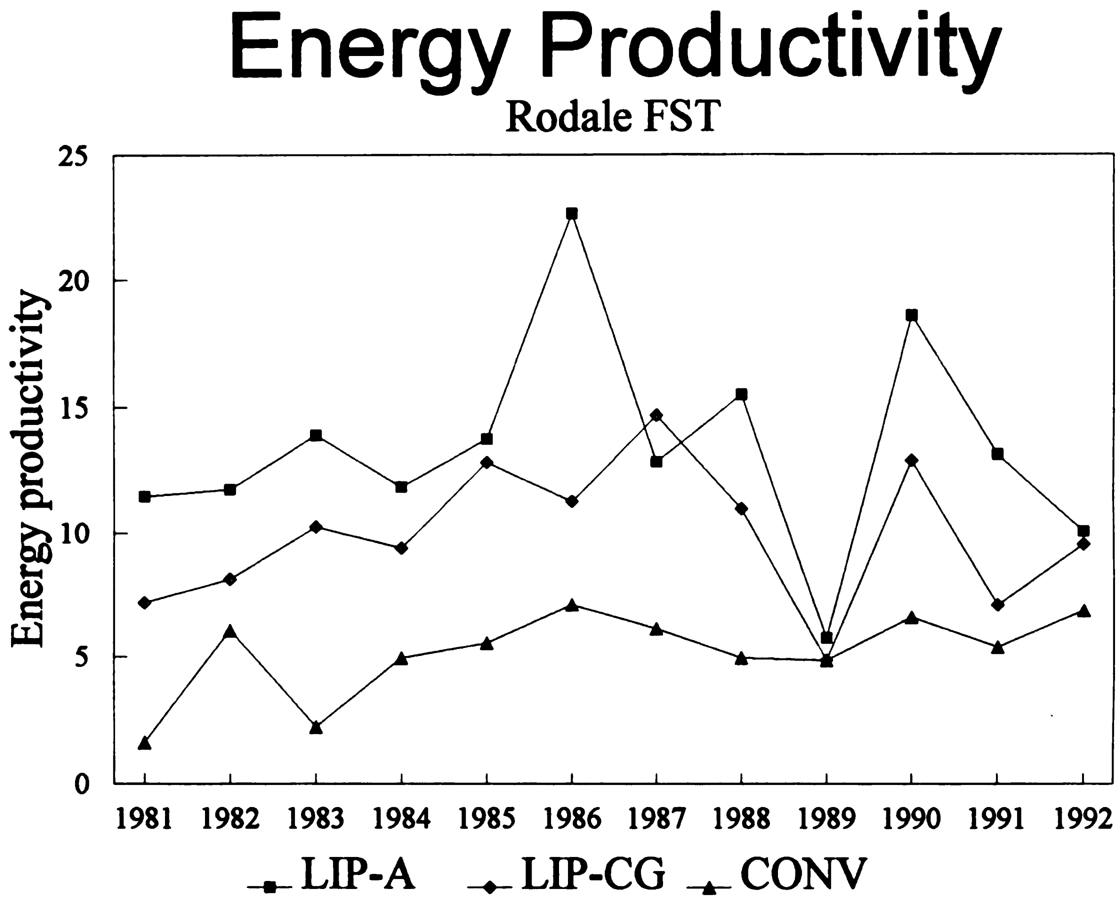

Figure 5.5 Energy productivity in the Rodale Farming Systems Trial.

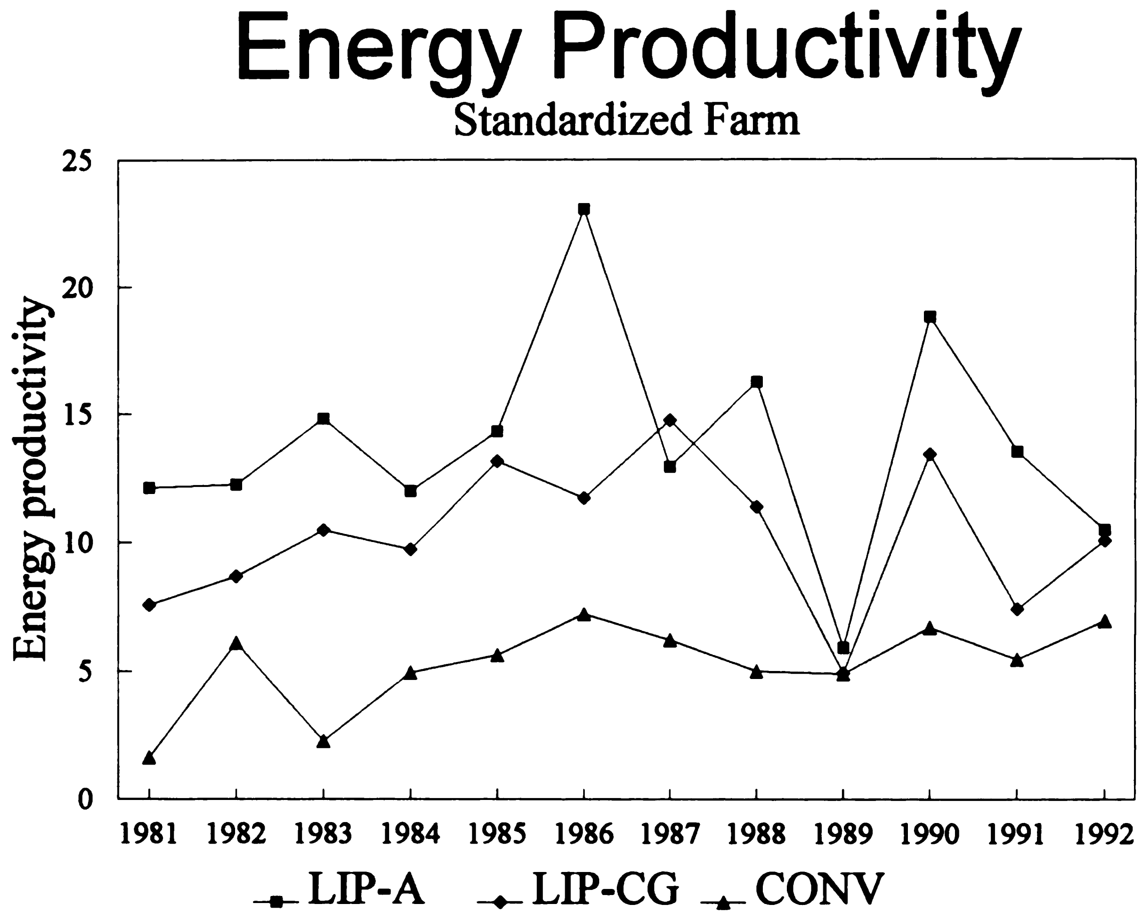

Figure 5.6 Energy productivity on a 500-acre standardized farm.

in Table 5.5. Overall, LIP-CG was the most stable system among the three farming systems in Rodale FST, followed by LIP-A, and CONV. The energy stability index[4] is 3.7 for LIP-CG, 3.4 for LIP-A, and 3.2 for CONV. Both the ratios in LIP systems were greater than that of CONV. Hence, the hypothesis that LIP systems were more energy stable than CONV in the twelve-year period is supported.

However, for different study periods, comparative energy stability also differed. In the conversion phase (1981-1985), the stability index of LIP-A was much greater than those of LIP-CG and CONV. CONV was the least stable system in this period. In the post-conversion period (1986-1992), the stability of CONV increased to be the highest among the systems. Energy stability of both LIP systems declined for the same period, particularly for LIP-A, which decreased by nearly 77%. This resulted in the rejection of the hypothesis for the second period.

There were some factors which contributed to the dramatic drop of energy stability in LIP systems in the post-conversion period: the production peak of 1986 in LIP-A, and the input increases in 1989, causing valleys on the curve for both energy productivity in LIP systems.

4

Energy stability index was measured by the reciprocal of the coefficient of variation of energy productivity in the twelve-year period.

Table 5.5 Energy and economic stability indexes, 1981-1992.

System	Period I 1981-1985	Period II 1986-1992	12-year Period 1991-1992
Rodale Farming Systems Trial			
Energy stability*			
LIP-A	12.0	2.8	3.4
LIP-CG	5.0	3.3	3.7
CONV	2.3	6.9	3.2
Economic stability**			
LIP-A	5.7	3.2	3.6
LIP-CG	4.7	4.5	4.5
CONV	2.6	6.9	3.8
500-acre Standardized Farm			
Energy stability*			
LIP-A	10.9	2.8	3.4
LIP-CG	5.2	3.3	3.8
CONV	2.3	6.9	3.2
Economic stability**			
LIP-A	5.4	3.2	3.6
LIP-CG	4.7	4.5	4.5
CONV	2.6	6.9	3.8

* Energy stability index is calculated by the reciprocal of coefficient of variation of energy productivity.

