Chapter 6
An Environmental, Energetic and Economic Comparison of Organic and Conventional Farming Systems

David Pimentel and Michael Burgess

Contents

D. Pimentel (✉)
Department of Entomology, Department of Ecology and Evolutionary Biology,
Cornell University, Tower Road East, Blue Insectary-Old, Room 165,
Ithaca, New York 14853, USA
e-mail: dp18@cornell.edu

M. Burgess
Department of Entomology, Cornell University, Horticulture, Research Aide,
Greenhouse worker, Tower Road East, Blue Insectary-Old, Room 161,
Ithaca, New York 14853, USA
e-mail: mnb2@cornell.edu

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Abstract Various organic technologies have been utilized for about 6,000 years to make agriculture sustainable while at the same time conserving soil, water, energy and biological resources. Benefits of organic technologies include higher soil organic matter and nitrogen, lower fossil energy inputs, yields similar to conventional systems, and conservation of soil moisture and water resources, especially advantageous under drought conditions. Traditional organic farming technologies may be adopted by conventional agriculture to make it more sustainable and ecologically sound.

Keywords Cover crops · Soybeans · Corn · Soil organic matter

6.1 Introduction

Heavy agricultural reliance on synthetic-chemical fertilizers and pesticides is having serious impacts on public health and the environment (Colburn et al. 1997). The estimated environmental and health costs of the recommended use of pesticides costs the nation about $ 10 billion per year (Pimentel 2005). In the United States over 90 % of corn farmers rely on herbicides for weed control (Pimentel et al. 1993). Atrazine, one of the most widely used herbicides on corn, is also one of the most commonly found pesticides in streams and groundwater (USGS 2001). The allowable atrazine level in municipal water systems is 3 ppb and this is 30 times the biological threshold level that Hayes et al. (2002) have demonstrated alters developmental processes in frogs.

Fertilizer and animal manure-nutrient losses have been associated with deterioration of some large fisheries in North America (Frankenberger and Turco 2003). Doughty (2003) relates the runoff of soil and nitrogen fertilizer from US Corn Belt corn production to the anaerobic “dead zone” that has developed in the Gulf of Mexico. The National Academy of Sciences (NAS 2003) reports that excessive fertilizer use is responsible for $ 2.5 billion in annual losses in agricultural inputs. Modern agricultural practices are responsible for increased likelihood of soil erosion. The estimate of public and environment health costs related to soil erosion exceed $ 45 billion yearly (Pimentel et al. 1995).

Integrated pest and nutrient management systems and certified organic agriculture can reduce reliance on agrichemical inputs as well as make agriculture environmentally and economically sound. Pimentel and Pimentel (1996) and the National Academy of Sciences (NAS 2003) have demonstrated that sound management practices can reduce pesticide inputs while maintaining high crop yields and improving farm profitability. Some government programs in Sweden, Ontario, and Indonesia have demonstrated that pesticide use can be reduced 50–65 % without sacrificing high crop yields and quality (NAS 2003; Surgeoner and Roberts 1993).

Organic agriculture seeks to augment ecological processes that foster plant nutrition while conserving soil and water resources. Organic systems eliminate agrichemicals and reduce other external inputs to improve the environment as well as farm profitability. The National Organic Standards Program (USDA-AMS 2002) codifies organic production methods that are based on certified practices verified by independent third party reviewers. These systems give consumers assurance of how their food is produced and for the first time give them the ability to select foods based on food production methods. The National Organic Standards Program prohibits the use of synthetic chemicals, genetically modified organisms, and sewage sludge in organically certified production.

While starting from a small base, organic agriculture is now the fastest growing agricultural sector in the U.S. Dimitri and Greene (2002) report a doubling of hectar-age in organic production (from cropland and pasture) from 1992 to 1997 to more than 500,000 ha and increasing to 1.95 million ha in 2008 (ERS 2012). Organic food sales totaled $ 29 billion in 2010 and while the overall U.S. food sales grew by less than 1 % in 2010, organic food sales grew by 7.7 % (Willer and Kilcher 2012). With continuing consumer concerns about the environment and the chemicals used in food production, and the growing availability of certified organic production, the outlook for the continued growth of organic production is bright (Dimitri and Greene 2002).

Since 1981, the Rodale Institute Farming Systems Trial® has compared organic and conventional grain-based farming systems. This is a 22-year update of these farming systems based on environmental impacts, economic feasibility, energetic efficiency, soil quality, and other performance criteria. The information from these trials can be a tool for developing agricultural policies more in tune with the environment, while increasing economic returns to producers and increasing energy efficiency.

6.2 Methods and Materials

From 1981 through 2002, field investigations were conducted at The Rodale Institute Farming Systems Trial® in Kutztown, Pennsylvania on 6.1 ha. The soil is a Comly silt loam, which is moderately well drained. The land slopes ranged between 1 and 5 %. The growing season has 180 frost-free days, average temperature is 12.4 °C and average rainfall is 1,105 mm per year.

The main plots were 18 × 92 m, and these were split into three 6 × 92 m subplots, which allowed for the same crop comparisons in any 1 year. The main plots were separated with a 1.5 m grass strip to minimize cross movement of soil, fertilizers and pesticides. The subplots were large enough so that farm-scale equipment could be used in harvesting the crops.

The experimental design included three cropping systems (main plots) each replicated 8 times (see Figs. 6.1a and 6.1b):

6.2.1 Conventional (Synthetic Fertilizer and Herbicide-Based)

This system represented a typical cash grain, row-crop farming unit and used a simple 5-year crop rotation (See Figs. 6.1a and 6.1b) of corn, corn, soybeans,

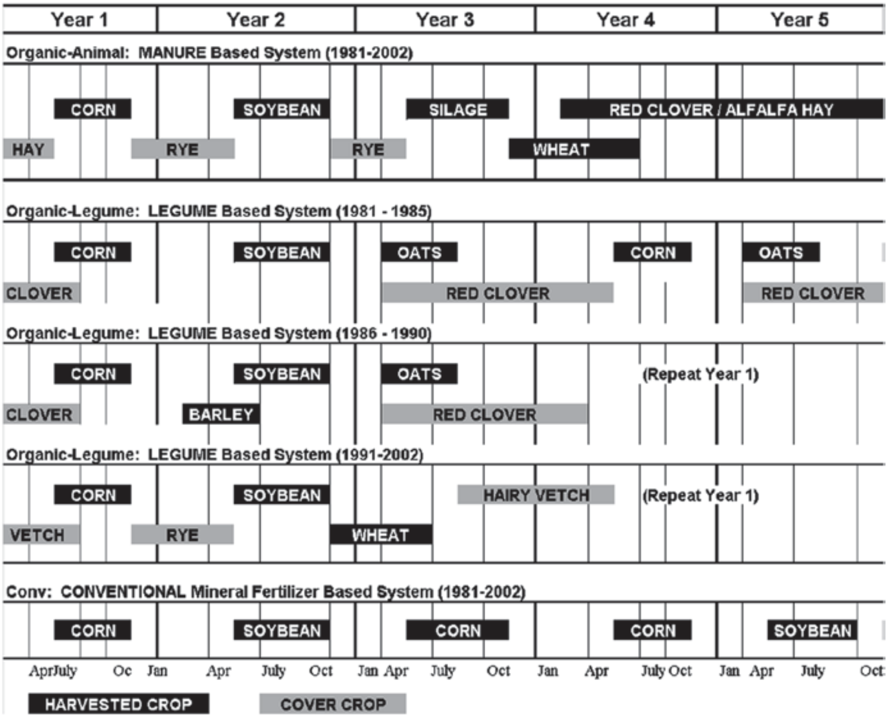


Fig. 6.1a The Rodale Institute Farming Systems Trial rotations . In each system the nitrogen input is added for the corn crop: Steer manure and legume plow-down in the organic-animal system; legume plow-down (red clover or hairy vetch) in the organic-legume system and mineral fertilizer in the conventional system. The rye cover crop was added as a catch crop to the animal system in 1992 and to the legume system in 1993

