

Organic and Conventional Farming Systems:
Environmental and Economic Issues

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July, 2005

Report 05-1

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INTRODUCTION

Heavy agricultural reliance on synthetic-chemical fertilizers and pesticides is having serious impacts on public health and the environment. The estimated environmental and health care costs of the recommended use of pesticides in the U.S. are 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).

Fertilizer and animal manure-nutrient losses have been associated with deterioration of some large fisheries in North America (Frankenberger and Turco 2003). Runoff of soil and nitrogen fertilizer from corn-belt corn production has contributed to the anaerobic “dead zone” in the Gulf of Mexico. The U.S. National Academy of Sciences (2003) reports that excessive fertilizer use costs \$2.5 billion from wasted fertilizer inputs. Modern agricultural practices are also a concern related to erosion of soil. The estimated costs of public and environment health losses 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 making agriculture environmentally and economically sound. Pimentel and Pimentel (1996) and the National Academy of Sciences (2003) have demonstrated that sound management practices can reduce pesticide inputs while maintaining high crop yields and improving farm economics. Some

government programs in Sweden, Ontario (Canada) and Indonesia have demonstrated that pesticide use can be reduced 50 to 65% without sacrificing high crop yields and quality (NAS 2003).

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 economics. The National Organic 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 consumers have 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 a fast growing agricultural sector in the U.S. Dimitri and Greene (2002) report a doubling of acreage in organic production from 1992 to 1997, currently on more than 500,000 ha. Organic food sales total more than \$7 billion per year and are growing at double-digit rates (Greene 2000, 2004, Odwalla 2002, ERS 2003). With continuing consumer concerns related to the environment and the chemicals used in food production, and the growing availability of certified organic production, the outlook for continuing growth of organic production is bright (Dimitri and Greene 2002).

The Rodale Institute Farming Systems Trial[®] has compared organic and conventional grain-based farming systems since 1981. This is an update after 22 years of

comparisons of these farming systems for a range of performance criteria including environmental impacts, economic feasibility, and energetic efficiency. The information from this trial can be a tool for developing agricultural policies more in tune with the environment while increasing economic returns to producers and increasing energy efficiency.

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. Soil consisted of a Comly silt loam, that 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 1105 mm per year.

The main plots were 18 x 92 m, and these were split into three 6 x 92 m subplots, which allowed for same crop comparisons in any one 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 (Figure 1a).

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 of corn, corn, soybeans, corn, and soybeans, which is reflective of commercial conventional operations in the region and throughout the Midwest (over 40 million hectares are in this production system in North America). Fertilizer and pesticide applications for corn and soybeans followed Pennsylvania State

University cooperative extension recommendations. 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.

Organic, animal manure and legume-based

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 consisted of a 5-year rotation of corn, soybeans, corn silage, wheat and red-clover-alfalfa hay plus a rye cover crop before corn silage and soybeans. This rotation was more complex than the rotation used in the conventional system.

Aged cattle manure served as the nitrogen source for corn and was applied at a rate of 5.6 t/ha (dry) to corn grown for grain and 7.7 t/ha (dry) to corn grown for silage. Thus, manure was applied two out of five years, immediately before plowing the soil for corn. Additional nitrogen was supplied to corn grain by the plow-down of a legume-hay crop. The total nitrogen applied per hectare with the combined sources of manure and hay was about 42 kg per year for corn grain (or 208 kg/ha for any given year with a corn grain crop) and 38 kg/ha for corn silage (or 188 kg/ha for any given year with a corn silage crop) (Figure 2).

Note:

The amount of manure applied to corn in the organic-animal system is roughly equivalent to the amount of manure that would be produced by animals fed crops from this rotation: At the production levels observed during the 1981-2000 period in the organic-animal rotation, it is estimated that approximately 2.1 animals, each weighing on average 400 kg could be supported on each hectare, each year (Culik et al., 1983, Doane-Western, Inc., 1982). Based on published estimates (Pennsylvania Department of Environmental Resources, 1986), 3 tons of manure and straw bedding should be available each year from

the 2.1 animals supported by each hectare. The actual amount of manure applied to the organic-animal system during the 1981-2000 period, was 2.7 t/ha/year (dry matter). Thus, the amount of manure estimated to be produced by 2.1 animals per hectare is sufficient to satisfy the manure application needs of the organic-animal system.

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.

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 it used no commercial synthetic fertilizers, relying instead on nitrogen-fixing green manure crops (red clover or hairy vetch) as the primary source of nitrogen. The final rotation system included hairy vetch (winter cover crop used as a green manure), corn, rye (winter cover crop), soybeans, and winter wheat. The hairy vetch winter cover crop was incorporated before corn planting as a green manure. The initial 5-year crop rotation in the legume-based system was modified twice to improve the rotation. The total nitrogen added per hectare per year to this systems averaged 49 kg (or 140 kg/ha for any given year with a corn crop) (Figure 2). 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.

In 2003 the rotations for each system were adjusted to allow for same crop comparison between all systems in any given year. 2003 was the transition year in which only oats were grown across the entire experimental field. Starting in 2004, all systems were switched to a rotation of corn-soybeans-winter wheat (Figure 1b).

Measurements recorded in the experimental treatments

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, economic inputs and returns were determined.

Plant biomass was determined by taking two to five 0.5m² 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.

In four of the eight replications in each cropping system a 76 cm long by 76 cm diameter steel cylinder (lysimeter) was installed in the fall of 1990 to enable the collection of percolated water (Figure 3). The top of each lysimeter is 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 are connected to the carboy. The air tube runs from the cap of the carboy to the soil surface. A second tube runs from the base tube fitting of the carboy to the soil surface, and serves as the extraction tube for the percolate. The carboy is positioned below and offset to one side of the steel cylinder to enable gravitational flow of liquid to the collection vessel. Any percolate flowing from the cylinder into the carboy is collected through a marine utility pump connected to the extraction tube (Moyer et al., 1996). Water cannot escape from the lysimeter system. Leachate samples were collected throughout the year.

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, 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).

RESULTS

Crop Yields under Normal Rainfall - For the first five years of the experiment (1981-1985) corn grain yields averaged 4,222, 4,743 and 5,903 kg/ha for the organic-animal, organic-legume and conventional system, respectively, with the conventional system being significantly higher than the two organic systems. After this transition period, corn grain yields have been similar for all systems: 6,431, 6,368 and 6,553 kg/ha for the organic-animal, organic-legume and conventional system, respectively (Figure 4). Overall, soybean yields from 1981-2001 were 2,461, 2,235, and 2,546 kg/ha for the organic-animal, organic-legume and conventional system, respectively. The organic-legume system was significantly lower than the other two systems. This includes,

however, the crop failure in 1988 in the organic-legume soybeans, when climate conditions were too dry to grow a relay crop of barley and soybeans. If 1988 is taken out of the analysis, soy bean yields are similar for all systems (Figure 5).

Yields of small grains- From 1981 to 2002, small grains (winter wheat and oats) were grown in the two organic systems and not in the conventional corn and soybean row crop system (see Figure 1a). No fertilizers were applied to the small grains; instead they relied on carry-over nutrients remaining in the soil after summer crops. Overall yields for winter wheat for the 22-year period were similar but slightly lower than the county average yields: 2,741 and 2,786 kg/ha in the organic-animal and organic-legume systems, respectively, compared to a county average of 2,898 kg/ha. Oats were grown in the organic-legume system for the first ten years of the trial (1981-1990). Yields were generally higher than the county average. Overall yields were 2,462 kg/ha in the organic-legume system compared to a county average of 1,933 kg/ha (Figure 6).

During the transition year of 2003, the organic-animal system was significantly higher in oat crop biomass (9,279 kg/ha), followed by the conventional and organic-legume systems (8127 and 6431 kg/ha respectively). Due to severe lodging in the organic-animal system, crop yields did not reflect the same trend: Yields were the same for the organic-animal and the conventional system: 2,910 and 3,175 kg/ha respectively; whereas, the organic-legume system was significantly lower (2,363 kg/ha). However, oat yields in all systems were much higher than the county average (1,875 kg/ha). These findings show organic small grain production compared well to conventional production systems with no evidence of declining productivity over the trial period.