** Profitability stability index is calculated by the reciprocal of coefficient of variation of profitability index.

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Economic Analysis

Costs. Tables 5.6, 5.7, and 5.8 show the balance of costs[5] and revenue[6] in LIP-A, LIP-CG, and CONV, respectively. On average, total annual variable and amortized equipment costs were approximately $453 per hectare in LIP-A, $316 in CONV, and $297 in LIP-CG. The higher cost of LIP-A compared to LIP-CG was due to manure costs in LIP-A. The curves of the costs in the three systems during the twelve-year period are shown in Figure 5.7.

Although CONV consumed the greatest amount of nonrenewable energy, its total variable and amortized equipment costs were substantially less than those of LIP-A. One reason for this was the extremely inexpensive price of fertilizer and pesticide. Costs per million cals of nonrenewable energy were estimated to be 0.21 dollar for the operation, 0.09 for seed, and only 0.03 and 0.04 for the fertilizer and pesticide, respectively. Obviously, the costs per unit of energy of the agrichemicals were less than one-half of the seed costs, and were only 14-19% of the operation costs from the perspective of energy use.

5

Costs include the costs of operation (i.e., labor, fuel, and amortized equipment), seeds, manure, commercial fertilizers, and pesticides.

6

Revenue include the sales of all crops (i.e., corn grain, soybeans, wheat, oats, barley, corn silage, hay, and straw) produced in the three systems of Rodale Farming Systems Trial.

Table 5.6 Economic balance in LIP-A system, dollar per hectare.

Rodale Farming Systems Trial													
Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Average
COSTS													
Operation	199.90	215.10	221.60	223.20	283.60	243.20	249.20	257.90	255.80	253.70	279.20	274.30	246.39
Manure	165.00	121.40	161.80	149.80	151.60	232.30	0.00	235.40	123.20	132.00	267.60	0.00	145.01
Seed	49.60	37.40	38.40	66.60	50.00	71.20	46.80	37.60	77.10	39.40	87.40	38.90	53.37
Fertilizer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.70	0.00	0.00	0.00	8.39
Pesticide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total cost*	414.50	373.90	421.80	439.60	485.20	546.70	296.00	530.90	556.80	425.10	634.20	313.20	453.16
SALES													
Corn	64.50	0.00	227.80	369.70	0.00	395.10	0.00	176.50	258.90	0.00	232.50	0.00	143.75
Soybeans	0.00	259.60	0.00	345.90	273.40	0.00	222.40	0.00	255.80	225.50	0.00	214.70	149.78
Wheat	0.00	123.40	0.00	99.60	0.00	145.30	132.90	0.00	148.10	0.00	101.10	189.70	78.34
Oats	99.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.28
Barley	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn silage	263.70	0.00	243.30	0.00	392.00	489.00	0.00	273.10	0.00	425.70	359.00	0.00	203.82
Hay	65.30	328.00	170.20	73.20	212.40	169.40	339.40	91.30	102.90	320.90	66.70	253.60	182.78
Straw	0.00	0.00	0.00	0.00	0.00	41.00	111.40	0.00	48.00	0.00	23.70	32.90	21.42
Total revenue	492.90	711.00	641.30	888.40	877.80	1,239.80	806.10	540.90	813.70	972.10	783.00	690.90	788.16
Returns**	78.40	337.10	219.50	448.80	392.60	693.10	510.10	10.00	256.90	547.00	148.80	377.70	335.00
Profit. idx***	1.19	1.90	1.52	2.02	1.81	2.27	2.72	1.02	1.46	2.29	1.23	2.21	1.80
500-acre Standardized Farm													
COSTS													
Operation	180.20	199.80	205.10	211.90	261.10	226.40	238.70	239.50	236.00	238.00	261.60	253.50	229.32
Manure	165.00	121.40	161.80	149.80	151.60	232.30	0.00	235.40	123.20	132.00	267.60	0.00	145.01
Seed	49.60	37.40	38.40	66.60	50.00	71.20	46.80	37.60	77.10	39.40	87.40	38.90	53.37
Fertilizer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.70	0.00	0.00	0.00	8.39
Pesticide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total cost*	394.80	358.60	405.30	428.30	462.70	529.90	285.50	512.50	537.00	409.40	616.60	292.40	436.08
Total revenue	492.90	711.00	641.30	888.40	877.80	1,239.80	806.10	540.90	813.70	972.10	783.00	690.90	788.16
Returns**	98.10	352.40	236.00	460.10	415.10	709.90	520.60	28.40	276.70	562.70	166.40	398.50	352.08
Profit. idx***	1.25	1.98	1.58	2.07	1.90	2.34	2.82	1.06	1.52	2.37	1.27	2.36	1.88

* Include variable costs and amortized equipment costs.

** Returns above variable and amortized equipment costs are calculated by the difference of total revenue from crop sales and the costs.

*** Profitability index is calculated by the ratio of total revenue from crop sales to total variable and amortized equipment costs.

Table 5.7 Economic balance in LIP-CG system, dollar per hectare.

Rodale Farming Systems Trial													
Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Average
COSTS													
Operation	159.00	213.20	239.20	247.70	212.60	221.90	171.30	236.30	213.00	192.00	239.20	252.70	216.51
Manure	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seed	50.50	49.70	63.20	73.90	73.90	70.60	81.80	66.70	103.80	69.50	85.10	79.00	72.31
Fertilizer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.70	0.00	0.00	0.00	8.39
Pesticide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total cost*	209.50	262.90	302.40	321.60	286.50	292.50	253.10	303.00	417.50	261.50	324.30	331.70	297.21
SALES													
Corn	56.70	188.90	188.80	539.90	373.80	314.80	225.70	174.90	231.80	320.40	163.10	276.30	254.59
Soybeans	150.60	259.60	0.00	0.00	284.00	251.60	222.40	0.00	196.30	139.10	238.60	218.80	163.42
Wheat	0.00	0.00	0.00	90.90	0.00	0.00	219.80	0.00	144.80	0.00	136.10	192.60	65.35
Oats	109.40	54.70	201.20	0.00	153.20	82.00	0.00	152.80	0.00	126.40	0.00	0.00	73.31
Barley	0.00	0.00	0.00	0.00	0.00	55.10	0.00	82.20	0.00	70.30	0.00	0.00	17.30
Corn silage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hay	64.80	40.20	164.50	0.00	55.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.08
Straw	0.00	0.00	0.00	0.00	0.00	35.00	111.40	143.50	98.80	67.80	29.80	58.20	45.38
Total revenue	381.50	543.40	554.50	630.80	866.40	738.50	779.30	553.40	671.70	724.00	567.60	745.90	646.42
Returns**	172.00	280.50	252.10	309.20	579.90	446.00	526.20	250.40	254.20	462.50	243.30	414.20	349.21
Profit. idx***	1.82	2.07	1.83	1.96	3.02	2.52	3.08	1.83	1.61	2.77	1.75	2.25	2.21
500-acre Standardized Farm													
COSTS													
Operation	146.30	196.10	228.60	231.50	200.10	207.60	165.40	224.00	199.40	180.60	221.10	234.50	202.93
Manure	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seed	50.50	49.70	63.20	73.90	73.90	70.60	81.80	66.70	103.80	69.50	85.10	79.00	72.31
Fertilizer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.70	0.00	0.00	0.00	8.39
Pesticide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total cost*	196.80	245.80	291.80	305.40	274.00	278.20	247.20	290.70	403.90	250.10	306.20	313.50	283.63
Total revenue	381.50	543.40	554.50	630.80	866.40	738.50	779.30	553.40	671.70	724.00	567.60	745.90	646.42
Returns**	184.70	297.60	262.70	325.40	592.40	460.30	532.10	262.70	267.80	473.90	261.40	432.40	362.78
Profit. idx***	1.94	2.21	1.90	2.07	3.16	2.65	3.15	1.90	1.66	2.89	1.85	2.38	2.31

* Include variable costs and amortized equipment costs.
** Returns above variable and amortized equipment costs are calculated by the difference of total revenue from crop sales and the costs.
*** Profitability index is calculated by the ratio of total revenue from crop sales to total variable and amortized equipment costs.

Table 5.8 Economic balance in CONV system, dollar per hectare.