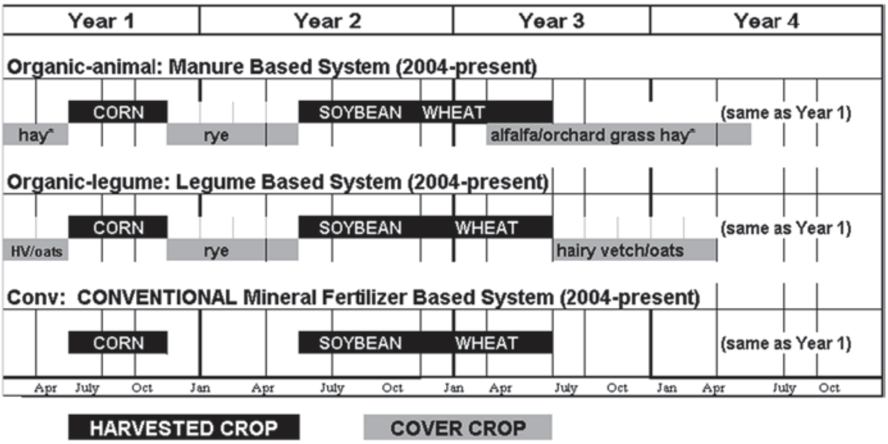
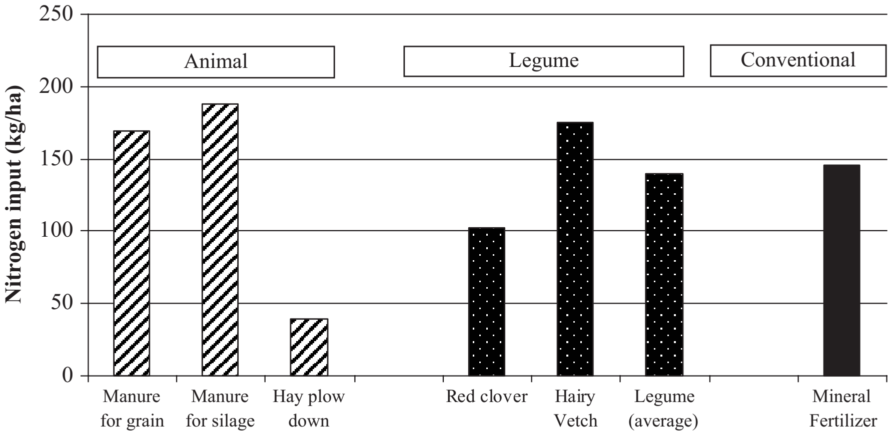


Fig. 6.1b The Rodale Institute Farming Systems Trial rotations. Each system has the same cash crops (corn, soybeans, wheat). In the two organic systems, nitrogen is only added for the corn crop: dairy manure-leaf compost and alfalfa-orchard grass plow-down in the organic-animal system; hairy vetch-oats plow-down in the organic-legume system. The conventional system receives mineral nitrogen fertilizer for both the corn and wheat crop



Average N input from different sources	
	N kg/ha
Manure for grain	169
Manure for silage	188
Hay plow down	39
Red clover	102
Hairy Vetch	176
Legume (average)	140
Mineral Fertilizer	146

Fig. 6.2 Average nitrogen inputs from different sources (mean values throughout the years, depending on the rotation). The Rodale Institute Farming Systems Trial 1981–2002 (ANIMAL = organic animal; LEGUME = organic legume)

corn, and soybeans, reflective of commercial conventional operations in the region and throughout the Midwest (over 40 million ha are in this production system in North America). Fertilizer and herbicide applications for corn and soybeans followed Pennsylvania State University Cooperative Extension recommendations (see Fig. 6.2). Crop residues were left on the surface of the land to conserve soil and water resources. The conventional system had no more exposed soil than in either the organic-animal or the organic-legume based systems during the growing season. However, it did not have cover crops during the non-growing season.

6.2.2 Organic, Animal Manure and Legume-Based

6.2.2.1 Organic, Animal Manure

This system represented a typical livestock operation in which grain crops were grown for animal feed, not cash sale. This Mid-Atlantic grain-rotation system included corn, soybeans, corn silage, wheat and red-clover-alfalfa hay plus a rye cover crop before corn silage and soybeans. This rotation (see Figs. 6.1a and 6.1b) was more complex than the rotation used in the conventional system.

Aged cattle manure served as the nitrogen source (see Fig. 6.2) and was applied at a rate of 5.6 t/ha (dry), 2 years out of every 5, immediately before plowing the soil for corn. Additional nitrogen was supplied by the plow-down of legume-hay crops. The system used no herbicides, relying instead on mechanical cultivation, weed-suppressing crop rotations, and relay cropping, in which one crop acted as a living mulch for another, for weed control.

6.2.2.2 Organic, Legume-Based

This system represented a cash grain operation, without livestock. Like the conventional system, it produced a cash grain crop every year, but used no commercial synthetic fertilizers, relying instead on nitrogen-fixing green manure crops as the primary source of nitrogen.

The final rotation included hairy vetch (winter cover crop), corn, rye (winter cover crop), soybeans, and winter wheat (see Figs. 6.1a and 6.1b). The hairy vetch winter cover crop was incorporated before corn planting as a green manure. The initial 5-year crop rotation (see Figs. 6.1a and 6.1b) in the legume-based system was modified twice to improve the rotation. Both organic systems (animal- and legume-based) included a small grain, such as wheat, grown alone or inter-seeded with a legume. Weed control practices were similar in both organic systems with no herbicide applied in either organic system.

6.3 Measurements Recorded in the Experimental Treatments

6.3.1 Data Collection

Cover crop biomass, crop biomass, weed biomass, grain yields, nitrate leaching, herbicide leaching, percolated water volumes, soil carbon, soil nitrogen, as well as soil water content were measured in all systems. In addition, seasonal total rainfall, energy inputs and returns, and economic inputs and returns were determined.

Plant biomass was determined by taking two to five 0.5 m^2 cuts in each plot. Corn grain yields were assayed by mechanically harvesting the center four rows of each plot. Soybean and wheat yields were obtained by mechanically harvesting a 2.4 m swath in the center of each plot.