In 2004, wheat yields showed the same trend: Yields were the same in the organic-animal and conventional systems: 2,914 and 3,080 kg/ha, respectively, although the organic-animal system had not received any fertilizer while the conventional system received about 70 kg/ha of nitrogen as recommended under Pennsylvania State University Cooperative Extension Service guidelines. The organic-legume system (2,412 kg/ha) was significantly lower in yield than the other two systems (Figure 6).

Crop Yields under Drought Conditions- 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). Average corn yields in those 5 dry years were significantly higher (28% to 34%) in the two organic systems: 6,938 and 7,235 kg/ha in the organic-animal and the organic-legume system, respectively, compared with 5,333 kg/ha in the conventional system. The two organic systems were not statistically different in terms of corn yields during the dry years (Figure 7).

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 (1511 kg/ha) than both the organic-legume (421 kg/ha) and the conventional system (1,100 kg/ha). Crop yields in the organic-legume system were much lower in 1999 because the high biomass of the winter cover crop of hairy vetch and weeds in the organic-legume corn used up a large amount of the soil water (Lotter et al., 2003).

Average corn yields of the two organic systems were higher in the five drought years than the overall average of corn yields after the transition period (1986-2001). This was most likely due to the fact that the overall average includes the 1999 crop failure and

two years with lower corn yields in which nitrogen inputs in the organic-legume system were below optimum (hairy vetch cover crop was winter killed in those two years).

Soybean yields responded differently than the corn during the 1999 drought. Specifically, soybean yields were about 1,800, 1,400, and 900 kg/ha for the organic-legume, the organic-animal, and the conventional systems, respectively. These treatments were statistically significant ($p=0.05$) from each other (Lotter et al., 2003).

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 (Figure 8). This indicated an increased groundwater recharge and reduced runoff in the organic management compared to the conventional system. 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. This accounted for the higher soybean yields in the organic-legume system in 1999.

Effect of weeds on crop yields - Weed biomass was collected in corn and soybeans from all three systems. Weed biomass varied from year to year but ranged on average between 1,000 and 1,400 kg/ha in the two organic systems compared to approximately 200 kg/ha in the conventional system (Figure 9). From 1991-2001, average weed biomass in the organic systems doubled compared to the first 10 years of the experiment, mostly due to:

- 1) Reduced tillage: In order to reduce soil organic matter losses through tillage, moldboard plowing was replaced by chisel plowing in 1997 and 1998. Chisel

plowing, however did not suppress weeds in the following crops as much as moldboard plowing which led to an increase in weed biomass in the organic systems for several years after that.'

- 2) Extreme weather conditions: Several years in the late 1990s featured summer dry spells that put the corn and soybean crops at a disadvantage to weeds. The worst weed problem, however, occurred in the soybeans in the year 2000 (6000 kg/ha weeds in both organic systems). Soybeans were planted early (mid May instead of late May or early June) because the soil was warm enough in early May. When it turned cool for the second half of May, soybeans stopped growing while weeds were not affected by the cool weather. For the remainder of the growing season, the beans were not able to compensate for that difference. In addition, seven days of rain right after planting made any field work impossible for two weeks which interfered with early weed management such as rotary hoeing (Figure 10).

Correlations between weed biomass and crop yield were highest in soybeans, ($R^2= 0.90$ and 0.80 for the organic-animal and organic-legume systems, respectively) and lower for corn (R^2 -value of 0.3) for both organic systems. In the conventional system there was little correlation ($R^2=0.1$) between weeds and yields for both corn and soybeans.

The Y intercept values give an indication of crop yield potentials in the absence of weeds. For soybeans, the potential yield without weeds was close to 3,000 kg/ha for all three systems (2,901 to 3,058 kg/ha). In corn, yield potentials in absence of weeds were 7,753, 7,619 and 7,384 kg/ha for the organic-animal, organic-legume, and conventional systems, respectively.

Slope values express the relationship of crop yield loss to the amounts of weeds present. Crop losses in organic soybeans and corn were 0.4 and 0.6 kg, respectively for each kilogram of weed. Although weed masses were low in the conventional system, their association with yield loss was high as measured by slope estimates: For corn and soybeans slope values were 2.9 and 0.8 kg, respectively (Table 1).

Most consistent results for crop losses due to weeds are found in soybeans with more than 1,000 kg/ha weed mass. Below this threshold there is less ability to correlate crop losses with weed levels. Determining the precise nature of weed thresholds that initiate crop losses can move weed analysis into integrated management approaches as are being used successfully in insect management.

Energy Inputs- The energy inputs in the organic-animal, organic-legume, and conventional corn production systems were assessed. The inputs included fossil fuels for farm machinery, fuel, fertilizers, seeds, and herbicides. About 5.2 million kcal of energy per ha were invested in the production of corn in the conventional system. The energy inputs for the organic-animal and organic-legume systems were 28 % and 32% less than those of the conventional system, respectively (Figure 11). Commercial fertilizers for the conventional system were produced employing fossil energy, whereas the nitrogen nutrients for the organic systems were obtained from legumes and/or cattle manure. The intensive requirement of fossil fuel energy of the conventional corn system for nitrogen production increases the overall energy inputs in conventional compared to organic production systems. Fossil energy inputs were also required to transport and apply the manure to the field.

The energy inputs for soybean production in the organic-animal, organic-legume and conventional systems were similar, 2.3 million kcal, 2.3 million kcal and 2.1 million kcal per ha, respectively (Figure 11).

Economics- Two economic studies were completed of the FST evaluating the first 9 years and the first 15 years of operation (Hanson et al. 1990, Hanson et al. 1997, respectively). These two studies captured the experiences of an organic farmer as s/he develops over time a rotation that best fits their 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 to 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 (Figure 12a).

The annual costs (\$/ha) for the conventional versus organic rotations, respectively, are: seed (\$73 vs. \$103), fertilizers and lime (\$79 vs. \$18), pesticides (\$76 vs. \$0), machinery costs (\$117 vs. \$154), and hired labor (\$9 vs. \$6) (Figure 12b). Similar revenue comparisons are \$538/ha and \$457/ha (conventional vs. organic). The net returns for the conventional rotation are more variable (i.e., risky). The standard deviation for net

returns over the 10-year period are \$127 and \$109 for the conventional and organic rotations, respectively.

When the costs of the biological transition for the organic rotation (1982-84) were included, then the net returns for the organic rotation were reduced to \$162 per ha while the conventional net returns remained unchanged. Including the costs of family labor for both rotations reduced 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 was only 10% above the conventional product (Figure 12a). Throughout the 1990s, the organic price premium for grains has exceeded this level and premiums now range between 65% and 140% (New Farm, 2003).

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 hours of "free" family labor per month. When labor requirements exceeded this level, labor was hired at \$13.00/hour. 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 hours/month). In contrast, the conventional farmer had large labor requirements in the spring and fall, planting and harvesting, but 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 (\$221/ha vs. \$178/ha). This was possible because organic corn yields were only 3% less than conventional yields (5,843 kg/ha vs. 6,011 kg/ha) while costs were 15% less (\$351/ha vs. \$412/ha). However, the organic grain rotation required a legume cover crop before the corn. This was established after the wheat harvest. Thus, 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. On the other hand, the reduced amount of corn grown in the organic rotation is partly compensated for with the additional crop of wheat.

Soil Carbon- Soil carbon, that correlates with soil organic matter levels, was measured in 1981 and 2002. In 1981, soil carbon levels were not different ($p=0.05$) between the three systems. In 2002, however, soil carbon levels in the organic-animal and organic-legume systems were significantly higher than in the conventional system: 2.5% and 2.4% versus 2.0%, respectively (Figure 13). The annual net above ground carbon input (based on plant biomass and manure) was the same in the organic-legume and the conventional system (about 3,000 kg/ha) but close to 12% higher in the organic-animal system (about 3,350 kg/ha). However, the two organic systems retained about two to three times more of that carbon in the soil, resulting in an annual soil carbon increase of 981 and 574 kg/ha in the organic-animal and organic-legume systems versus

only 293 kg/ha in the conventional system (calculated on the basis of about 4 million kg/ha of soil in the top 30 cm). This was also associated with higher soil water content of the soils in these systems compared with the conventional system. The higher soil water content in the organic systems accounted for the higher corn and soybean yields in the drought years in these systems compared with the conventional system (Lotter et al., 2003).