Rodale Farming Systems Trial													
Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Average
COSTS													
Operation	141.70	171.90	176.40	226.30	172.90	162.00	159.20	122.80	168.30	157.60	172.60	181.60	167.78
Manure	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seed	47.30	49.90	48.50	54.10	43.50	56.10	59.20	54.00	64.80	54.30	60.00	63.70	54.62
Fertilizer	106.80	74.00	290.30	84.30	40.90	53.60	49.50	53.40	89.20	24.50	53.80	50.40	80.89
Pesticide	12.70	10.70	9.20	8.30	11.00	16.80	15.20	10.50	26.90	11.20	16.40	9.50	13.20
Total cost*	308.50	306.50	524.40	373.00	268.30	288.50	283.10	240.70	349.20	247.60	302.80	305.20	316.48
SALES													
Corn	201.00	627.40	504.10	805.90	334.40	767.30	421.50	303.30	513.70	339.70	484.10	645.90	495.69
Soybeans	150.60	227.90	217.20	339.20	546.50	220.00	267.90	270.40	273.70	388.70	238.60	218.80	279.96
Wheat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oats	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Barley	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn silage	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hay	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Straw	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total revenue	351.60 775.65	855.30 790.84	721.30 764.80	1,145.10	880.90	987.30	689.40	573.70	787.40	728.40	722.70	864.70	775.65
Returns**	43.10	548.80	196.90	772.10	612.60	698.80	406.30	333.00	438.20	480.80	419.90	559.50	459.17
Profit. idx***	1.14	2.79	1.38	3.07	3.28	3.42	2.44	2.38	2.25	2.94	2.39	2.83	2.53
500-acre Standardized Farm													
COSTS													
Operation	130.30	160.70	163.30	216.90	161.30	151.40	148.60	111.60	156.10	147.20	163.50	172.70	156.97
Manure	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seed	47.30	49.90	48.50	54.10	43.50	56.10	59.20	54.00	64.80	54.30	60.00	63.70	54.62
Fertilizer	106.80	74.00	290.30	84.30	40.90	53.60	49.50	53.40	89.20	24.50	53.80	50.40	80.89
Pesticide	12.70	10.70	9.20	8.30	11.00	16.80	15.20	10.50	26.90	11.20	16.40	9.50	13.20
Total cost*	297.10	295.30	511.30	363.60	256.70	277.90	272.50	229.50	337.00	237.20	293.70	296.30	305.68
Total revenue	351.60	855.30	721.30	1,145.10	880.90	987.30	689.40	573.70	787.40	728.40	722.70	864.70	775.65
Returns**	54.50	560.00	210.00	781.50	624.20	709.40	416.90	344.20	450.40	491.20	429.00	568.40	469.98
Profit. idx***	1.18	2.90	1.41	3.15	3.43	3.55	2.53	2.50	2.34	3.07	2.46	2.92	2.62

* Include variable costs and amortized equipment costs.
** Returns above variable and amortized equipment costs are calculated by the difference of total revenue from crop sales and the costs.
*** Profitability index is calculated by the ratio of total revenue from crop sales to total variable and amortized equipment costs.

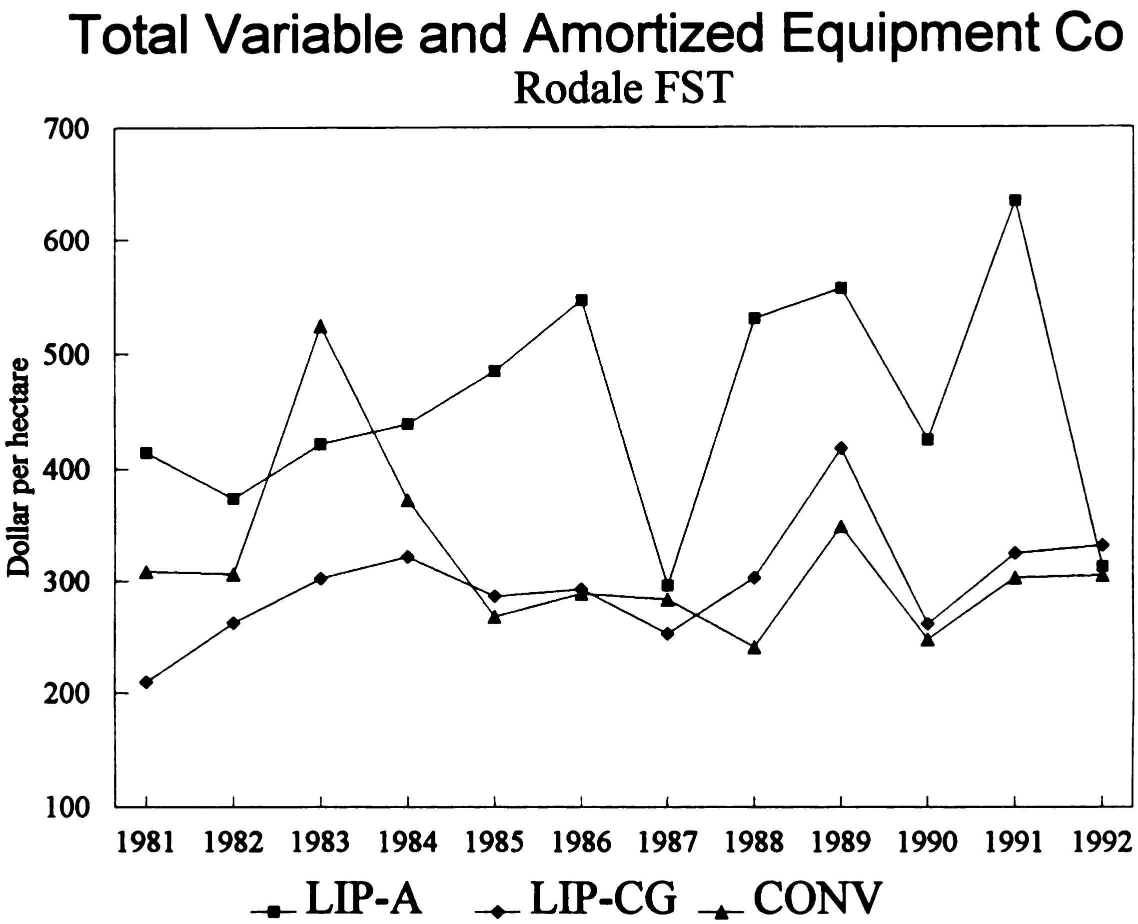

Figure 5.7 Total variable and amortized equipment costs in the Rodale Farming Systems Trial.

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A second reason is that the LIP systems generally used more machinery, fuel, and seed than CONV. Operation costs were about $246 per hectare per year in LIP-A, $217 in LIP-CG, and $168 in CONV. Seed costs were $72 in LIP-CG, $55 in CONV, and $53 in LIP-A. Because costs associated with operation and seed were fairly high compared to the costs of chemicals, LIP systems tended to cost more. In other words, <u>the greater energy savings of the LIP systems was not reflected in their total variable costs</u>.

In terms of the share of total variable and amortized equipment costs, operation costs accounted for the largest share of the costs in each system. In LIP-A, operation costs were 54%, manure 32%, seed 12%, and fertilizer 2% of the total costs. LIP-CG had a pattern similar to that of LIP-A except for no manure costs (Figure 5.8). Although fertilizer accounted for the greatest energy input in CONV, it accounted for 26% of its total variable costs, second to operation costs and followed by seed costs. Pesticide costs accounted for 4% of the total variable cost of CONV.

Average operation costs were the greatest in LIP-A, followed by LIP-CG, and CONV. The costs of LIP-CG was 29% higher than that of CONV. This is relatively in accord with the findings by Hanson et al.(1990) who reported that labor costs were 28% higher for LIP-CG. From this comparison, LIP systems can be concluded to use labor, machinery, and fuel more intensively from both energy and economic viewpoints.

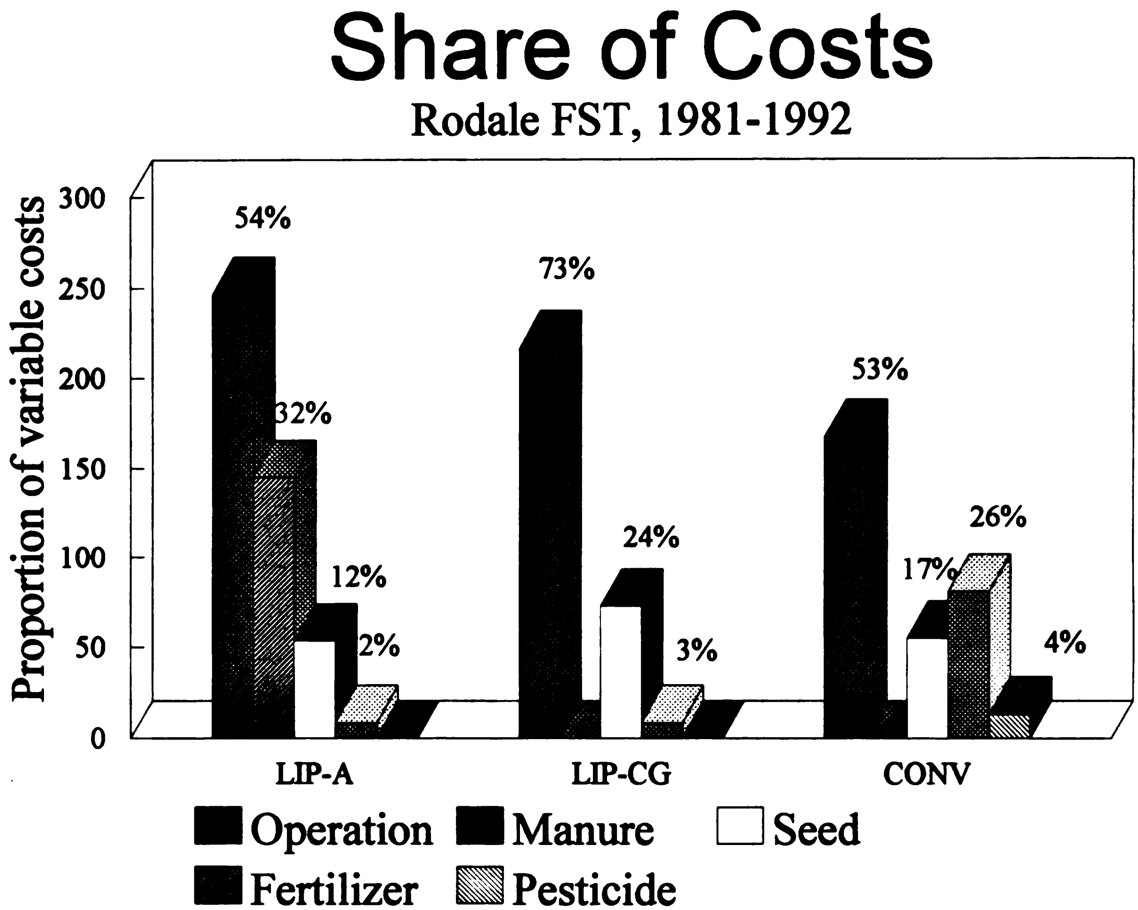

Figure 5.8 Share of costs in the Rodale Farming Systems Trial, 1981-1992.