A 76 cm long by 76 cm d steel cylinder (lysimeter) was installed in the fall of 1990 in four of the eight replications in each cropping system to enable the collec-

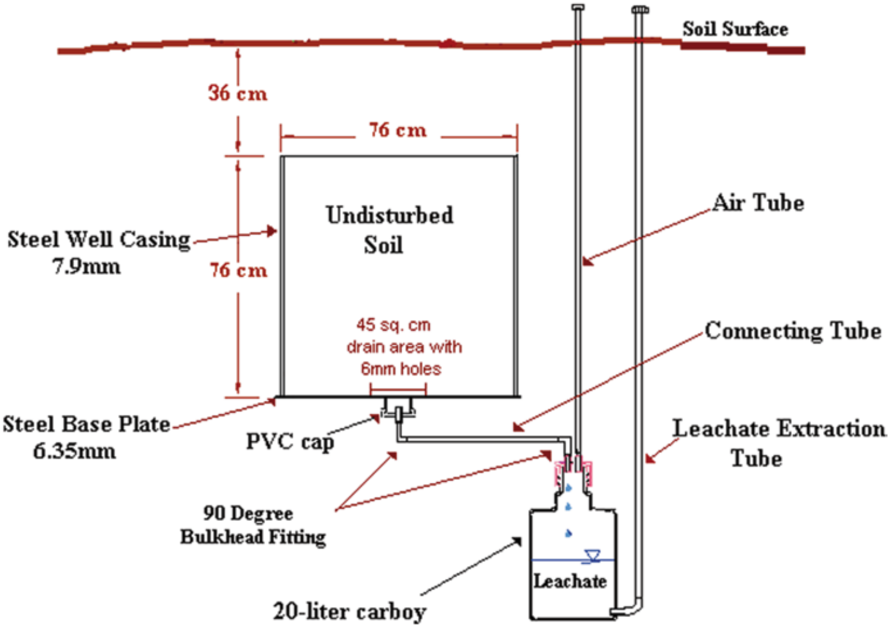


Fig. 6.3 Lysimeter used to collect percolated water in each system in The Rodale Institute Farming Systems Trial

tion of percolated water (Fig. 6.3). The top of each lysimeter was approximately 36 cm below the soil surface to allow field operations to be carried out in a normal fashion directly over the lysimeters. Approximately 20 holes were drilled in the center of the base plate to allow for unrestricted flow of percolate from the cylinder into the flexible tube leading to the collection vessel, a 20-liter polyethylene carboy. Two more tubes were connected to the carboy: the air tube, that ran from the cap of the carboy to the soil surface and the extraction tube that ran from the base of the carboy to the soil surface. The carboy was positioned below and offset to one side of the steel cylinder to enable gravitational flow of liquid to the collection vessel. Any percolate that flowed from the cylinder into the carboy was recovered using a marine utility pump connected to the extraction tube (Moyer et al. 1996). Water could not escape from the lysimeter system. Leachate samples were collected throughout the year.

6.3.2 Analytical Methods

Nitrate-nitrogen in leachate samples was determined by the cadmium reduction method using a Flow Injection Analysis (FIA) system from Lachat Instruments by the Soil and Plant Nutrient Laboratory, Michigan State University, East Lansing, MI.

Herbicides in leachate samples were analyzed using EPA 525.2 determination of organic compounds in water sample by liquid solid extraction and capillary column gas chromatography mass spectrometry by M.J. Reider Associates, Reading, PA.

Total soil carbon and nitrogen were determined by combustion using a Fisons NA1500 Elemental Analyzer by The Agricultural Analytical Services Laboratory, The Pennsylvania State University, University Park, PA.

Soil water content was determined gravimetrically on sieved soil (2 mm).

Statistical analyses were carried out using SPSS Version 10.1.3 General Linear Model Univariate Analysis of Variance (SPSS, Inc., Chicago, IL).

6.4 Results

6.4.1 Crop Yields under Normal Rainfall

From 1986 to 2001, corn grain yields averaged 6,700, 6,900, and 7,200 kg/ha for the conventional system, the organic-legume system, and for the organic-animal system, respectively (Pimentel et al. 2005). Corn yields in the animal system were essentially the same as for the conventional system (see Fig. 6.4). Soybean yields were 2,800, 2,400, and 2,500 kg/ha for the conventional system, for the organic-legume system, and for the organic-animal system, respectively (See Fig. 6.5) (Pimentel et al. 2005). In the conventional system, the soybean yield was not significantly higher than yields in either the organic-legume and organic-animal systems.

The 10-year period from 1988 to 1998 had 5 years in which the total rainfall from April to August was less than 350 mm (versus 500 mm in average years). Corn yields in those 5 dry years were significantly higher (28–34%) in the two organic systems: 6,947 and 7,234 kg/ha in the organic-animal and the organic-legume system, respectively, compared with 5,409 kg/ha in the conventional system. The two organic systems were not statistically different in terms of corn yields during the dry years but the corn yields in both organic systems were significantly different from the yields for the conventional system.

During the extreme drought of 1999 (total rainfall between April and August was only 224 mm compared with the normal average of 500 mm), the organic-animal system had significantly higher corn yields (1,511 kg/ha) than both the organic-legume (421 kg/ha) and the conventional system (1,100 kg/ha) (See Fig. 6.6). Crop yields in the organic-legume system were much lower in 1999 because of the high biomass of the hairy vetch winter cover crop used up a large amount of the soil water (Lotter et al. 2003).

Soybean yields responded differently than the corn during the 1999 drought. Specifically, soybean yields were about 1,800, 1,400, and 91 kg/ha for the organic-legume, the organic-animal, and the conventional systems, respectively (See Fig. 6.6). These treatments were statistically significant ($p = 0.05$) from each other (Pimentel et al. 2005).

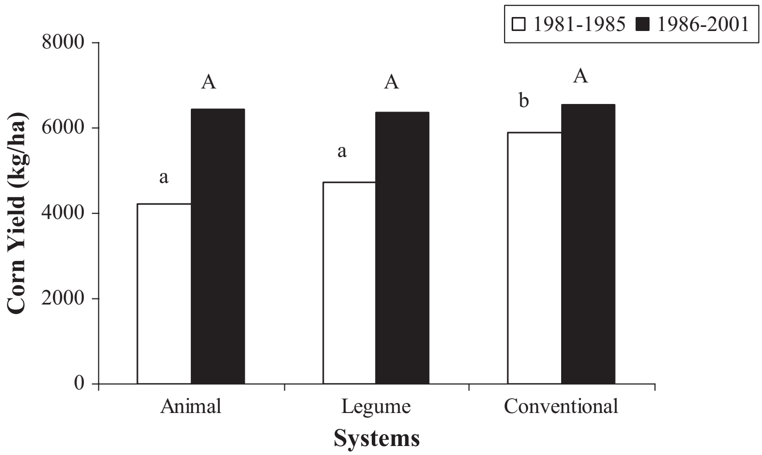


Fig. 6.4 Long-term average corn yields, The Rodale Institute Farming Systems Trial 1981–2001, (ANIMAL = organic animal; LEGUME = organic legume). Different letters above bars denote statistical differences at the 0.05 level for the same time period, according to Duncan's multiple range test