Soil Nitrogen- Soil nitrogen levels were measured in 1981 and 2002 in the organic-animal, organic-legume, and conventional systems. 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-animal and organic-legume significantly increased to 0.35% and 0.33%, respectively (Figure 13).

Harris et al. (1994) used N^{15} 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 one year after application.

Nitrate Leaching- Overall, nitrate-nitrogen concentrations of leachates from the farming systems varied between 0 and 28 ppm throughout the year (per sampling event). Leachate 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 (Figure 14).

Water leachate samples from the conventional system sometimes 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 nitrate limit, respectively (Figure 15).

Over the 12-year period of monitoring (1991-2002), all three systems leached between 16 kg to 18 kg of nitrate-nitrogen per hectare per year. These rates were low compared to results from other experiments with similar nitrogen inputs, 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 the nitrogen originally applied to the crops in each system, the organic-animal, organic-legume, and the conventional systems lost about 20%, 32%, 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 (Figure 16). 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 to the soil, making it available for leaching. In 1999, the heavy nitrogen input from hairy vetch 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 contrast 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 the Farming Systems Trial rotations study than those reported by Hansen and others.

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 only detected in water leachate samples collected from the conventional system. No metribuzin or pendimethalin were detected after application.

In all samples from the conventional system, atrazine concentrations exceeded the 0.1 ppb concentration known to produce deformities in frogs (Hayes et al., 2002). In the conventional plots where corn was planted after corn and atrazine was applied two 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. In the conventional system, metolachlor was also detected at 0.2 to 0.6 ppb. When metolachlor was applied two years in a row in a corn-after-corn treatment, it peaked at 3 ppb (Figures 17 and 18). EPA has not yet established a MCL for metolachlor for drinking water.

Soil Biology- Among the natural biological processes upon which the organic rotations depend is symbiosis of arbuscular mycorrhizae [AM] and this aspect was investigated in the Rodale Institute Farming Systems Trial. 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 disease resistance, improve water relations, and increase soil aggregation (Hooker et al. 1994, Augé 2000, Miller and Jastrow 1990, Wright et al. 1999). Efficient utilization of this symbiosis contributes to the success of organic production systems.

Soils of Farming Systems Trial 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 provide roots for the AM fungi to colonize and maintain the fungi's viability during the interval from cash crop senescence to next year's planting. Though levels of AM fungi were greater in the organically farmed soils, ecological species diversity indices were similar in the three farming systems (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 Systems Trial. Microbial activity in the organic soils may be higher than in the conventional systems soils and hence could explain the higher metabolism rates in the organic systems (Lavelle and Spain 2001).

DISCUSSION

Soil Organic Matter and Biodiversity- Soil organic matter provides the base for productive organic farming and sustainable agriculture. After 22 years of separate management, soil carbon (soil organic matter) was significantly higher in both the organic-animal and organic-legume systems than in the conventional system. Soil carbon increased 27.9%, 15.1%, and 8.6% in the organic-animal, organic-legume, and the conventional systems, respectively (Figure 13).

The amount of organic matter in the upper 15 cm of soil the organic farming systems was approximately 110,000 kg/ha. The soil of this depth weighed about 2.2 million kg/ha. Approximately 41% of the volume of the organic matter in the organic systems consisted of water compared with only 35% in the conventional systems (ATTRA, 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 the systems more drought tolerant, such as occurred in the 1999 drought and other drought years.

Large amounts of biomass (soil organic matter) are expected to 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 million to 5 million and earthworms from 1 million to 5 million (Lavelle and Spain, 2001 Gray, 2003). The micro-arthropods 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, which encourages the percolation of water into the soil and helps prevent excess run off.

Soil organic matter is an important source of nutrients and 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.

In conventional crop management in New Zealand, Nguyen et al. (1995) did not report any adverse effect on soil microbial activity. These conventional systems, however, were part of a rotation pastoral-arable system with a relatively high level of soil organic matter (carbon content of the soil ranged from 2.9 to 3.5%).

Overall, environmental damage from agricultural chemicals was reduced in the organic systems because no commercial fertilizers or pesticides were applied to the organic systems. As a result, overall public health and ecological integrity could be improved through the adoption of these practices which decrease the quantities of pesticides and commercial fertilizers applied in agriculture (NAS, 2003).

Oil and Natural Gas Inputs- Significantly less fossil energy was expended in The Rodale Institute's organic-animal and organic-legume systems with corn compared with the conventional production system (Figure 11). There was little difference in the different treatments producing soybeans. In the organic systems, fertilizers and

pesticides were seldom or not used. 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 the problem of global climate change (FAO, 2003).

Crop Yields and Economics- Except for the 1999 drought year, the Farming Systems Trial crop yields for corn and soybeans were similar in the organic-animal, organic-legume, 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 an 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 kg/ha 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. These results might be expected given the shorter growing season (146 days) and lower precipitation (460 mm) 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, 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 systems.

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 (Figure 12a and 12b). 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. However, Smolik et al. (1995) reported higher net returns for the

organic alternative system in their study with alfalfa and nearly equal returns in the green manure treatment.

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; New Farm, 2003). 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 Farming Systems Trial.

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 (Sean 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 (Sean et al., 1999).

One of the longest running (more than 150 years) organic agricultural trials is the Broadbalk experiment at the Rothamsted Experiment Station in the United Kingdom.

The trial compared a manure-based organic system with a synthetic chemical fertilizer-farming system. Wheat yields were slightly higher in the manure-organic plots (3.45 t/ha) than in the plots receiving chemical fertilizers (average 3.40 t/ha). The soil quality improved more in the manured plots than those receiving chemical fertilizer, based on greater accumulations of soil carbon (Jenkinson et al., 1994; Vasilikiotis, 2000).

Challenges for Organic Agriculture- Two primary problems identified with the organic system study in California were nitrogen deficiency and weed competition (Sean et al., 1999). This was also noted for the organic farming systems in the Midwest U.S. region (Lockeretz et al., 1981). Although the Rodale experiment overcame nitrogen deficiency challenges through legume cover crop management, other researchers have been less successful in maintaining and improving soil fertility levels in organic systems. Rodale's results could also be influenced by geographical soil characteristics and not be universally applicable.

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 in 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 disease (Kotcon et al., 2001). With other crops, like potatoes and apples, dealing with pest insects and plant pathogens that adversely affect yields are major problems in organic-crop production (Pimentel et al., 1983).

Adoption of Organic Technologies- Several organic technologies, if adopted by current conventional production systems, would likely be beneficial. These include: 1) Employing off season cover crops; 2) Using more extended crop rotations which act both to conserve soil and water resources and also to reduce insect, disease, and weed problems; 3) Increasing soil organic matter levels which helps conserve water resources and mitigates drought effects on crops; and 4) Employing natural biodiversity to reduce or eliminate the use of nitrogen fertilizers, herbicides, insecticides, and fungicides. Some or all of these technologies have the potential to increase the ecological, energetic, and economic sustainability of all agricultural cropping systems, not exclusively organic systems.

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 were:

- Soil organic matter (soil carbon) and nitrogen were higher in the organic farming systems providing many benefits to the overall sustainability of organic agriculture.
- Although higher soil organic matter and nitrogen levels of the organic systems were identified similar rates of nitrate leaching were found as in conventional corn and soybean production.
- Fossil energy inputs for organic crop production were about 30% lower than for conventionally produced corn.
- 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.

Year 1		Year 2			Year 3			Year 4			Year 5			
Organic-Animal: MANURE Based System (1981-2002)														
	CORN			SOYBEAN			SILAGE			RED CLOVER / ALFALFA HAY				
HAY		RYE			RYE			WHEAT						
Organic-Legume: LEGUME Based System (1981 - 1985)														
	CORN			SOYBEAN			OATS			CORN			OATS	
CLOVER							RED CLOVER						RED CLOVER	
Organic-Legume: LEGUME Based System (1986 - 1990)														
	CORN			SOYBEAN			OATS			(Repeat Year 1)				
CLOVER			BARLEY				RED CLOVER							
Organic-Legume: LEGUME Based System (1991-2002)														
	CORN			SOYBEAN					HAIRY VETCH	(Repeat Year 1)				
VETCH		RYE			WHEAT									
Conv: CONVENTIONAL Mineral Fertilizer Based System (1981-2002)														
	CORN			SOYBEAN			CORN			CORN			SOYBEAN	
Apr	July	Oc	Jan	Apr	July	Oct	Jan	Apr	July	Oct	Jan	Apr	July	Oct
HARVESTED CROP			COVER CROP											

Figure 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.