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As shown in Table 5.9, total variable and amortized equipment costs in LIP-A increased by 10% from the transition period to the post-transition period partly due to the growing operation costs. In the meanwhile, LIP-CG's total variable costs increased by 13%, largely because of the gradual increase of seed costs. On the contrary, the total variable cost in CONV decreased by 19%, mostly due to lower fertilizer costs in the second period. These patterns of change in total variable and amortized equipment costs corresponded with those of energy input in the three systems.

It has been shown in the Figure 5.7 that manure costs greatly affected the variable and amortized equipment costs of LIP-A. In 1987 and 1992 , in which no manure was spread, and in 1990, in which only a limited amount of manure was spread, the total annual costs of LIP-A dropped to three valleys. The effect of the application of fertilizer on the costs was also observed. In 1989, the application of additional fertilizer in the three systems, particularly in the LIP systems, caused a peak of the costs in each system. The highest peak of the costs among the systems occurred in LIP-A in 1991, when the costs of operation, manure, and seed reached their maximum values during the twelve year study.

Total variable and amortized equipment costs on a 500-acre standardized farm were calculated to be slightly lower than those of the Rodale experiment in each system, due to

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Table 5.9 Summary of economic balances, 1981-1992. Dollars per hectare per year.

System	Period I 1981-1985	Period II 1986-1992	12-year period 1981-1992
Rodale Farming Systems Trial			
Total variable and amortized equipment costs			
LIP-A	427	472	453
LIP-CG	277	312	297
CONV	356	288	316
Total revenue from crop sales			
LIP-A	722	835	788
LIP-CG	595	683	646
CONV	791	765	776
Returns above costs*			
LIP-A	295	363	335
LIP-CG	319	371	349
CONV	435	476	459
Profitability index**			
LIP-A	1.7	1.9	1.8
LIP-CG	2.1	2.2	2.2
CONV	2.3	2.7	2.5
500-acre Standardized Farm			
Total variable and amortized equipment costs			
LIP-A	410	455	436
LIP-CG	263	299	284
CONV	345	278	306
Total revenue (Same as Rodale FST.)			
Returns above costs*			
LIP-A	312	381	352
LIP-CG	333	384	363
CONV	446	487	470
Profitability index**			
LIP-A	1.8	2.0	1.9
LIP-CG	2.3	2.4	2.3
CONV	2.4	2.8	2.6

* Difference of total revenue and total variable and amortized equipment costs.

** Profitability index is calculated by the ratio of total revenue to total variable and amortized equipment costs.

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the lower operation costs. The average total annual costs shows the following decrease from Rodale FST to the standardized farm: LIP-A, 3.7%; LIP-CG, 4.4%; and CONV, 3.2% (Table 5.9).

Revenue. Overall, total average revenue from crop sales was the greatest, about $788 per hectare per year in LIP-A, followed by $776 in CONV, and $646 in LIP-CG. This result is similar to the report of Hanson et al. (1990) that LIP-CG total revenue of sales was at average 19% lower each year than that of CONV. Also this relationship is similar to that of energy production among the systems, which means the total crop revenue have reflected energy production in Rodale FST.

Transition effects in LIP systems have also been shown to effect the total income from crop sales. From the first five-year period to the last seven-year period, total income increased by 16% in LIP-A, and 15% in LIP-CG, but decreased slightly in CONV. Analyzed another way, the revenue of CONV was the highest in the first phase while LIP-A generated the greatest revenue in the second period. Both energy production and total revenue show that LIP systems were less productive in the transition period than they would be after the conversion was completed.

Another finding illustrated by the curves in Figure 5.9 is that total revenue from crop sales was more sensitive to

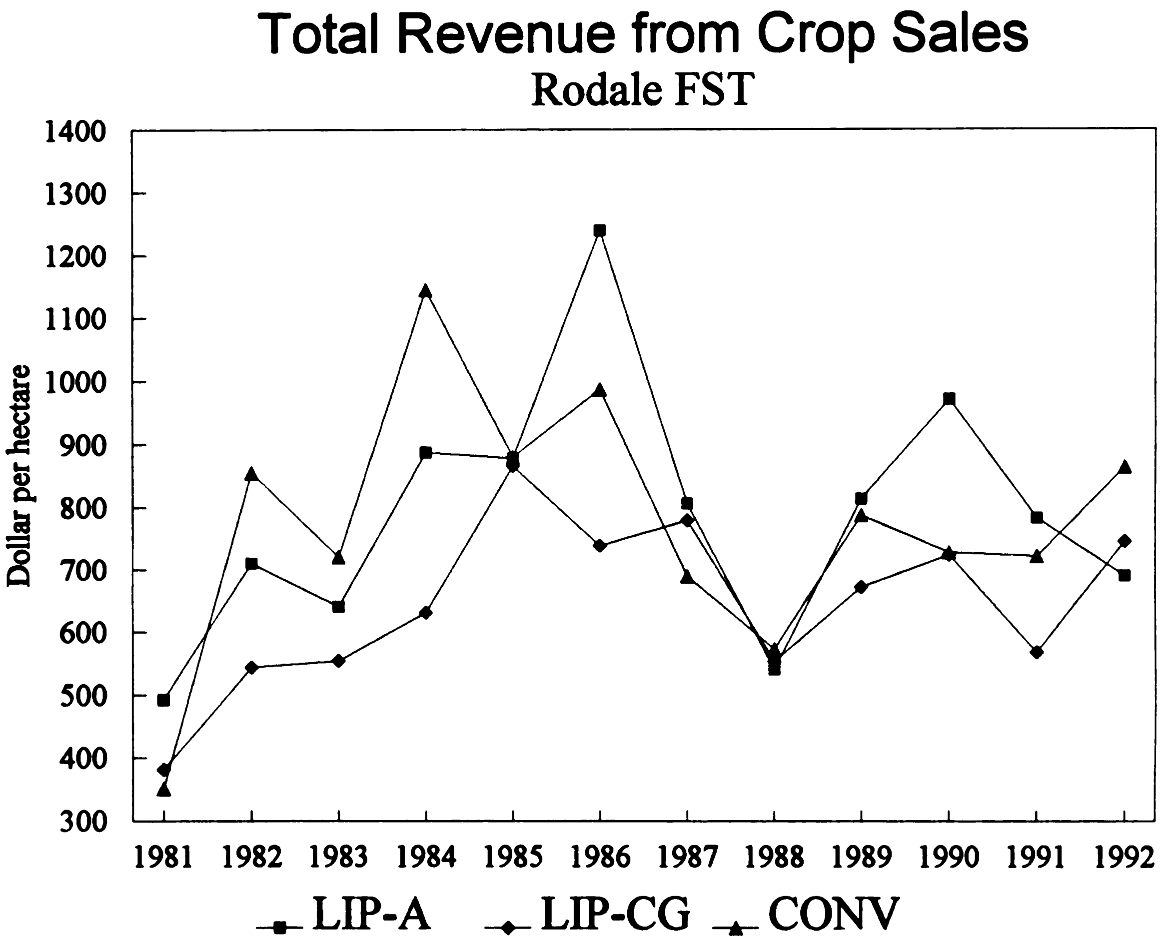

Figure 5.9 Total revenue from crop sales in the Rodale Farming Systems Trial.

weather than was energy production. 1988 was a dry year in which total revenue in all systems dropped significantly to the same level and recovered in the following year. Values of total energy production for 1988 in the systems were not significantly lower compared to those in other years. Similar results were found for 1981 and 1983 which were also dry years (See Figure 5.4, showing energy production curves.). The reason for the sensitivity is not clear.

Lockeretz et al. (1981) used the ratio of total energy consumption to total income from crop sales to compare various systems and found that the value on low-input/ organic farms was only 40% of the ratio for conventional farms. A comparison of the same ratio between systems in this study agreed closely with this figure. The energy consumed to produce a dollar's worth of crops in LIP-A and LIP-CG was about 40% and 52% of that in CONV, respectively.