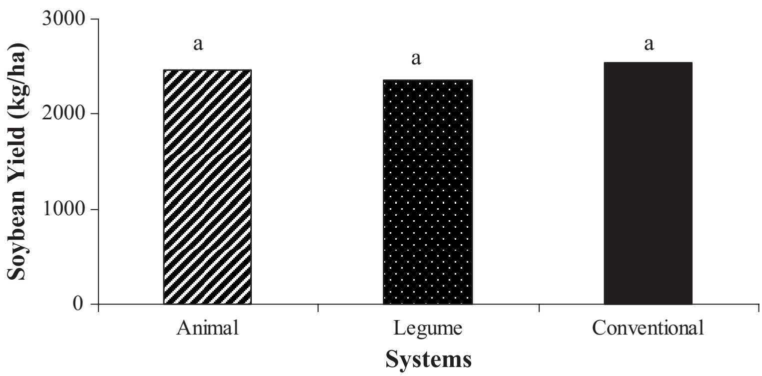


Fig. 6.5 Long-term average soybean yields, The Rodale Institute Farming Systems Trial 1981–2001, excluding 1988 (ANIMAL = organic animal; LEGUME = organic legume). Same letters above bars denote no statistical differences at the 0.05 level, according to Duncan's multiple range test

Over a 12-year period, water volumes percolating through each system (collected in lysimeters), were 15 and 20 % higher in the organic-legume and organic-animal systems, respectively, than in the conventional system. This indicated an increased groundwater recharge and reduced runoff in the organic systems compared to the conventional system (See Fig. 6.7). During the growing seasons of 1995, 1996, 1998 and 1999, soil water content was measured for the organic-legume and conventional systems. The measurements showed significantly more water in the organic-legume soil than in the conventional system (Fig. 6.7) (Pimentel et al. 2005). This accounted for the higher soybean yields in the organic-legume system in 1999 (Pimentel et al. 2005).

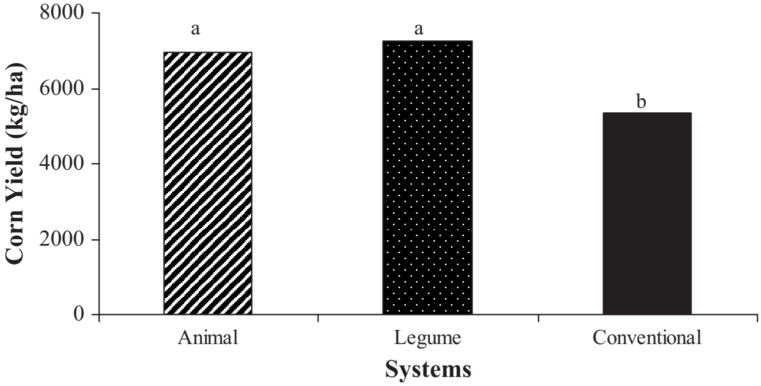


Fig. 6.6 Average corn yields in drought years (1988, 1994, 1995, 1997, 1998), The Rodale Institute Farming Systems Trial, (ANIMAL = organic animal; LEGUME = organic legume). Different letters above bars denote statistical differences at the 0.05 level, according to Duncan's multiple range test

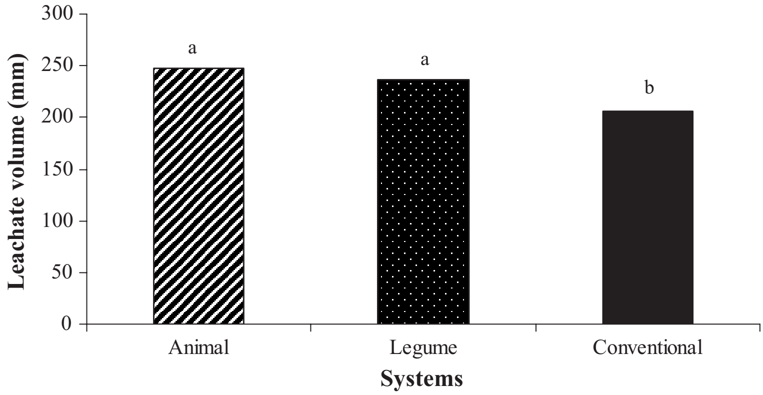


Fig. 6.7 Average amount of leachate volume per year, The Rodale Institute Farming Systems Trial 1991–2002 (ANIMAL = organic animal; LEGUME = organic legume). Different letters above bars denote statistical differences at the 0.05 level, according to Duncan's multiple range test

6.4.2 Energy Inputs

The energy inputs in the conventional, organic-legume, and organic-animal corn production systems were assessed. The inputs included fossil fuels for farm machinery, fuel, fertilizers, seeds, and herbicides. About 7.6 million kcal of energy per ha were invested in the production of corn in the conventional system (Fig. 6.8). The energy inputs for the organic-legume and organic-animal systems were about half that of the conventional system (3.8 million and 3.4 million kcal per ha, respectively) (Fig. 6.8). Commercial fertilizers for the conventional system were produced

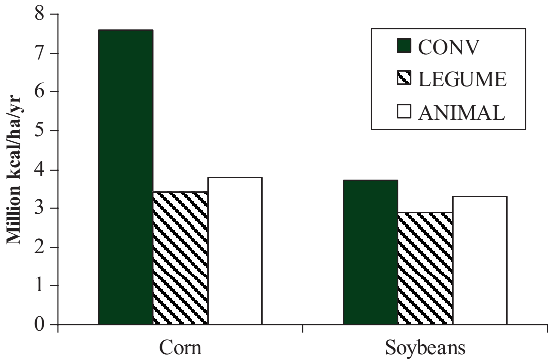


Fig. 6.8 Farming systems trial from 1985 to 2000, average energy inputs for corn and soybeans in the three systems (CONV = conventional; LEGUME = organic legume; ANIMAL = organic animal)

using energy from fossil fuel, but the nitrogen nutrients for the organic systems were obtained from legumes and/or cattle manure. Fossil energy inputs were required to transport and apply the manure to the field.

The energy inputs for soybean production in the conventional and organic-animal systems were similar, 3.7 million kcal and 3.3 million kcal per ha, respectively. The inputs for the organic-legume system of 2.9 million kcal per ha were somewhat lower than both the conventional and organic-animal based systems (Fig. 6.8).

6.4.3 Economics

Two economic studies were completed of the FST (Farm Systems Trial) evaluating the first 9 years and the first 15 years of operation (Hanson et al. 1990 and Hanson et al. 1997, respectively). As inclusive evaluations, these two studies captured the experiences of an organic farmer as s/he develops over time a rotation that best fits one's farm. With the development of the final rotation, however, a third evaluation was completed comparing this rotation with its conventional alternative (Hanson and Musser 2003). Many organic grain farmers in the Mid-Atlantic region have been adopting this 'Rodale rotation' on their farms and there was strong interest in an economic evaluation of only this rotation (i.e., without the transition period or learning curve).

The third economic comparison of the organic corn/soybean rotation and conventional corn/soybean systems covered the period 1991–2001. Without price premiums for the organic rotation, the net returns for both rotations were similar. The annual net return for the conventional system averaged about $ 184 per ha while the organic-legume system for cash grain production averaged $ 176 per ha. When the costs of the biological transition for the organic rotation (1982–1984) are included, then the net returns for the organic rotation are reduced to $ 162 per ha while the conventional net returns remain unchanged. Including the costs of family labor for both rotations reduces the net returns of conventional to $ 162 and organic to $ 127. However, even with the inclusion of the biological transition and family labor costs, the amount of an organic price premium required to equalize the organic and conventional returns is only 10 %. Throughout the 1990s, the organic price premium for grains has exceeded this level and premiums now range between 65 and 140 % (Pimentel et al. 2005).