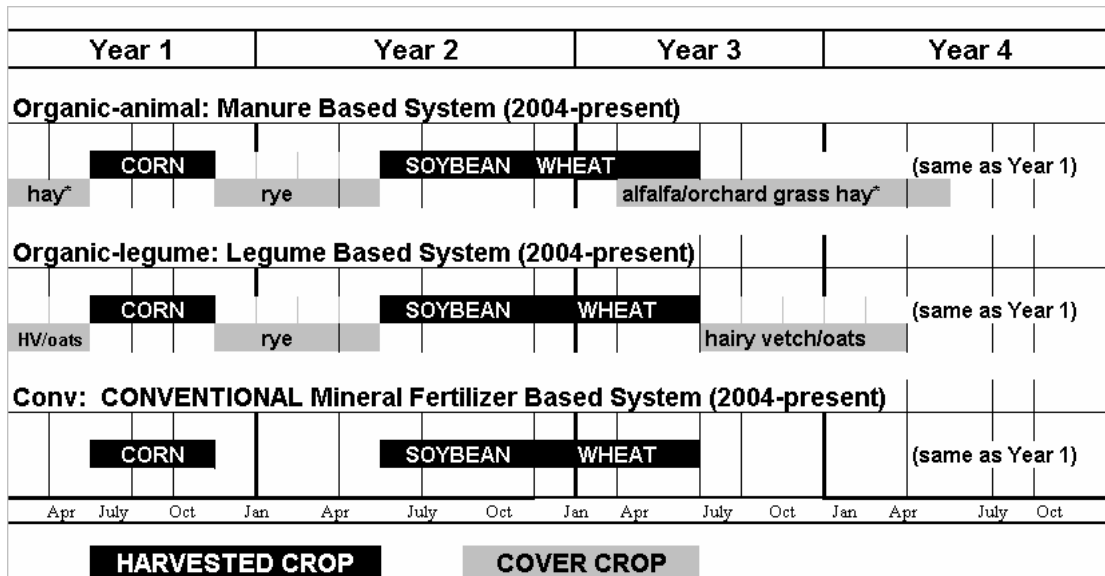


Figure 1b: The Rodale Institute Farming Systems Trial rotations. Each system has the same cash crops (corn, soybeans, wheat). In the two organic systems, nitrogen is only added for the corn crop: Dairy manure-leaf compost and alfalfa-orchard grass plow-down in the organic-animal system; hairy vetch-oats plow-down in the organic-legume system. The conventional system receives mineral nitrogen fertilizer for both the corn and wheat crop.

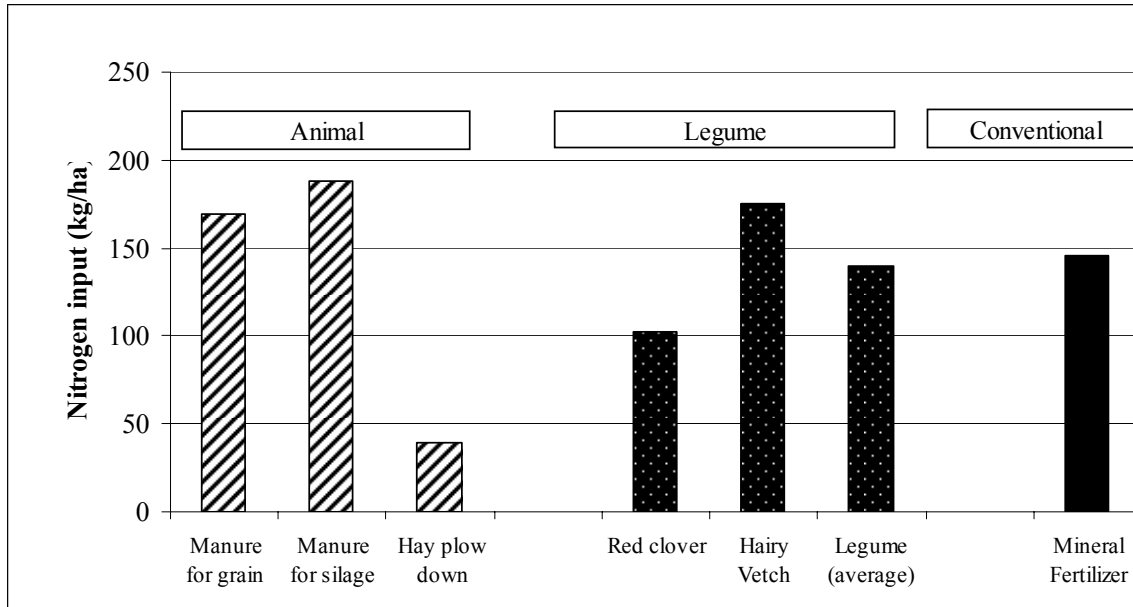


Figure 2: Average nitrogen inputs from different sources (mean values throughout the years, depending on the rotation). The Rodale Institute Farming Systems Trial 1981-2002 (Animal = organic animal; Legume = organic legume).

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

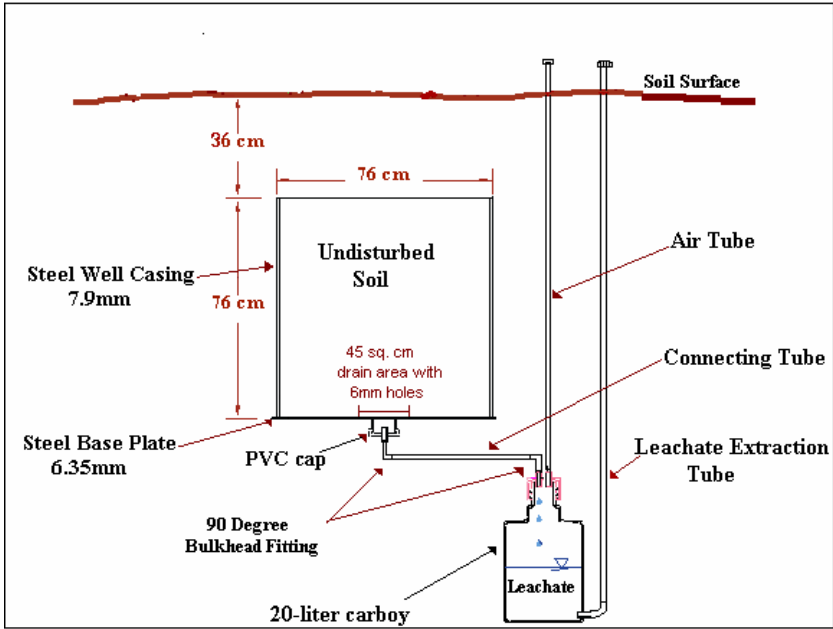


Figure 3: Lysimeter used to collect percolated water in each system in the Rodale Institute Farming Systems Trial.