The revenue on a standardized farm remains unchanged from the Rodale FST.

Returns above variable and amortized equipment costs and test of hypothesis 4. As revealed in Table 5.9, CONV had greater returns above variable and amortized equipment costs than LIP systems. Values of the returns in LIP systems were close to each other, but considerably lower than those in CONV, by more than $110 per hectare per year. This relationship was the same for both study periods.

Therefore, the hypothesis that LIP systems would generate equal or higher returns above variable costs than CONV is not supported. Stated another way, the returns above variable and amortized equipment costs of both LIP systems were significantly lower than those of CONV, based on a commercial cash grain farm operation in the twelve years.

The major reason for the lower returns above costs in LIP systems is the inexpensive fertilizer and pesticide, which greatly reduced the costs of CONV. Other factors in LIP systems could also contribute to their lower returns. As described earlier, LIP systems generally consumed more machinery, seed, and fuel, resulting higher costs for these inputs. Individually, LIP-A had very high manure costs and production of LIP-CG was lower than those of the other systems.

Some previous economic studies also concluded that LIP-CG was less profitable than CONV under current U.S. agricultural policies and market operation (Duffy et al., 1989; Hanson et al., 1990; Dunbar, 1991). Their findings correspond to those of this study. However, Dunbar pointed out that LIP systems returns above variable costs were slightly less than those of CONV, but a large difference in the returns between LIP and CONV systems was found in this analysis.

Additionally, this analysis revealed that LIP-CG generated slightly higher returns above variable and amortized equipment costs than LIP-A. Nevertheless, according to the economic analysis by Duffy et al. (1989), LIP-A, which was equal to CONV in net returns, was superior to LIP-CG from a farm net return viewpoint. One cannot identify from this study whether the results would remain the same if the economic analysis of LIP-A was conducted on a beef farm basis.

An examination of returns above variable and amortized equipment costs year by year shows that LIP-A generated higher returns than CONV in 1981, 1983, 1986, 1987, and 1990; as did LIP-CG in 1981, 1983, and 1987 (Figure 5.10). In 1981, 1983, and 1987, both LIP systems had higher returns than CONV. However, except for 1987, the differences were limited. The less unfavorable impacts of dry weather on LIP energy production were not as significant as on LIP returns. In comparing LIP-A and LIP-CG, 1982, 1984, 1986, 1989, and 1990 were the years in which LIP-A had higher returns than LIP-CG. It seems that wetter weather conditions tended to favor LIP-A more than LIP-CG, because 1982, 1984, 1986, and 1989 were wetter years.

Dry weather had a significant negative impact on returns for all systems. As shown by the curves in Figure 5.10, the returns in each system dropped greatly in 1981, 1983, and 1988, which were the three driest years of the study. No such declines in energy production were noted.

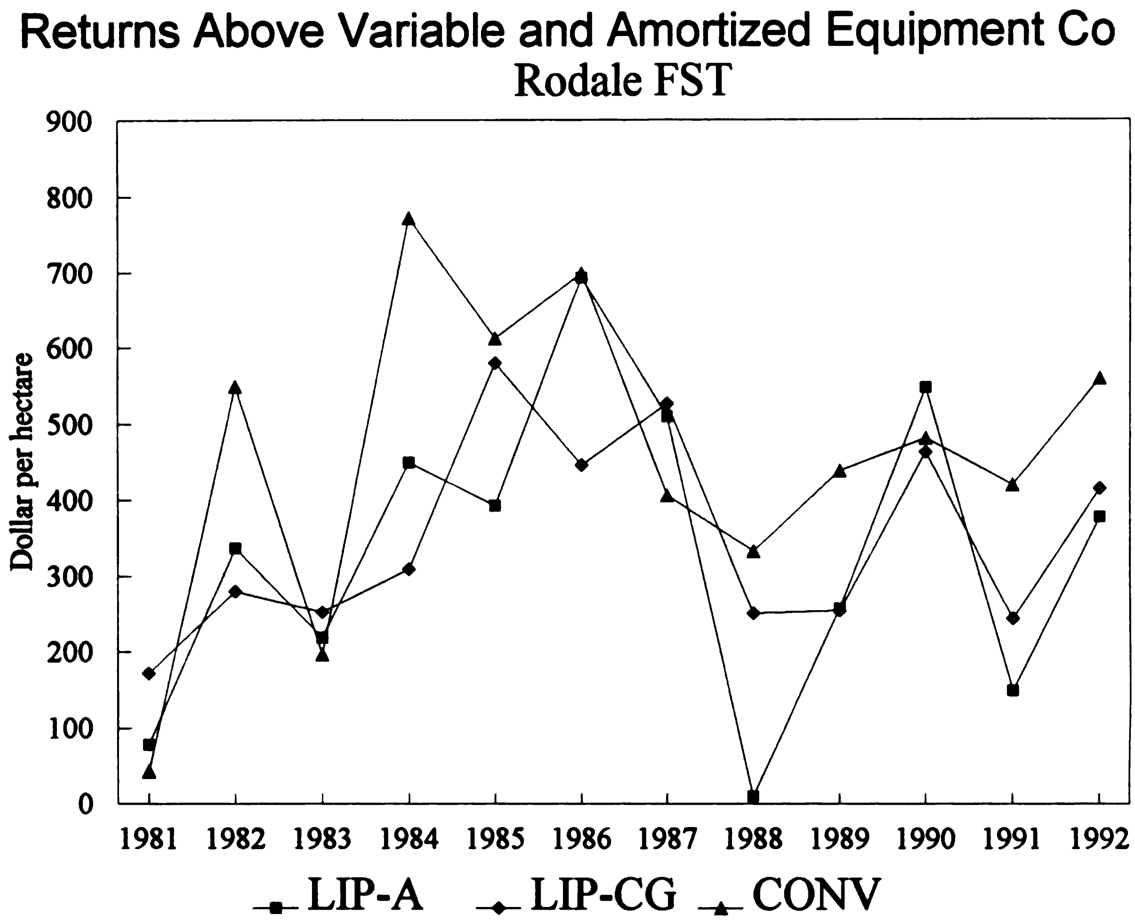

Figure 5.10 Returns above variable and amortized equipment costs in the Rodale Farming Systems Trial.

In dry years crop production and sales were generally low. If total energy input and costs were also high in the same years, dramatically low returns could occur. This is the reason why the returns of LIP-A in 1988 and those of CONV in 1981 were particularly low. A system with more constant and lower inputs like LIP-CG could insulate itself from such shocks to some degree. It can be seen in Figure 5.10 that in these dry years, returns above variable and amortized equipment costs of LIP-CG never dropped as much as LIP-A and CONV, and they were maintained above $200 in Rodale FST during these dry years.

As shown in Table 5.9, the average returns above variable costs to LIP-A increased by 23% from the transition period to the post-transition period. The increase for LIP-CG was 16% for the same period. Both increases were due to increases in total revenue from crop sales. Hanson et al. (1990) reported an 46% increase of profits for LIP-CG from the 1981-1984 period to the 1985-1989 period. In this thesis, a 62% increase of returns above variable costs for LIP-CG was measured during the same study period of Hanson et al. For CONV, a 9% increase in the returns was shown, due largely to decreases in total costs. The greater increases of the returns from the first phase to the second phase in LIP systems serves to illustrate the transition effects on the systems.

All returns above variable and amortized equipment costs measured on the standardized farm showed slight increases from Rodale FST. The average increase is 5%, 4%, and 2.4% in LIP-A, LIP-CG, and CONV respectively. Although only minor, LIP systems have both greater absolute and relative increases of returns than CONV.

Profitability. Another technique to identify and compare the profitability of the systems is to calculate a profitability index[7]. As shown in Table 5.9, average profitability index in the twelve years was 2.5 for CONV, 2.2 for LIP-CG, and 1.8 for LIP-A. The CONV profitability index was considerably greater than those of LIP systems. This result corresponds with the relationship of returns above variable and amortized equipment costs among the systems. One could thus conclude from this analysis that CONV is the most profitable system among the three systems.

Analyzing profitability with the profitability index and the returns showed one difference between the two methods. The average returns of LIP-CG were only slightly greater than LIP-A's returns. However, the LIP-CG's profitability index was substantially greater than that of LIP-A. This is primarily due to the lower costs for LIP-CG.

7 In this study, profitability index was measured by the ratio of total revenue from crop sales to total variable and amortized equipment costs of a farming system.

Overall, the profitability of the operation on a 500-acre standardized cash grain farm is improved sightly compared to that in Rodale FST.

Economic stability and test of hypothesis 5. Table 5.5 shows the economic stability analysis in Rodale FST. The overall economic stability index[8] was 4.5, 3.8, and 3.6 for LIP-CG, CONV, and LIP-A respectively. Profits for LIP-CG were significantly more stable than for the other systems. This result corresponds to the energy stability analysis. However, LIP-A was not economically more stable than CONV, as it was in energy stability; actually, it was slightly less stable than CONV in profitability. Therefore, <u>the hypothesis that LIP system profits are more stable than CONV is supported for LIP-CG but not for LIP-A</u>.