The organic system requires 35 % more labor, but since it is spread out over the growing season, the hired labor costs per ha are about equal between the two systems. Each system was allowed 250 h of "free" family labor per month. When labor requirements exceeded this level, labor was hired at $ 13.00/h. With the organic system, the farmer was busy throughout the summer with the wheat crop, hairy vetch cover crop, and mechanical weed control (but less than 250 h/month). In contrast, the conventional farmer had large labor requirements in the spring and fall, planting and harvesting, but very little in the summer months. This may have implications for the growing number of part-time farmers for whom the availability of family farm labor is severely limited. Other organic systems have been shown to require more labor per hectare than conventional crop production. On average, organic systems require about 15 % more labor (Sorby 2002; Granatstein 2003), but the increased labor input may range from an increase of 7 % (Brumfield et al. 2000) to a high of 75 % (Nguyen and Haynes 1995; Karlen et al. 1995).

Over the 10-year period, organic corn (without price premiums) was 25 % more profitable than conventional corn. This was possible because organic corn yields were only 3 % less than conventional yields while costs were 15 % less. This success is achieved by growing wheat with a high soil-investing value-crop in the previous year. More specifically, corn was grown 60 % of the time in the conventional rotation, but only 33 % of the time with the organic rotation. Stated in another way, the yields per ha between organic and conventional corn for grain may be similar within a given year; however, overall production of organic corn is diminished over a multiple-year period because it is grown less frequently.

6.4.4 Soil Carbon

Soil carbon, which correlates with soil organic matter levels, was measured in 1981 and 2002. Soil carbon values were statistically the same for all three systems at the start of the experiment in 1981 (Fig. 6.9). In 1981, soil carbon levels found in the soil of the three systems were not different ($p = 0.05$). In 2002, however, soil carbon levels in the organic-legume and organic-animal systems were significantly higher than in the conventional system (Fig. 6.9). The soil carbon level in the conventional system from 1981 to 2002 did not differ statistically, whereas both organic systems had increased and were significantly higher in 2002 than in 1981. The higher level of soil organic matter (soil carbon) in both the organic-legume and organic-animal systems was associated with higher soil water content of the soils in these systems compared with the conventional system. Higher soil water content in the organic systems accounted for the higher corn and soybean yields during drought years in the organic-legume and organic-animal systems compared with the conventional system (Lotter et al. 2003).

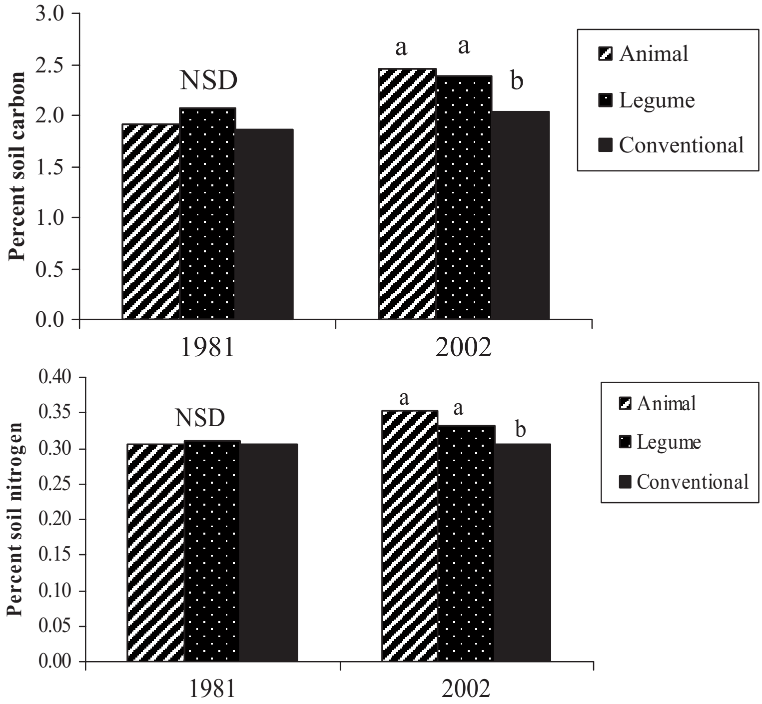


Fig. 6.9 Percent soil carbon and soil nitrogen for the three systems in 1981 and 2002, The Rodale Institute Farming Systems Trial, (ANIMAL = organic animal, LEGUME = organic legume). Different letters indicate statistically significant differences, NSD = not significantly different

6.4.5 Soil Nitrogen

Soil nitrogen levels were measured in 1981 and 2002 in the organic-legume, organic-animal, and conventional systems (Fig. 6.9). Initially the three systems had similar percentages of soil nitrogen or approximately 0.31 %. By 2002, the conventional system remained unchanged at 0.31 % while the organic-manure and organic-legume significantly increased to 0.35 and 0.33 %, respectively. Thus, soil nitrogen was slowly increasing in both organic systems at a rate of 0.3–0.6 % per year.

Harris et al. (1994) used N15 to demonstrate that 47, 38, and 17 % of the nitrogen from the organic-animal, organic-legume, and conventional systems, respectively, were retained in the soil a year after application. The nitrogen losses were 53, 62, and 83 % for the organic-animal, organic-legume, and conventional systems, respectively.

6.4.6 Nitrate Leaching

Overall, nitrate-nitrogen concentrations of leachates from the farming systems varied between 0 and 28 ppm throughout the year (Pimentel et al. 2005). Leachate

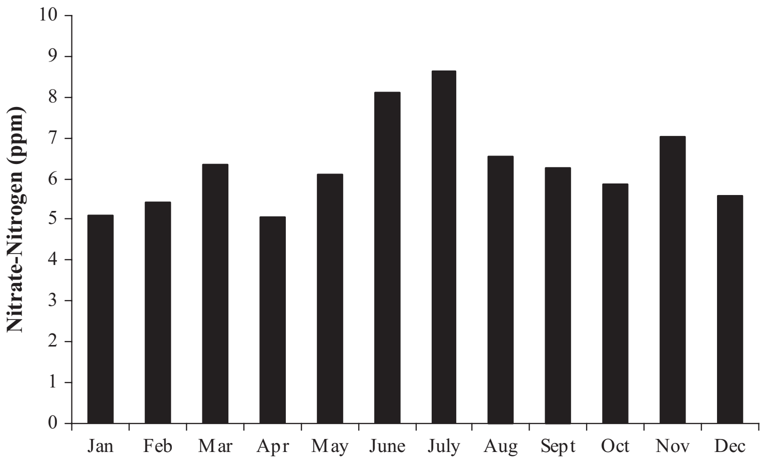
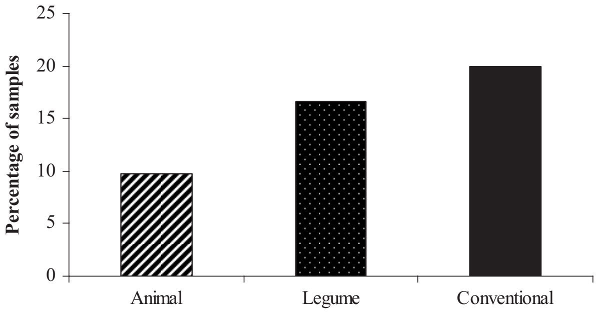


Fig. 6.10 Average monthly nitrate-nitrogen concentration in leachate across all systems, The Rodale Institute Farming Systems Trial, 1991–2001

Fig. 6.11 Percentage of samples exceeding the concentration limit of 10 ppm for nitrate-nitrogen in leachate, The Rodale Institute Farming Systems Trial 1991–2002 (ANIMAL = organic animal; LEGUME = organic legume)



concentrations were usually highest in June and July, shortly after fertilizer application in the conventional systems or plow down of the animal manure and legume cover crop. In all systems, increased soil microbial activity during the growing season appears to have contributed to increased nitrate leaching (Fig. 6.10).