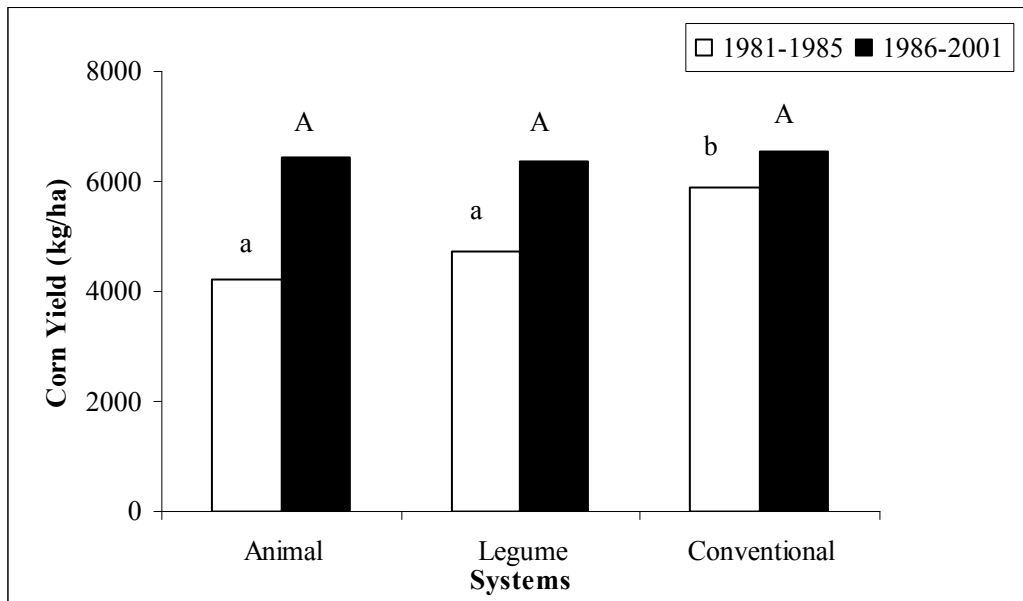


Figure 4: Long-term average corn yields, The Rodale Institute Farming Systems Trial 1981-2001, (Animal = organic animal; Legume = organic legume). Different letters above bars denote statistical differences at the 0.05 level for the same time period, according to Duncan's Multiple Range Test.

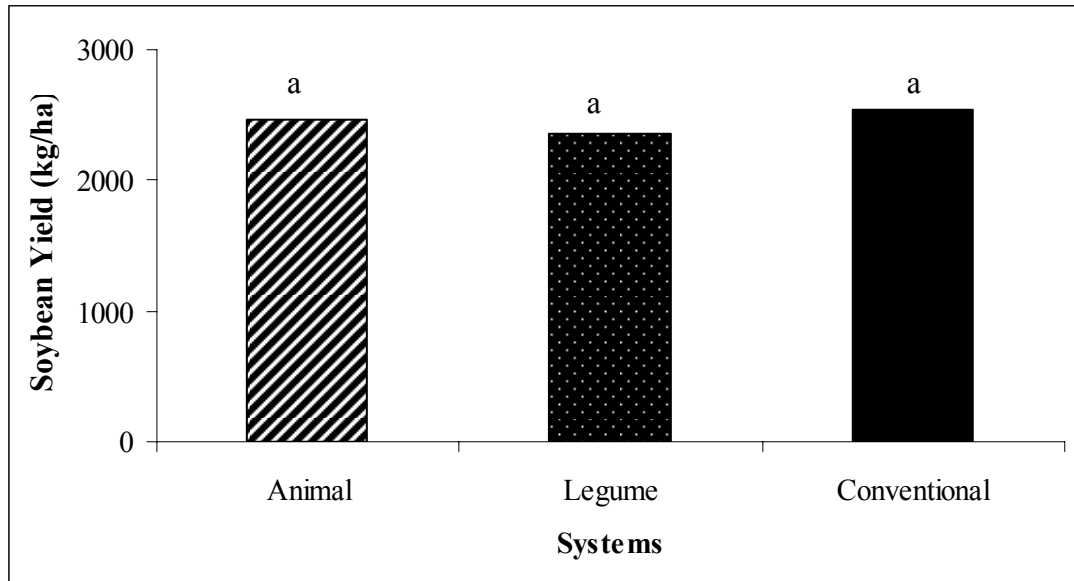


Figure 5: Long-term average soybean yields, The Rodale Institute Farming Systems Trial 1981-2001, excluding 1988 (Animal = organic animal; Legume = organic legume). Same letters above bars denote no statistical differences at the 0.05 level, according to Duncan's Multiple Range Test.

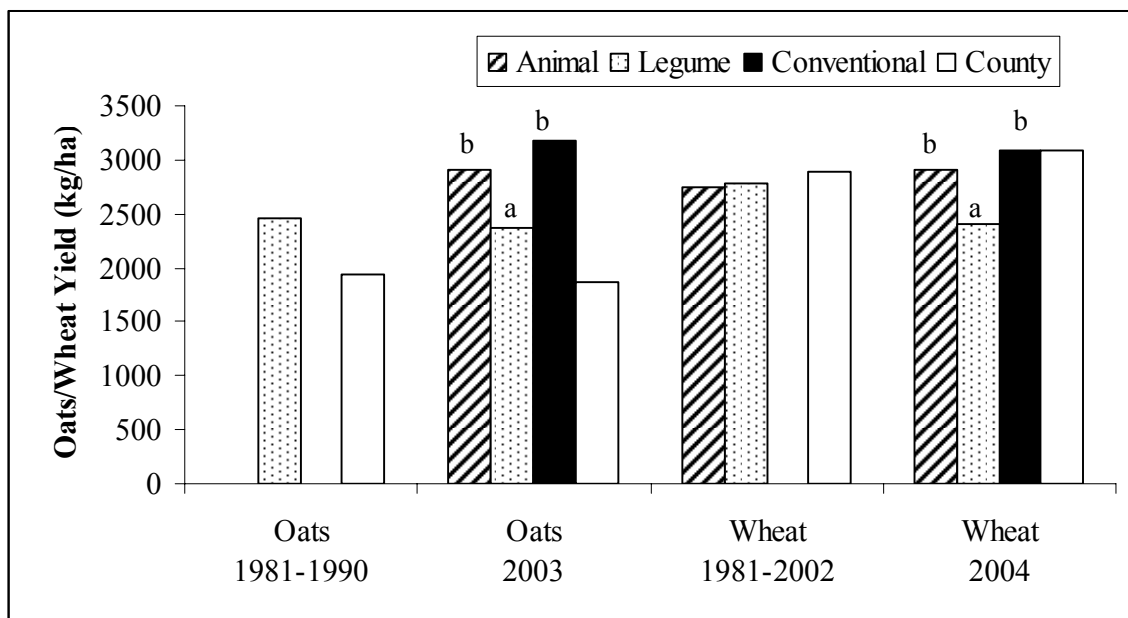


Figure 6: Long-term average oat and wheat yields, The Rodale Institute Farming Systems Trial 1981-2004, (Animal = organic animal; Legume = organic legume). Different letters above bars denote statistical differences at the 0.05 level, according to Duncan's Multiple Range Test. Letters denoting significance are for the same crop only. No statistical analyses were performed for county averages.

	Oats Yield kg/ha 1981-1990	Oats Yield kg/ha 2003	Wheat Yield kg/ha 1981-2002	Wheat Yield kg/ha 2004
Organic-animal	-	2910 b	2741	2914 b
Organic-legume	2462	2363 a	2786	2412 a
Conventional	-	3175 b	-	3080 b
County Average	1933	1875	2898	3096

Long-term average oat and wheat yields, The Rodale Institute Farming Systems Trial 1981-2004. Yields followed by different letters denote statistical differences at the 0.05 level, Duncan's Multiple Range Test. Letters denoting significance are for the same crop only. No statistical analyses were performed for county averages.

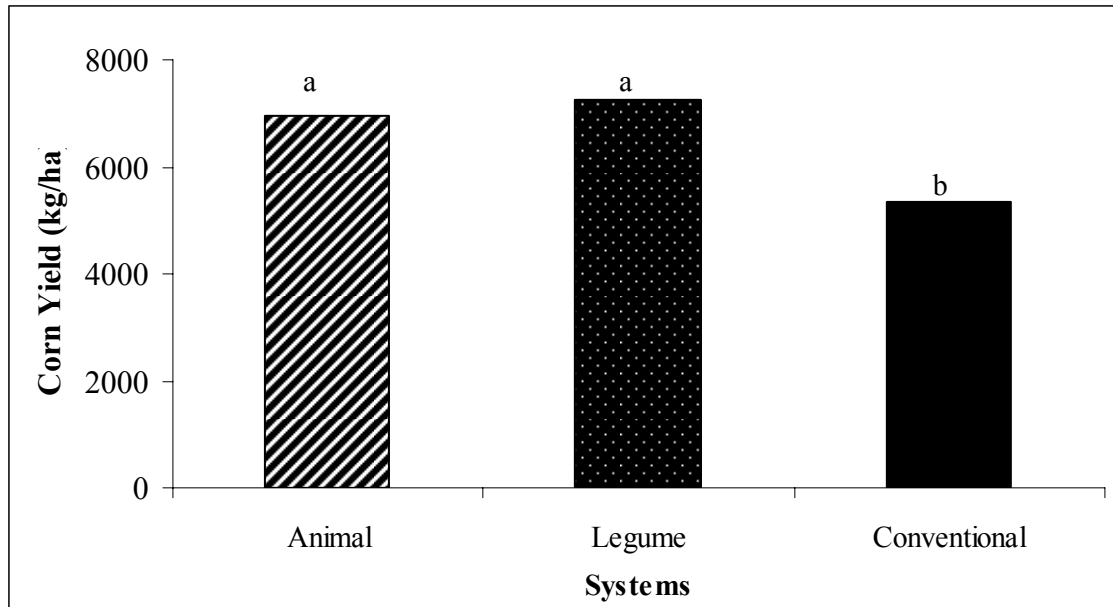


Figure 7: Average corn yields in drought years (1988, 1994, 1995, 1997, 1998), The Rodale Institute Farming Systems Trial, (Animal = organic animal; Legume = organic legume). Different letters above bars denote statistical differences at the 0.05 level, according to Duncan's Multiple Range Test.