This might be due partly to the commercial cash grain farm basis on which the economic analysis was conducted; it is biased against LIP-A, because on a real dairy farm there are no manure costs and silage and hay sales, all of which greatly affect LIP-A economic performance in this study. Additionally, LIP systems economic stability decreased while that of CONV increased from 1981-1985 to 1986-1992. The same trends were observed in energy stability analysis, suggesting that LIP systems, particularly LIP-A, were less

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Profitability stability index was calculated by the reciprocal of the coefficient of variation of the profitability index.

stable after entering the post-conversion phase. On the contrary, CONV improved its stability during the study. This problem might result from the current agricultural policy or market operation, but further study is needed to explore the causes.

CHAPTER 6

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

Summary

The central question this study seeks to answer is whether or not the two low-input cropping systems in the Rodale Farming Systems Trial, described in chapter Two, are more sustainable than the conventional system, from the viewpoint of energy and economic performance. In the two low-input farming (LIP) systems, low-input with animal system (LIP-A) is a simulated beef farm operation, using steer manure and producing corn, soybeans, wheat, oats, corn silage and hay through a five-year rotation. The low-input cash grain system (LIP-CG) was operated without an animal sector, planting green manure crops as its nutrient source and growing corn, soybeans, wheat, and oats in a five-year crop rotation. No agrichemical products (i.e., commercial synthetic fertilizers and pesticides) were applied in LIP systems except for the application of commercial fertilizers in 1989. The conventional system (CONV) practiced a corn-corn-soybeans rotation with recommended amounts of agrichemicals.

In this study, an operational definition was formulated and five associated hypotheses of comparative sustainability were developed and tested. The definition includes three major components: (1) less nonrenewable energy consumption, (2) acceptable production levels, and (3) higher long-term stability. Two hypotheses were constructed based on each of the second and third characteristics of the definition from energy and economic perspectives, respectively. In addressing the acceptable production level of LIP systems, two approaches were used: (1) for energy analysis - energy production, and (2) for economic analysis - returns above variable costs. To explore long-term stability, two types of stability were included: (1) energy productivity stability, and (2) economic stability. These four hypotheses served as the central theme of this thesis.

The analytical methods used to examine the relationships listed above are energy and economic analyses. They are generally parallel to one another methodologically and similar in their approach, but different in terms of analytical indicators. Economic analysis analyzes a system by tracing money flows and by calculating financial balances, while energy analysis explores a system through its energy flows (both inputs and outputs). In addition to testing the hypotheses, energy input, output, energy productivity, costs, total revenue from crop sales, returns above variable costs, and profitability index were also compared and analyzed.

Major Findings

The major findings of the analyses are summarized as follows:

* LIP systems consumed less than 50% of the CONV nonrenewable energy consumption in each year of the study period from 1981 to 1992. LIP-CG used the least amount of off-farm energy. Commercial fertilizers in CONV alone exceeded total energy consumption in each LIP system and accounted for the greatest amount of energy inputs to the system. In general, LIP systems consumed slightly more off-farm energy in the form of seeds, machinery, and fuel than did the CONV system.

* LIP-A total energy production was above those of CONV and LIP-CG. If only food grains were considered, CONV had the greatest average gross energy production among the systems. LIP-CG food energy production was about 75% that of CONV.

* LIP systems were more stable overall than CONV from the energy performance perspective. LIP-CG profits were much more stable than those of LIP-A and CONV. Economic stability levels for CONV and LIP-A were generally close when compared on a commercial cash grain basis. The energy and economic stability of the CONV system increased significantly from the period of 1981-1985 to that of 1986-1992. In contrast, the stability of the LIP-A decreased greatly during the same period. In addition to the unusually high production in 1986, and the application of fertilizer in 1989, there was a tradeoff between productivity and stability for LIP-A during the post-transition period.

* Both LIP average returns above variable and amortized equipment costs were significantly lower than those of CONV. Profitability indexes also show that LIP operations were not as profitable as CONV based on a cash grain farm operation. This was due primarily to the fact that larger total nonrenewable energy

consumption in CONV was a relatively small portion of its total variable costs, because fertilizers and pesticides were very inexpensive compared with other inputs on a per unit of energy basis.

* Energy productivity in LIP systems is significantly higher than CONV productivity. On average, LIP-CG was 62% more productive or efficient than CONV in producing food energy per unit of nonrenewable energy input.

* If each of the three practices in Rodale FST were operated on a 500-acre standardized farm, all three systems' energy consumption per unit of land would be slightly lower, energy productivity would be improved, but energy stability would be close to the same, because the energy savings are limited.

* Operation costs were measured to be lower on the 500-acre standardized farm, as were total variable and amortized equipment costs; returns above variable and amortized equipment costs were higher on the standardized farm. This difference is not significant enough to alter the relationships of economic performance among the systems.

* Total variable and amortized equipment costs of LIP-A were considerably higher than those of CONV and LIP-CG, due largely to the application of manure in LIP-A. LIP-CG had the lowest total costs because it did not have manure and fertilizer costs, the two major variable costs in LIP-A and CONV, respectively.

* Transition effects in LIP systems were observed. Energy production, total revenue from crop sales, and returns above variable and amortized equipment costs increased significantly between period one, 1981-1985, to period two, 1986-1992. Substantially small increases in these measures were also noted for the CONV system.

* Energy productivity and stability, and economic stability in CONV increased significantly from the 1981-1985 period to the 1986-1992 period, resulting in a part from the decrease of fertilizer inputs in the latter period.

* Dry weather hurt LIP energy production less than CONV energy production, thus favoring LIP systems. In other words; under dry conditions, energy production in LIP systems was more stable CONV. No similar effect was noted for returns above variable and amortized equipment costs because dry conditions caused

proportional drops in returns for each system. Economic factors like total revenue from crop sales seemed more sensitive to dry weather than were biophysical ones, such as energy production for all systems.

Conclusions

In conclusion, **LIP systems are more sustainable than CONV from the energy perspective.** Both LIP systems overall consumed much less nonrenewable energy and had higher stability than CONV. Individually, LIP-A also produced more energy than CONV during the study period. The criteria of being more sustainable in energy analysis have all been satisfied for the LIP-A system. Although the LIP-CG system produced about three-fourths of CONV food energy production, stability of the system was the greatest among the systems; also, its significant increased rate of production has been noted and might raise its energy production to be comparable to that of CONV and make it more sustainable than CONV in the near future.

However, **LIP systems may not be more sustainable than CONV under current economic circumstances.** Although LIP-CG may have higher long-term economic stability than CONV, its profitability is significantly lower than that of CONV. Based on a commercial cash grain operation, LIP-A was not economically sustainable, due mostly to its lower profitability.

Recommendations

Recommendations for policy. Two types of sustainability have been addressed in this thesis: **Energy** sustainability (a bio-physical phenomenon) and **economic** sustainability (a social-political phenomenon). Humans cannot change laws of physics, so overcoming biophysical barriers may be more difficult than addressing social-political barriers. By understanding this, one could state that energy sustainability is above economic sustainability in long-term priority. Therefore, what one needs to do is to make economic sustainability correspond with energy sustainability. Stated another way, because LIP systems are more energy sustainable, efforts should be undertaken to make LIP systems more economically sustainable. One important step to achieve an economically sustainable low-input system is to make it more profitable.

Two ways to make LIP systems' profitability levels comparable to CONV are: 1) increase in agrichemical prices - if prices of chemicals go up or the external costs of the chemicals are internalized and reflected in the commodities' prices, total costs for CONV operation would increase and profitability would decrease; 2) increase in prices of crops produced by low-input operation could increase its income as well as net returns.

However, in a free market country like the U.S., these two possibilities can hardly be achieved without significant government regulation and increased social awareness. More environmentally-sound or energy-conserving regulations and policies should be implemented to internalize the environmental and social costs of agrichemical products on the one hand, and to provide financial encouragement for the development and adoption of low-energy-input, organic, or other alternative farming practices.

Social awareness of the side effects of conventional farming practices and public appreciation of low-input operations is also critical. Realization of these goals will increase public willingness to support and purchase organic or low-input farm products, even though these products may be priced higher. Community support for organic farming could be a key factor influencing the future development of sustainable agriculture in the U.S.

Recommendations for future research. There are at least two types of questions that are not fully understood and thus need further study. First, because the LIP-A system was originally designed for a beef farm operation, the energy and economic comparisons based on a commercial cash grain farm in this study may not be able to actually portray the system. Therefore, analyses based on a beef farm operation should be carried out to evaluate the energy performance and profitability of the LIP-A system.

Second, analyses of a longer term are needed to fully understand the systems dynamics in the Rodale Farming Systems Trial. For example, problems and reasons associated with the decline and increase of stability in LIP-A and CONV, respectively, over the study time period are not clear. One can not identify from this thesis if the changes are simply temporary phenomena or long-term trends. Also, efforts should be made to determine the factors (e.g., weather, crop rotation, soil structure, etc.) that resulted in the phenomena or trends based on the data of further experiment. It is thus suggested that the Rodale farming systems trial continue to provide additional data for these studies.