Water leachate samples from the conventional system most frequently exceeded the regulatory limit of 10 ppm for nitrate concentration in drinking water. A total of 20 % of the conventional system samples were above the 10 ppm limit, while 10 and 16 % of the samples from the organic-animal and organic-legume systems exceeded the limit, respectively (Fig. 6.11).

Over the 12-year period of monitoring (1991–2002), all three systems leached between 16 to 18 kg of nitrate-nitrogen per hectare per year (See Fig. 6.12). These rates were low compared to results from other similar experiments where nitrate-nitrogen leaching ranged from 30 to 146 kg/ha per year (Fox et al. 2001; Power et al. 2001). When measuring these nitrate-nitrogen losses as a percentage of

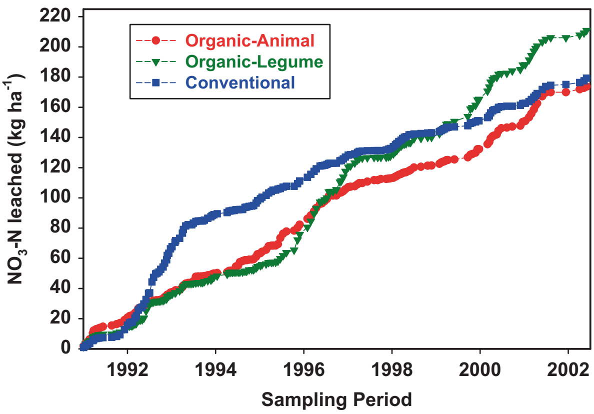


Fig. 6.12 Cumulative nitrate-nitrogen leached, The Rodale Institute Farming Systems Trial 1991–2002

the nitrogen originally available to the crops in each system, the organic-legume, organic-animal, and the conventional systems lost about 32, 20, and 20 %, respectively, of the total nitrogen as nitrate.

The high nitrate leaching in the organic-legume system was not steady over the entire period of the study; instead, it occurred sporadically, especially during a few years of extreme weather. For example, in 1995 and 1999, the hairy vetch green manure supplied approximately twice as much nitrogen as needed for the corn crop that followed, contributing excess nitrogen in the soil and available for leaching. In 1999, the heavy nitrogen input was followed by a severe drought that stunted corn growth and reduced the corn's demand for nitrogen. In both years, these nitrogen-rich soils were also subjected to unusually heavy fall and winter rains that leached the excess nitrogen into the lower soil layers. Monitoring soil nitrogen and cover crop production are needed to manage excessive nitrate-nitrogen potential in all systems.

These data contrasts with experiments in Denmark that indicated that nitrogen leaching from the conventional treatments was twice that in the organic agricultural systems (Hansen et al. 2001). Overall nitrogen leaching levels were lower in this study than those reported by Hansen et al. (2001).

6.4.7 Herbicide Leaching

The following herbicides were applied to the conventional system: atrazine, metolachlor, and pendimethalin to corn and metolachlor and metribuzin to soybeans. From 2001 to 2003, atrazine and metolachlor were detected in water leachate samples collected only in the conventional system (Fig. 6.13). No metribuzin or pendimethalin were detected after application (Pimentel et al. 2005).

In all samples, in the conventional system atrazine concentrations exceeded the 0.1 ppb concentration known to produce deformities in frogs (Fig. 6.13) (Hayes

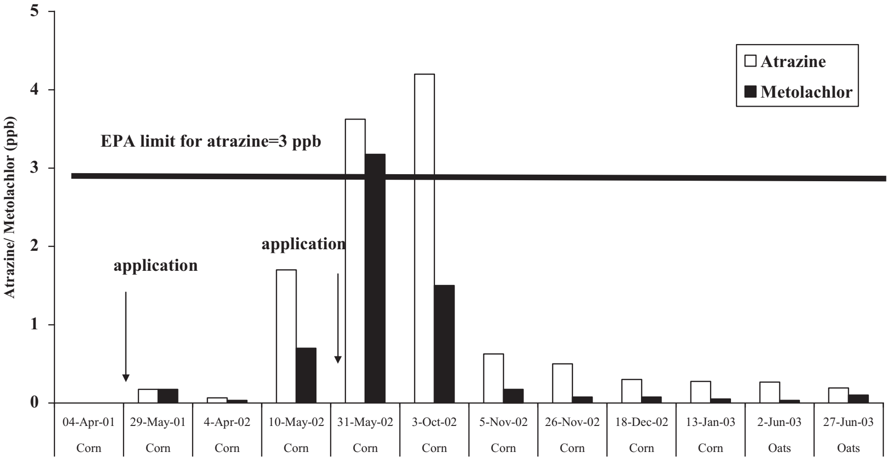


Fig. 6.13 Trends of atrazine and metolachlor concentrations in leachate found in corn after corn plots of the conventional system, The Rodale Institute Farming Systems Trial, 2001–2003

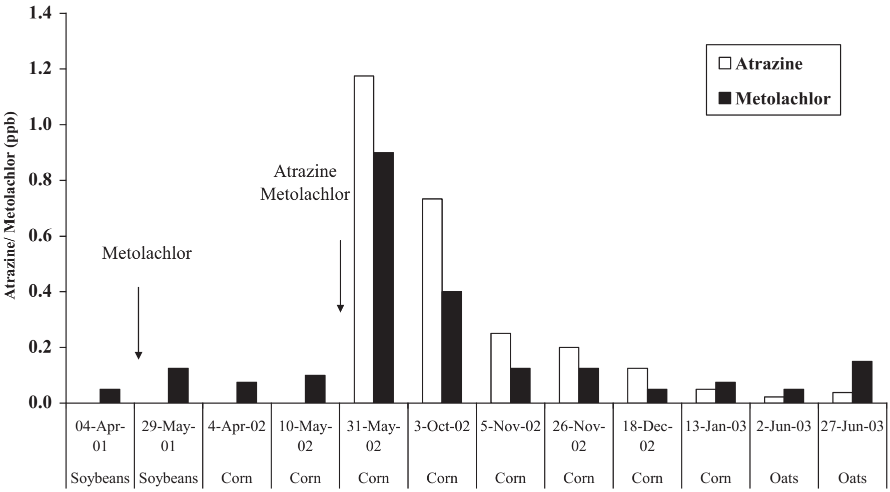


Fig. 6.14 Trends of atrazine and metolachlor concentrations in leachate found in corn after soybean plots of the conventional system, The Rodale Institute Farming Systems Trial, 2001–2003

et al. 2002). In the conventional plots where corn was planted after corn and atrazine was applied 2 years in a row, atrazine in the leachate sometimes exceeded 3 ppb (the MCL set by EPA for drinking water). These atrazine levels were higher than those in the corn-after-soybean treatment (Pimentel et al. 2005). In the conventional system, metolachlor was also detected at 0.2–0.6 ppb generally (Fig. 6.14).