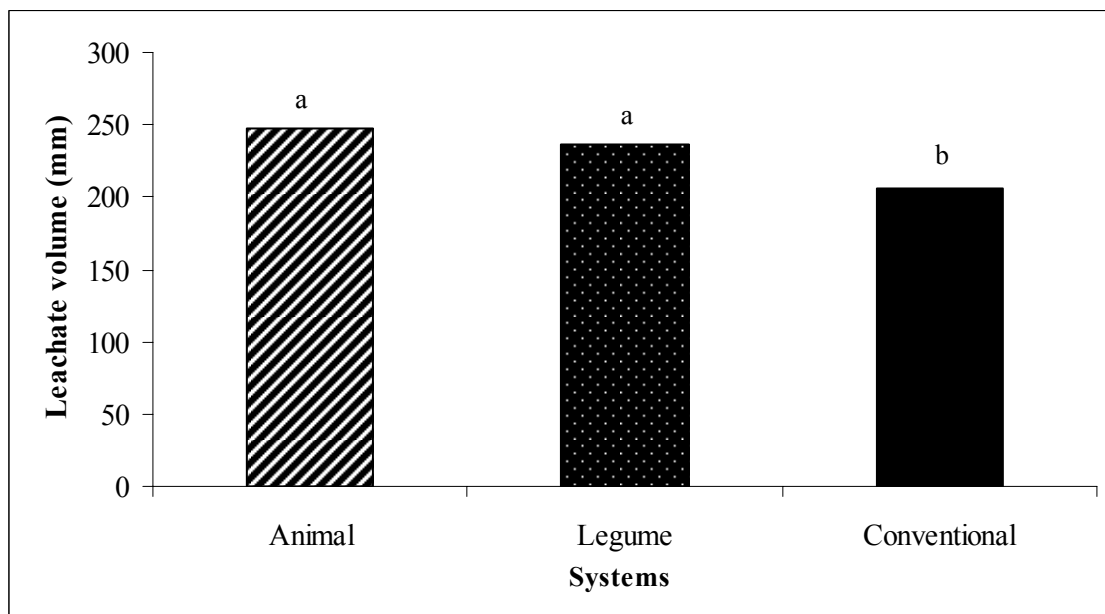


Figure 8: Average amount of leachate volume per year, The Rodale Institute Farming Systems Trial 1991-2002 (Animal = organic animal; Legume = organic legume). Different letters above bars denote statistical differences at the 0.05 level, according to Duncan's Multiple Range Test.

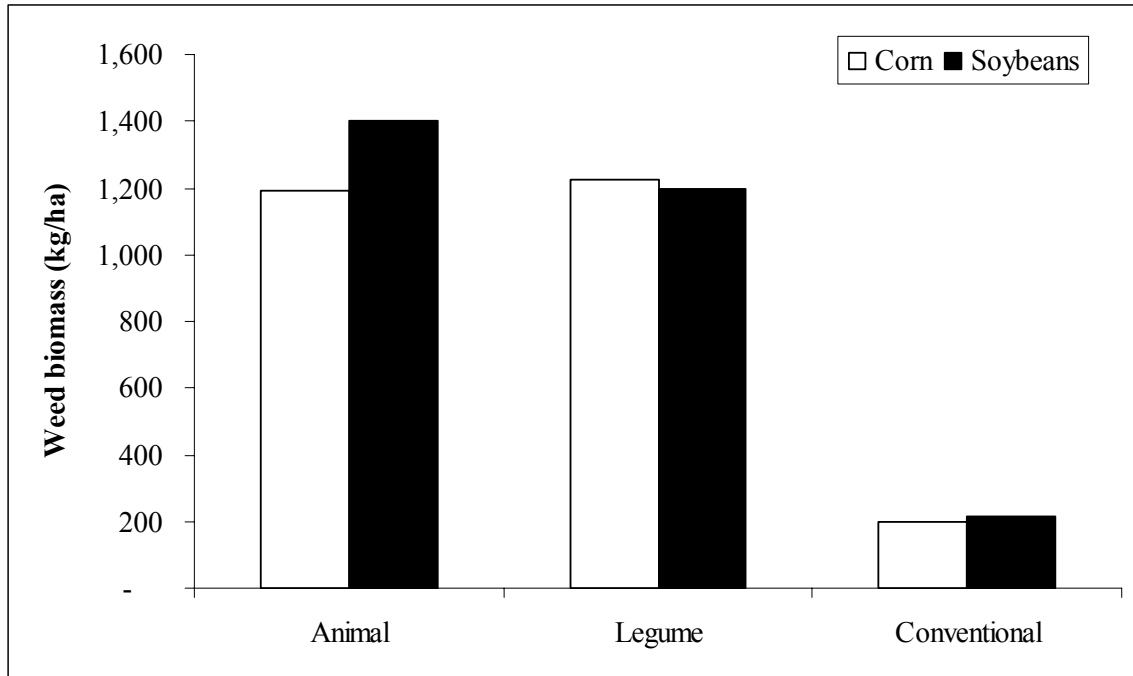


Figure 9: Average weed biomass in corn and soybeans, The Rodale Institute Farming Systems Trial 1981-2001 (Animal = organic animal; Legume = organic legume).

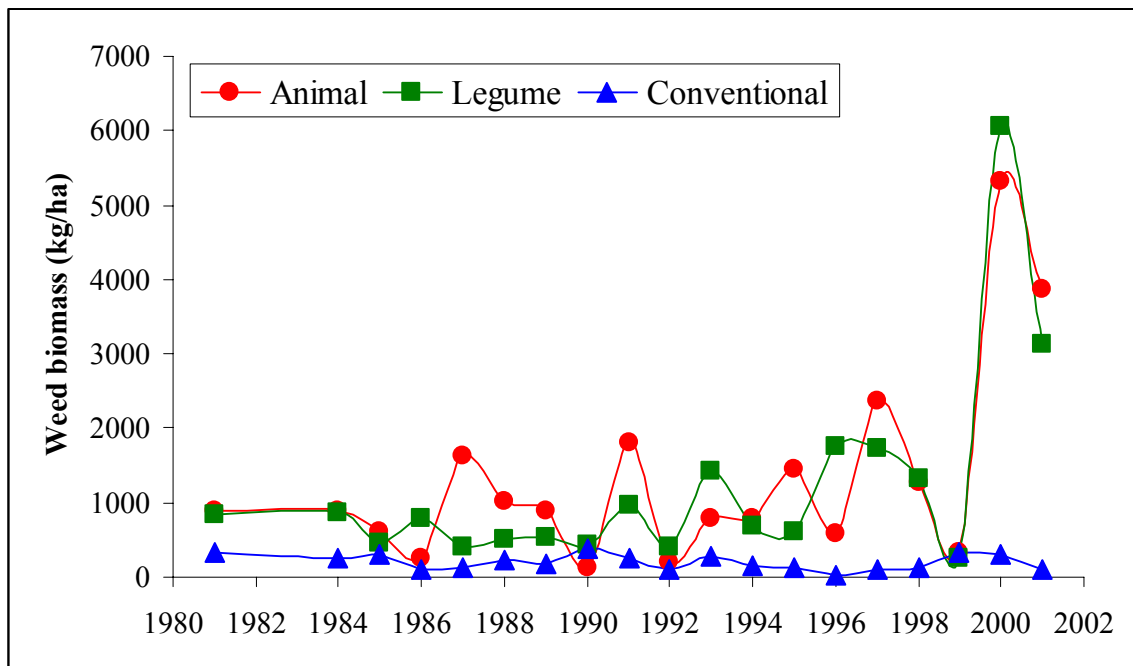


Figure 10: Average weed biomass in corn and soybeans throughout the years, The Rodale Institute Farming Systems Trial 1981-2001 (Animal = organic animal; Legume = organic legume).