Finally, as the interest of farmers and researchers in conducting on-farm experiments and studies on alternative farming practices increases, energy analyses could be included to provide a more comprehensive understanding of these systems. It is hoped that the straightforward design, method, and data presented in this thesis could be easily applied by researchers studying alternative farming systems and that the results can be transmitted to farmers to help them achieve greater sustainability on their farms.

LIST OF REFERENCES

American Society of Agricultural Engineers (ASAE). 1992. ASAE Standards: Standards, Engineering Practices and Data Adopted by the American Society of Agricultural Engineers. ASAE, St. Joseph, Michigan.

Axinn, G.H. and N.W. Axinn. 1984. Energy and food relationships in developing countries: a perspective from the social sciences. In D. Pimentel and C.W. Hall (eds). Food and Energy Resources. Academic Press, Inc., Orlando, Florida. pp. 121-146.

Balfour, L.E. 1977. The living soil. In Towards a Sustainable Agriculture. International Federation of Organic Agriculture Movements. pp. 18-27.

Berardi, G.M. 1978. Organic and conventional wheat production: examination of energy and economics. Agro-Ecosystems 4:367-376.

Burnett, M.S. 1978. Energy analysis of intermediate technology agricultural systems. M.S. thesis, University of Florida. Gainesville, Florida.

Cervinka, V. 1980. Fuel and energy efficiency. In D. Pimentel (ed). Handbook of Energy Utilization in Agriculture. CRC Press, Boca Raton, Florida. pp. 15-21.

Chambers, R. 1992. Methods for analysis by farmers: the professional challenge. In Toward a New Paradigm for Farming Systems Research/Extension: Working Papers Set for the 12th Annual Farming Systems Symposium, Michigan State University, East Lansing, Michigan, September 13-18, 1992.

Charoenwatana, T. and A.T. Rambo. 1988. Preface. In T. Charoenwatana and A.T. Rambo (eds). Sustainable Rural Development in Asia: Proceedings of the Fourth SUAN Regional Symposium on Agroecosystem Research held at Khon Kaen University, July 4-7, 1988. Farming Systems Research Project and Southeast Asian Universities Agroecosystem Network (SUAN), Khon Kaen, Thailand. pp. vii-xi.

Chou, T.H. 1992. Farming systems research: a case study of the Triple Tree Farm. Unpublished draft.

Conway, G.R. 1986. Agroecosystem Analysis for Research and Development. Winrock International, Bangkok, Thailand.

Conway, G.R. 1990. Agroecosystems. In J.G.W. Jones and P.R. Street (eds). Systems Theory Applied to Agriculture and the Food Chain. Elsevier Applied Science, New York. pp. 205-233.

Culik, M.N., J.C. McAllister, M.C. Palada, and S. Rieger. 1983. Kutztown Farm Report: A Study of a Low-input Crop/Livestock Farm. Regenerative Agriculture Library Technical Bulletin. Rodale Research Center, Kutztown, Pennsylvania.

Cunningham, L., J. Doll, J. Hall, D. Mueller, J. Posner, R. Saxby, and A. Wood. 1992. The Wisconsin Integrated Cropping Systems Trial: First Report. Lakeland Agricultural Complex Arlington Research Station.

Cutter, S.L., H.L. Renwick, and W.H. Renwick. 1991. Exploitation, Conservation, Preservation: A Geographic Perspective on Natural Resource Use. John Wiley & Sons, New York.

Dabbert, S. 1986. A dynamic simulation model of the transition from conventional to organic farming. M.S. thesis, The Pennsylvania State University. State College, Pennsylvania.

DeWit, C.T. 1979. The efficient use of labor, land and energy in agriculture. Agricultural Systems 4:279-287.

Douglass, G.K. 1984. The meanings of agricultural sustainability. In G.K. Douglass (ed). Agricultural Sustainability in a Changing World Order. Westview Press, Boulder, Colorado. pp. 3-29.

Douglass, G.K. 1985. When is agriculture "sustainable"? In T.C. Edens and C. Fridgen (eds). Sustainable Agriculture and Integrated Farming Systems: 1984 Conference Proceedings. Michigan State University, East Lansing, Michigan. pp. 10-21.

Doyle, C.J. 1990. Application of systems theory to farm planning and control: modelling resource allocation. In J.G.W. Jones and P.R. Street (eds). Systems Theory Applied to Agriculture and the Food Chain. Elsevier Applied Science, New York. pp. 89-112.

Duffy, M., R. Ginder, S. Nicholson. 1989. An economic analysis of the Rodale conversion project: overview. Staff paper No. 212, Department of Economics, Iowa State University, Ames, Iowa.

Dunbar, T.V. 1991. An economic evaluation of alternative agriculture production methods in south central Pennsylvania. M.S. Thesis, The Pennsylvania State University, State College, Pennsylvania.

Dyck, V.A., B.C. Misra, S. Alam, C.N. Chen, C.Y. Hsieh, and R.S. Rejesus. 1979. Ecology of the brown planthopper in the tropics. In Brown Planthopper: Threat to Rice Production in Asia. International Rice Research Institute, Manila. pp. 61-98.

Edens, T.C., and D.L. Haynes. 1982. Closed system agriculture: resource constraints, management options and design alternatives. Annual Review of Phytopathol 20:363-395.

Edens, T.C., and H.E. Koenig. 1980. Agroecosystem management in a resource-limited world. BioScience 30:697-701.

Eggert, F.P. 1977. Preliminary results from plot trials to compare the efficacy of several soil management systems as determined by a number of soil parameters and the yields of some vegetable crops. in Towards a Sustainable Agriculture. International Federation of Organic Agriculture Movements. pp. 77-86.

Eggert, F.P. and C.L. Kahrmann. 1984. Response of three vegetable crops to organic and inorganic nutrient sources. In Organic Farming: Current Technology and Its Role in a Sustainable Agriculture. American Society of Agronomy Special Publication No. 46, Madison, Wisconsin. pp. 97-109.

Fluck, R.C. 1977. Energy productivity: a measure of energy utilisation in agricultural systems. Agricultural Systems 4:29-37.

Francis, C.A. and J.W. King. 1988. Cropping systems based on farm-derived, renewable resources. Agricultural Systems 27:67-75.

Fuller, E., B. Lazarus, L. Carrigan, and G. Green. 1992. Minnesota farm machinery economic cost estimates for 1992. AG-FO-2308-C. Minnesota Extension Service, University of Minnesota, St. Paul, Minnesota.

Hanson, J.C., D.M. Johnson, S.E. Peters, and R.R. Janke. 1990. The profitability of sustainable agriculture on a representative grain farm in the Mid-Atlantic region, 1981-89. Northeastern Journal of Agricultural and Resource Economics 19(2):90-98.

Harrington, L. 1992. Sustainability in perspective: strengths and limitations of FSRE in contributing to a sustainable agriculture. In Toward a New Paradigm for Farming Systems Research/Extension (FSRE): Working Papers Set for the 12th Annual Farming Systems Symposium, Michigan State University, East Lansing, Michigan, September 13-18, 1992. pp. 562-584.

Harsh, S.B., L.J. Connor, and G.D. Schwab. 1981. Managing the Farm Business. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Harwood, R.R. 1984. Organic farming research at the Rodale Research center. In Organic Farming: Current Technology and Its Role in a Sustainable Agriculture. American Society of Agronomy Special Publication No. 46, Madison, Wisconsin. pp. 1-17.

Harwood, R.R. 1985. The integrated efficiencies of cropping systems. In T.C. Edens and C.Fridgen (eds). Sustainable Agriculture and Integrated Farming Systems: 1984 Conference Proceedings. Michigan State University, East Lansing, Michigan. pp. 64-75.

Harwood, R.R. 1988. History of sustainable agriculture: US and international perspective. International Conference on Sustainable Agricultural Systems. September 9, 1988, Ohio State University, Columbus, Ohio. pp. 1-20.

Harwood, R.R. 1990. A history of sustainable agriculture. In C.A. Edwards, R. Lal, P. Madden, R.H. Miller and G. House (eds). Sustainable Agricultural Systems. Soil and Water Conservation Society. Ankeny, Iowa. pp. 3-19.

Heichel, G.H. 1980. Assessing the fossil energy costs of propagating agricultural crops. In D. Pimentel (ed). Handbook of Energy Utilization in Agriculture. CRC Press, Boca Raton, Florida. pp. 27-33.

Heichel, G.H. and D.K. Barnes. 1984. Opportunities for meeting crop nitrogen needs from symbiotic nitrogen fixation. In Organic Farming: Current Technology and Its Role in a Sustainable Agriculture. American Society of Agronomy Special Publication No.46, Madison, Wisconsin. pp. 49-59.

International Federation of Institutes of Advanced Study (IFIAS). 1974. Energy Analysis: Workshop Report No. 6. International Federation of Institutes of Advanced Study, Stockholm.

Jackson, M. 1988. Amish agriculture and no-till: the hazards of applying the USLE to unusual farms. Journal of Soil and Water Conservation 43:483-486.

Jones, M.R. 1989. Analysis of the use of energy in agriculture - approaches and problems. Agricultural Systems 29:339-355.