When metolachlor was applied 2 years in a row in a corn-after-corn treatment, it peaked at 3 ppb (Pimentel et al. 2005). EPA has not yet established a MCL for metolachlor for drinking water.

6.5 Discussion

6.5.1 Soil Organic Matter and Biodiversity

Soil organic matter provides the base for productive organic farming and sustainable agriculture. Soil carbon (soil organic matter) was significantly higher in both the organic-animal and organic-legume systems than in the conventional system (Fig. 6.9). In 2002, the soil carbon was 2.5 % in the organic-animal system, 2.4 % in the organic-legume system, and 2.0 % in the conventional system. Soil carbon increased in all three systems from 1981 to 2002. However, the soil carbon increased 27.9, 15.1, and 8.6 % in the organic-animal, organic-legume, and the conventional systems, respectively (Fig. 6.9). The conventional system increase was not statistically significant ($p = 0.05$).

The amount of organic matter in the upper 15 cm of soil in the organic farming systems was approximately 110,000 kg/ha. The soil of this depth weighed about 2.2 million tons/ha. Approximately 41 % of the volume of the organic matter in the organic systems consisted of water compared with only 35 % in the conventional system (Sullivan 2002). The amount of water held in both of the organic systems is estimated at 816,000 liters/ha. The large amount of soil organic matter present in the organic systems aided in making these systems more drought tolerant in the 1999 drought and other drought years.

Large amounts of biomass (soil organic matter) significantly increase soil biodiversity (Pimentel et al. 1992; Troeh and Thompson 1993; Mader et al. 2002; Lavelle and Spain 2001). The arthropods per hectare can number from 2 to 5 million and earthworms from 1 to 5 million (Lavelle and Spain 2001; Gray 2003). The microarthropods and earthworms were reported to be twice as abundant in organic versus conventional agricultural systems in Denmark (Hansen et al. 2001). The weight of the earthworms per hectare in agricultural soils can range from 2,000 to 4,000 kg (Lavelle and Spain 2001). There can be as many as 1,000 earthworm and insect holes per square meter of land. Earthworms and insects are particularly helpful in constructing large holes in the soil that encourage the percolation of water into the soil and prevent excess water run off.

Biomass can help increase biodiversity which provides vital ecological services including crop protection (Altieri 1999). For example, adding compost and other organic matter reduces crop diseases (Cook 1988; Hoitink et al. 1991; Altieri 1999), and also increases the number of species of microbes in the agroecosystem (van Elsen 2000). In addition, in the organic systems, not using synthetic pesticides and commercial fertilizers minimizes the harmful effects of these chemicals upon non-target organisms (Pimentel 2005).

Among the natural biological processes upon which the organic rotations depend is symbiosis of arbuscular mycorrhizae (AB) and crop roots. Arbuscular mycorrhizal fungi are beneficial and indigenous to most soils. They colonize the roots of most crop plants, forming a mutualistic symbiosis (the "mycorrhiza"). The fungus receives sugars from the host-plant root and the plant benefits primarily from enhanced nutrient uptake from the fungus. The extraradical mycelium of the AM fungi act, in effect, as extensions of the root system, more thoroughly exploring the soil for immobile mineral nutrients such as phosphate (Smith and Read 1997). Arbuscular mycorrhizae have been shown to enhance crop disease resistance, improve water relations, and increase soil aggregation (Hooker et al. 1994; Miller and Jastrow 1990; Wright et al. 1999). Efficient utilization of this symbiosis contributes to the success of organic production systems.

Soils of The Rodale Institute Farming Systems Trial (FST) and other field trials at Rodale have been sampled to study the impact of conventional and organic agricultural management upon indigenous populations of AM fungi. Soils farmed with the two organic systems had both greater populations of spores of AM fungi and produced greater colonization of plant roots than in the conventional system (Douds et al. 1993). Most of this difference was ascribed to greater plant cover (70 %) on the organic systems compared with the conventional corn-soybean rotation (40 %). This was due to over-wintering cover crops in the organic rotation (Galvez et al. 1995). In addition to fixing or retaining soil nitrogen, these cover crops allow the AM fungi roots to colonize and maintain their viability during the interval from cash crop senescence to next year planting. Though levels of AM fungi were greater in the organically farmed soils, ecological species diversity indices were similar in the other farming system (Franke-Snyder et al. 2001).

Wander et al. (1994) demonstrated that soil respiration was 50 % higher in the organic-animal system compared with the conventional system 10 years after initiation of The Rodale Institute Farming System Trial. Soil nitrogen and mineralized nitrogen in the organic-animal system increased 19 and 23 %, respectively, compared with the conventional system.

Overall, environmental damage from agricultural chemicals was reduced in the organic systems. Overall, public health and ecological integrity could be improved through the adoption of practices that decrease the quantities of pesticides and commercial fertilizers applied in agriculture (NAS 2003; Pimentel 2005).

6.5.2 Oil and Natural Gas Inputs

Significantly less fossil energy was expended in The Rodale Institute's organic-legume and organic-animal systems compared with the conventional production system, especially with corn (Fig. 6.8). In the organic system, only small amounts of phosphorous (fertilizer) were applied once or twice. Other investigators have reported similar findings (Pimentel et al. 1983; Pimentel 1993; Smolik et al. 1995; Karlen et al. 1995; Dalgaard et al. 2001; Mader et al. 2002; Core 4 2003). In general, the utilization of less fossil energy and energy conservation by organic agriculture systems, reduces the amount of carbon dioxide released to the atmosphere, and therefore reduces the problem of global climate change (FAO 2002).

6.5.3 Crop Yields and Economics

Except for the 1999 drought year, the crop yields for corn and soybeans were similar in the organic-legume, organic-animal, and conventional farming systems. In contrast, Smolik et al. (1995) found corn yields in South Dakota were somewhat higher in the conventional system with average yields of 5,708 kg/ha compared with organic-legume system that averaged 4,767 kg/ha. However, the soybean yields in both systems were similar at 1,814 kg/ha. In a second study comparing wheat and soybean yields, the wheat yields were fairly similar averaging 2,600 kg/ha in the conventional and 2,822 kg/ha in the organic-legume system. Soybean yields were 1,949 and 2,016 kg/ha for the conventional and the organic-legume systems, respectively (Smolik et al. 1995). In The Rodale experiments, corn, soybeans, and wheat yields were considerably higher than those reported in South Dakota.