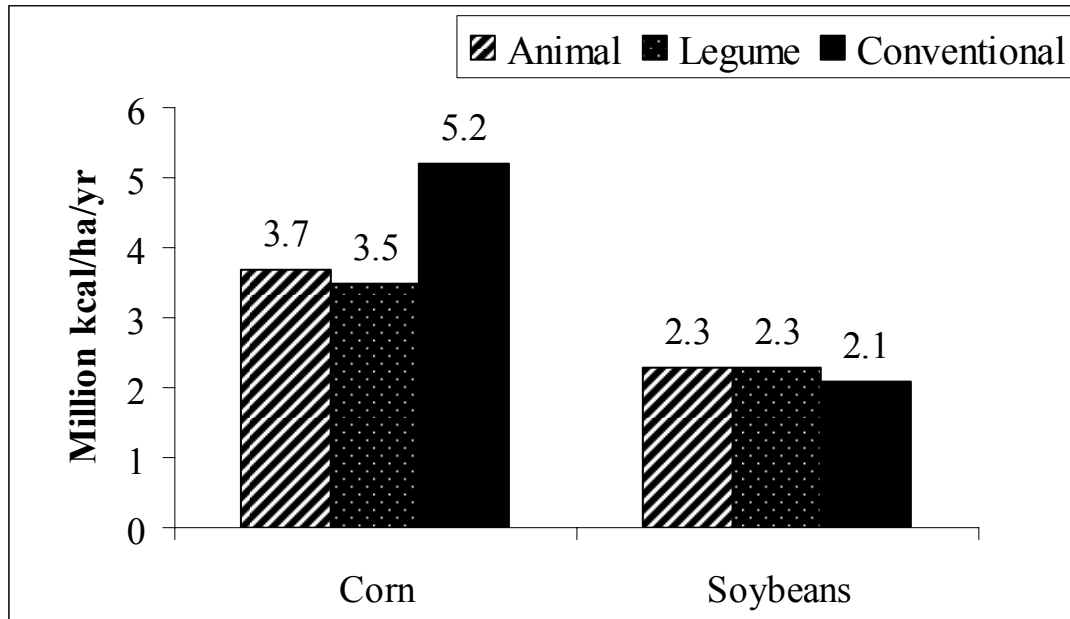


Figure 11: Average energy inputs for corn and soybeans per system, The Rodale Institute Farming Systems Trial 1991-2000 (Animal = organic animal; Legume = organic legume).

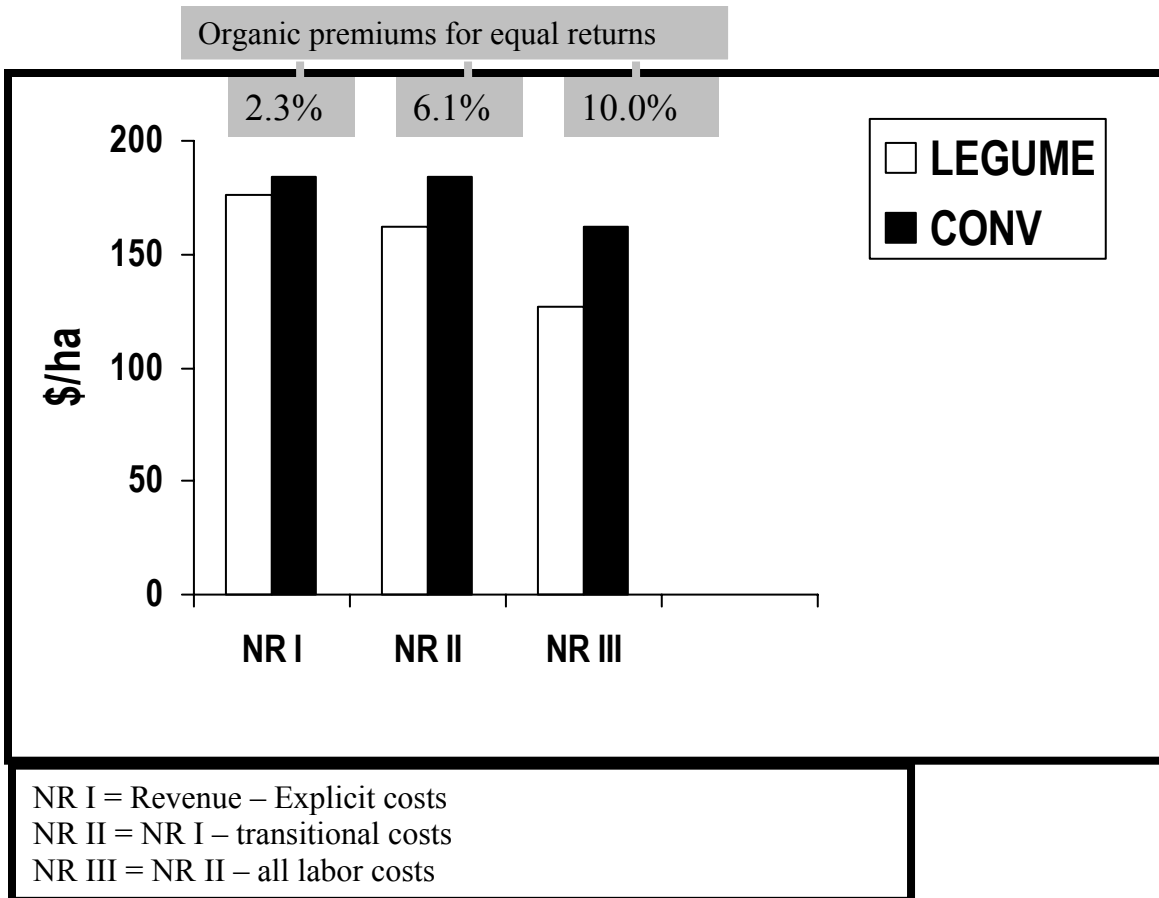


Figure 12a: Average net returns per hectare for the organic-legume (LEGUME) and conventional (CONV) grain rotations, The Rodale Institute Farming Systems Trial from 1991 to 2001, (Source: Hanson and Musser 2003).

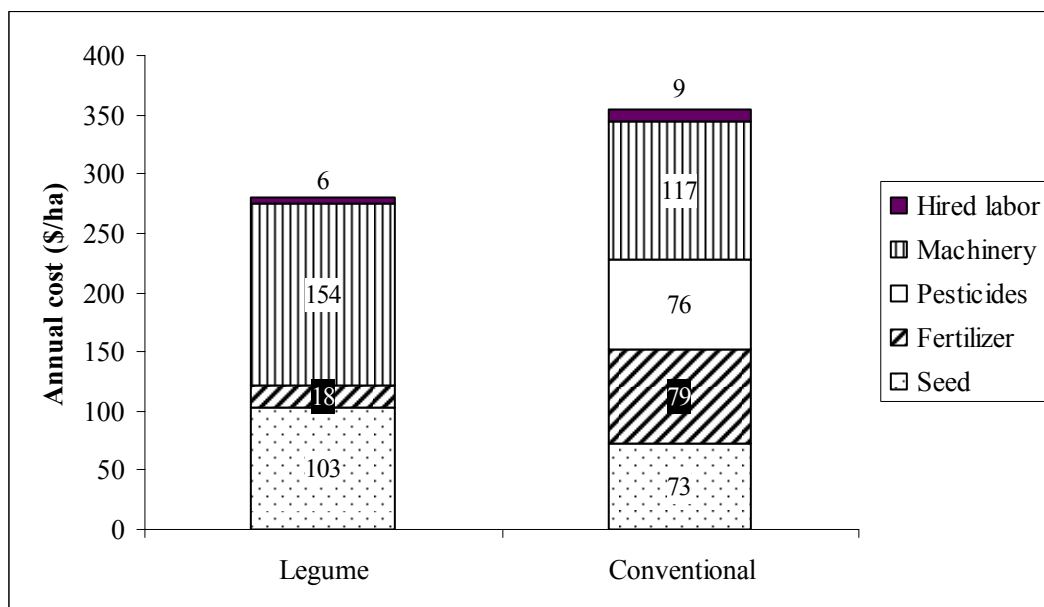


Figure 12b: Annual input costs (dollar per hectare) for the organic-legume (Legume) and conventional grain rotations, The Rodale Institute Farming Systems Trial from 1991 to 2001, (Source: Hanson and Musser 2003).