Jonson, W.A., V. Stoltzfus, and P. Craumer. 1977. Energy conservation in Amish agriculture. Science 198:373-378

Kaffka, S. 1984. Dairy farm management and energy use efficiency: A case study with comparisons. M.S. thesis, Cornell University, Ithaca, New York.

Liebhardt, W.C., R.W. Andrews, M.N. Culik, R.R. Hardwood, R.R. Janke, J.K. Radke, and S.L. Rieger-Schwartz. 1989. Crop production during conversion from conventional to low-input methods. Agronomy Journal 81(2):150-159.

Lockeretz, W. 1980. Energy inputs for nitrogen, phosphorus, and potash fertilizers. In D. Pimentel (ed). Handbook of Energy Utilization in Agriculture. CRC Press, Boca Raton, Florida. pp. 23-24.

Lockeretz, W. 1984. Energy and the sustainability of the American agricultural system. In G.K. Douglass (ed). Agricultural Sustainability in a Changing World Order. Westview Press, Boulder, Colorado. pp. 77-88.

Lockeretz, W., G. Shearer, and D.H. Kohl. 1981. Organic farming in the Corn Belt. Science 211:540-547.

Lowrance, R., P.F. Hendrix, and E.P. Odum. 1986. A hierarchical approach to sustainable agriculture. American Journal of Alternative Agriculture 1(4):169-173.

Luo, S and C. Han. 1990. Ecological agriculture in China. In C.A. Edwards, R. Lal, P. Madden, R.H. Miller and G. House (eds). Sustainable Agricultural Systems. Soil and Water Conservation Society. Ankeny, Iowa. pp. 299-322.

MacKay, K.T. 1989. Sustainable agricultural systems: issues for farming systems research. In S. Sukmana, P. Amir, and D.M. Mulyadi (eds). Developments in Procedures for Farming Systems Research: Proceedings of an International Workshop; 13-17 March, 1989, Puncak, Bogor, Indonesia. pp. 105-118.

Madden, J.P. and T.L. Dobbs. 1990. The role of economics in achieving low-input farming systems. In C.A. Edwards, R. Lal, P. Madden, R.H. Miller and G. House (eds). Sustainable Agricultural Systems. Soil and Water Conservation Society. Ankeny, Iowa. pp. 459-477.

Marten, G.G. 1988. Productivity, stability, sustainability, equitability and autonomy as properties for agroecosystem assessment. Agricultural Systems 26:291-316.

Motyka, G. and T.C. Edens. 1984. A comparison of heterogeneity and abundance of pests and beneficial across a spectrum of chemical and cultural controls. Pest Management Technical Report #41, Department of Entomology, Michigan State University. 44pp.

Mudahar, M.S. and T.P. Hignett. 1987. Energy requirements, technology, and resources in the fertilizer sector. In Z.R. Helsel (ed). Energy in Plant Nutrition and Pest Control. Elsevier, Amsterdam. pp. 25-61.

National Research Council. 1989. Alternative Agriculture. National Academy Press, Washington, D.C.

North American Equipment Dealer Association (NAEDA). 1992. Official Guide: Tractors and Farm Equipment, Spring 1992. NAEDA, St. Louis, Missouri.

Norum, L. 1983. Problem formulation and quantification in energy analysis. Energy in Agriculture 2:1-10.

Odum, H.T. 1983. Systems Ecology: An Introduction. John Wiley & Sons, New York.

Parr, J.F., R.I. Papendick, I.G. Youngberg, and R.E. Meyer. 1990. Sustainable agriculture in the United States. In C.A. Edwards, R. Lal, P. Madden, R.H. Miller and G. House (eds). Sustainable Agricultural Systems. Soil and Water Conservation Society. Ankeny, Iowa. pp. 50-67.

Patten, A.G.W. 1982. Comparison of nitrogen and phosphorus flows on an organic and conventional farm. M.S. thesis, Washington State University. Pullman, Washington.

Peters, S., R. Janke, and M. Bohlke. 1992. Rodale's Farming Systems Trial: 1986-1990. Rodale Institute Research Center, Kutztown, Pennsylvania. 45pp.

Pettersson, B.D. 1977. A comparison between the conventional and biodynamic farming systems as indicated by yields and quality. In Towards a Sustainable Agriculture. International Federation of Organic Agriculture Movements. pp. 87-94.

Pimentel, D. 1980. Energy inputs for the production, formulation, packaging, and transport of various pesticides. In D. Pimentel (ed). Handbook of Energy Utilization in Agriculture. CRC Press, Boca Raton, Inc., Florida. pp. 45-48.

Pimentel, D. 1984. Energy flow in the food system. In D. Pimentel and C.W. Hall (eds). Food and Energy Resources. Academic Press, Inc., Orlando. pp. 1-24.

Pimentel, D. and L. Levitan. 1986. Pesticides: amounts applied and amounts reaching pests. BioScience 36:86-91.

Pimentel, D. and M. Pimentel. 1979. Food, Energy, and Society. John Wiley & Sons, New York.

Pimentel, D., L.E. Hurd, A.C. Bellotti, M.J. Forster, I.N. Oka, O.D. Sholes, and R.J. Whitman. 1973. Food production and the energy crisis. Science 182:443-449.

Pimentel, D., G. Berardi, and S. Fast. 1984. Energy efficiencies of farming wheat, corn, and potatoes organically. In Organic Farming: Current Technology and Its Role in a Sustainable Agriculture. American Society of Agronomy Special Publication No. 46, Madison, Wisconsin. pp. 151-161.

Pimentel, D., H. Acquay, M. Biltonen, P. Rice, M. Silva, J. Nelson, V. Lipner, S. Giordano, A. Horowitz, and M. D'Amore. 1992. Environmental and economic costs of pesticide use. BioScience 42(10):750-760.

Reganold, J.P., L.E. Elliott, and Y.L. Unger. 1987. Long-term effects of organic and conventional farming on soil erosion. Nature 330: 370-372.

Reeves, D.L. 1980. Energy requirements in rye production. In D. Pimentel (ed). Handbook of Energy Utilization in Agriculture. CRC Press, Boca Raton, Inc., Florida. pp. 99-101.

Renborg, U. 1981. Energy analysis of agriculture: biology or economics - a survey of approaches, problems and traps. In C. Johnson and A. Maunder (eds). Rural change - The Challenge for Agricultural Economists. Proceedings 17th International Conference of Agricultural Economists, 3-12 September 1979, Banff, Canada. pp. 231-241.

Robbins, R.D. 1986. A comparison of alfalfa haylage and corn silage and their effects on digestibility, feedlot performance, and economic value. M.S. thesis, Michigan State University. East Lansing, Michigan.

Rodale, R. 1983. Breaking new ground: the search for a sustainable agriculture. The futurist 1: 15-20.

Sahs, W.W. and G. Lesoing. 1985. Crop rotations and manure versus agricultural chemicals in dryland grain production. Journal of Soil and Water Conservation 40:511-516.

Scott, W.O., and J. Krummel. 1980. Energy used in producing soybeans. In D. Pimentel (ed). Handbook of Energy Utilization in Agriculture. CRC Press, Boca Raton, Inc., Florida. pp. 117-121.

Seetisarn, M. 1988. Sustainable rural development in a systems perspective. In T. Charoenwatana and A.T. Rambo (eds). Sustainable Rural Development in Asia: Proceedings of the Fourth SUAN Regional Symposium on Agroecosystem research held at Khon Kaen University, July 4-7, 1988. Farming Systems research Project and Southeast Asian Universities Agroecosystem Network (SUAN), Khon Kaen, Thailand. pp. 3-8.

Soule, J.D. and J.K. Piper. 1992. Farming in Nature's Image: An Ecological Approach to Agriculture. Island Press, Washington, D.C.

Stinner, D.H., M.G. Paoletti, and B.R. Stinner. 1989. In search of traditional farm wisdom for a more sustainable agriculture: A study of Amish farming and society. Agriculture, Ecosystems and Environment 27:77-90.

Stockton, J.R. and C.T. Clark. 1980. Introduction to Business and Economic Statistics. South-Western Publishing Co., Cincinnati.

Stout, B.A. 1984. Energy Use and Management in Agriculture. Breton Publishers, North Scituate, Massachusetts.

Terhune, E.C. 1980. Energy used in the United States for agricultural liming materials. In D. Pimentel (ed). Handbook of Energy Utilization in Agriculture. CRC Press, Boca Raton, Inc., Florida. pp. 25-26.

Thomas, J.J. 1983. An Introduction to Statistical Analysis for Economists. Weidenfeld and Nicolson, London.

United States Department of Agriculture. National Agricultural Statistics Service, Agricultural Statistics Board. Agricultural Prices. Various Issues, 1981-1992.

United States Department of Agriculture. 1980. Report and Recommendations on Organic Farming. U.S. Government Printing Office, Washington, D.C.

Wilson, C.L. 1974. Initial session. In Energy Analysis: Workshop Report No. 6. International federation of Institutes of Advanced Study, Stockholm. pp. 5-9.