European field tests indicate that organic wheat and other cereal grain yields average from 30 to 50 % lower than conventional cereal grain production (Mader et al. 2002). The lower yields for the organic system in their experiments compared with the conventional systems appear to be caused by lower nitrogen nutrient inputs in the organic systems. In New Zealand, organic wheat yields were reported to average 38 % lower than those in the conventional system or similar to the results in Europe (Nguyen and Haynes 1995). In New Jersey, organically produced sweet corn yields were reported to be 7 % lower than in a conventional system there (Brumfield et al. 2000). In The Rodale experiments, nitrogen levels in the organic systems have improved and have not been limiting the crop yields after the first 3 years. In the short term in organic systems, there may be nitrogen shortages that may reduce crop yields temporarily, but these can be eliminated by raising the soil nitrogen level through the use of animal manure and/or legume cropping.

In a subsequent field test in South Dakota, corn yields in the conventional system and the organic-alternative system were 7,652 and 7,276 kg/ha, respectively (Dobbs and Smolik 1996). Soybean yields were significantly higher in the conventional system averaging 2,486 kg/ha compared with only 1,919 kg/ha in the organic-alternative system.

The Rodale crop yields were similar to the results in the conventional and organic-legume farming system experiments conducted in Iowa (Delate et al. 2002). In the Iowa experiments, corn yields were 8,655 and 8,342 kg/ha for the conventional and organic-legume systems, respectively. Soybean yields averaged 2,890 and 2,957 kg/ha for the conventional and organic-legume systems, respectively.

Although the inputs for the organic-legume and conventional farming systems were quite different, the overall economic net returns were similar (Fig. 6.4, 6.5). Yet these net returns in The Rodale experiments differ from those of Dobbs and Smolik (1996) who reported a 38 % higher gross income for the conventional than the organic-alternative system. In the latter comparison, however, the organic premiums were not calculated. Often in the market place, prices for organic corn and soybeans range from 20 to 140 % higher than conventional corn, soybeans, and other grains (Dobbs 1998; Bertramsen and Dobbs 2002). Thus, when the market price differential was factored in, the differences between the organic-alternative and conventional would be relatively small and in most cases the returns on the organic produce would be higher, as in the results here for the FST.

In contrast to corn/soybeans, the economic returns (dollar return per unit) for organic sweet corn production in New Jersey were slightly higher (2 %) than conventional sweet corn production (Brumfield et al. 2000). In the Netherlands, organic agricultural systems producing cereal grains, legume, and sugar beets reported a net return of 953 Euros/ha compared with conventional agricultural systems producing the same crops that reported 902 Euros/ha (Pacini et al. 2003).

In a California investigation of four crops (tomato, soybean, safflower, and corn) grown organically and conventionally, production costs for all four crops were 53 % higher in the organic system compared with the conventional system (Clark et al. 1999). However, the profits for the four crops were only 25 % higher in the conventional system compared with the organic system. If the 44 % price advantage of the four organic-system crops were included, the organic crops would be slightly more profitable than the conventional (Clark et al. 1999).

6.5.4 Challenges for Organic Agriculture

Two primary problems identified with the organic system study in California were nitrogen deficiency and weed competition (Clark et al. 1999). This was also noted for the organic farming systems in the U.S. Midwest (Lockeretz et al. 1981). Nitrogen deficiencies and excessive weeds can be overcome with improved crop management, though "predicting the actual amount of nitrogen fixed is notoriously difficult as it depends on many factors including the legume species and cultivar management, weather conditions, and age of the ley" (Watson et al. 2002, p. 242). The *Trifolium pratense* L. cover crops used here supply an average of 138 kg N/ha, nearly the equivalent to the mean N supplied to corn as chemical fertilizer (141 kg N/ha; (Liebhardt et al. 1989).

Pest control can be a problem in organic crop production. Weed control is frequently a problem in organic crops because the farmer is limited to only mechanical and biological weed control, while under conventional production mechanical, biological, and chemical weed control options often are employed. Also weather conditions influence weed control. Mechanical weed control is usually more effective than chemical weed control under dry conditions, while the reverse holds under wet conditions. In the Rodale experiments, only the organic soybeans suffered negative impacts from weed competition.

Insect pests and plant pathogens can be effectively controlled in corn and soybean production by employing crop rotations (Pimentel et al. 1993). Some insect pests can be effectively controlled by an increase in parasitoids; reports on organic tomato production indicate nearly twice as many parasitoids in the organic compared with the conventional system (Letourneau and Goldstein 2001). However, increased plant diversity in tomato production was found to increase the incidence of plant diseases (Kotcon et al. 2001). With other crops, like potatoes and apples, dealing with pest insects and plant pathogens that adversely affect yields is a major problem in organic crop production (Pimentel et al. 1983).

6.5.5 Policy Needs

U.S. Government agricultural policies over time have resulted in increased use of pesticides, fertilizers, and reduced recycling of livestock wastes and reduced crop rotations (NAS 1989). For example, prior to the 1990s, farmers grew mostly program crops (in monocrop production) so as to protect their base hectares (and increase government payments). This reduced the diversity of crops grown and, in turn, livestock production was reduced. During the four decades from 1950 to 1990, pesticide and fertilizer use increased 10 times or more per hectare while soil erosion also increased significantly due to a reduction in crop rotation (Pimentel 1975; Pimentel 1993; Pimentel and Kounang 1998). Finally in 1990, new legislation was passed that encouraged farmers to rotate their crops and hopefully bring livestock back on the farm. If this could be accomplished, it would significantly improve the recycling of livestock wastes and improve the environment, plus reduce fossil energy inputs in crop production.

Some nations have already implemented programs to make their agriculture environmentally sound and sustainable (Kumm 2001; O'Riorda and Cobb 2001). As mentioned, Sweden has reduced pesticide use during the past decade by 68 % without reducing crop yields. This major reduction in pesticide use has led to a 77 % decrease in human poisonings from pesticides (Ekstrom and Bergkvist 2001). Studies have confirmed that U.S. pesticide use on average could be reduced by more than 50 % without any reduction in crop yields (Pimentel et al. 1993).

6.6 Conclusion

Various organic agricultural technologies have been utilized for about 6,000 years to make agriculture sustainable while at the same time conserving soil, water, energy, and biological resources. Some of the benefits of organic technologies identified in this investigation are as follows:

- Soil organic matter (soil carbon) and nitrogen are higher in the organic farming systems providing many benefits to the overall sustainability of organic agriculture.
- Fossil energy inputs for organic crop production are from 30 to 50 % lower than for conventionally produced crops.
- Depending on the crop, soil, and weather conditions, organically managed crop yields on a per hectare basis can equal those from conventional agriculture, but it is likely that organic cash crops cannot be grown as frequently over time because of the dependence on cultural practices to supply nutrients and control pests.
- Labor inputs average about 15 % higher in organic farming systems and range from 7 to 75 % higher.
- Because organic foods frequently bring higher prices in the market place, the net economic return per hectare is often equal or higher than conventionally produced crops.
- Crop rotations and cover cropping typical of organic agriculture, reduce soil erosion, pest problems, and the need for pesticides.
- High soil organic matter helps conserve soil and water resources and is proven beneficial during drought years.
- The recycling of livestock wastes reduces pollution and at the same time benefits organic agriculture.
- Abundant biomass both above and below ground (soil organic matter) also increases biodiversity which helps in the biological control of pests and increases crop pollination by insects.
- Traditional organic farming technologies may be adopted by conventional agriculture to make it more sustainable and ecologically sound.

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