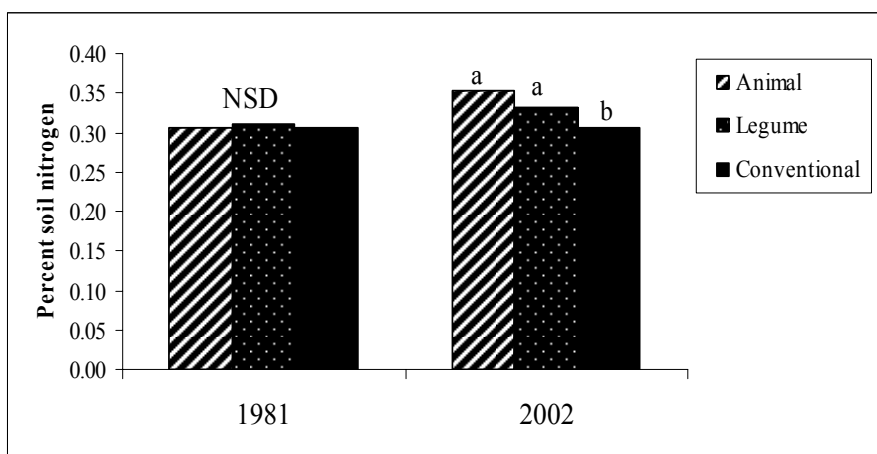
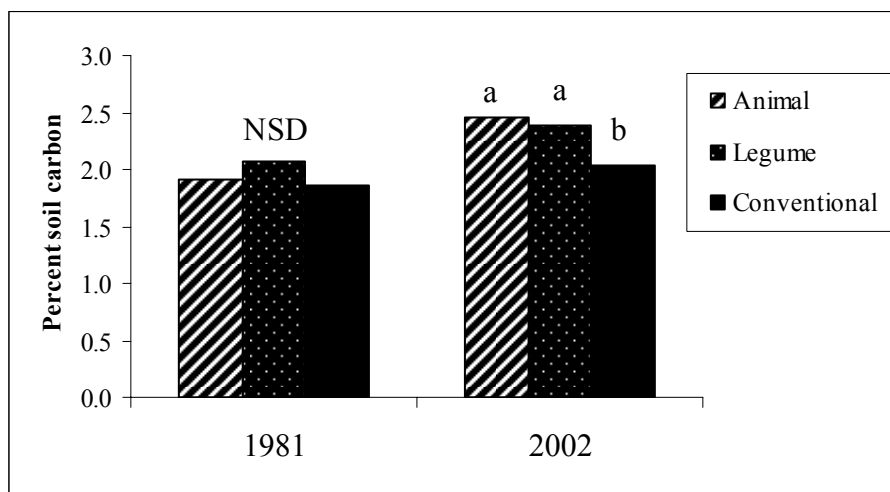


Figure 13: Percent soil carbon and soil nitrogen for the three systems in 1981 and 2002, The Rodale Institute Farming Systems Trial, (Animal = organic animal; Legume = organic legume). Different letters indicate statistically significant differences, NSD= not significantly different.

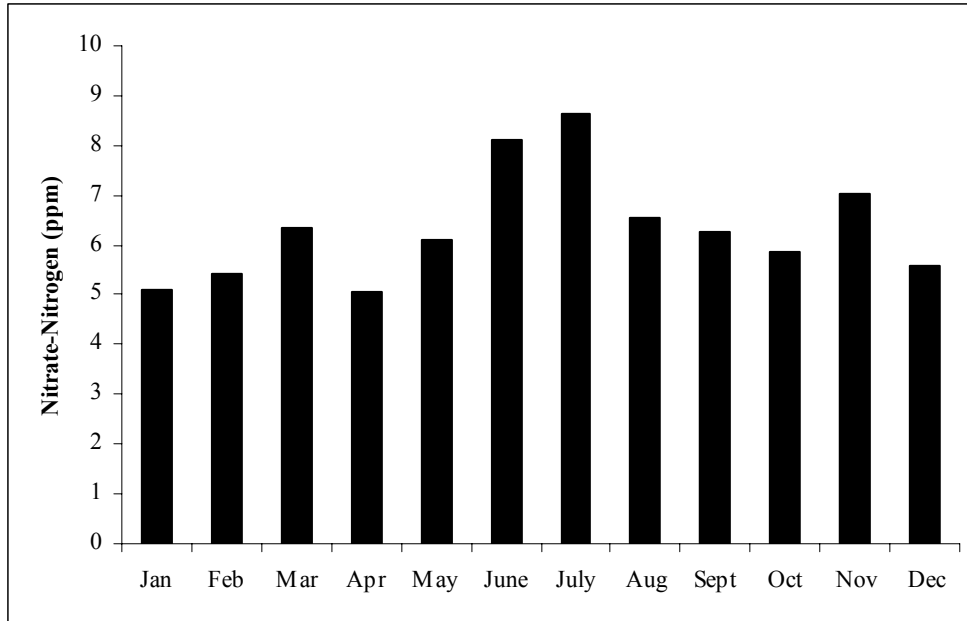


Figure 14: Average monthly nitrate-nitrogen concentration in leachate across all systems, The Rodale Institute Farming Systems Trial, 1991-2001.

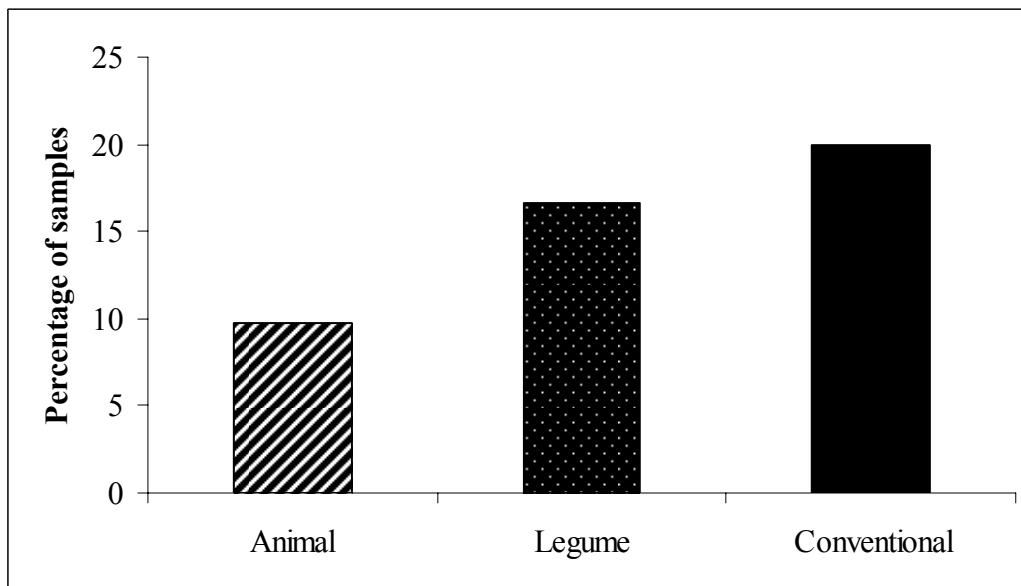


Figure 15: Percentage of samples exceeding the concentration limit of 10 ppm for nitrate-nitrogen in leachate, The Rodale Institute Farming Systems Trial 1991-2002 (Animal = organic animal; Legume = organic legume).

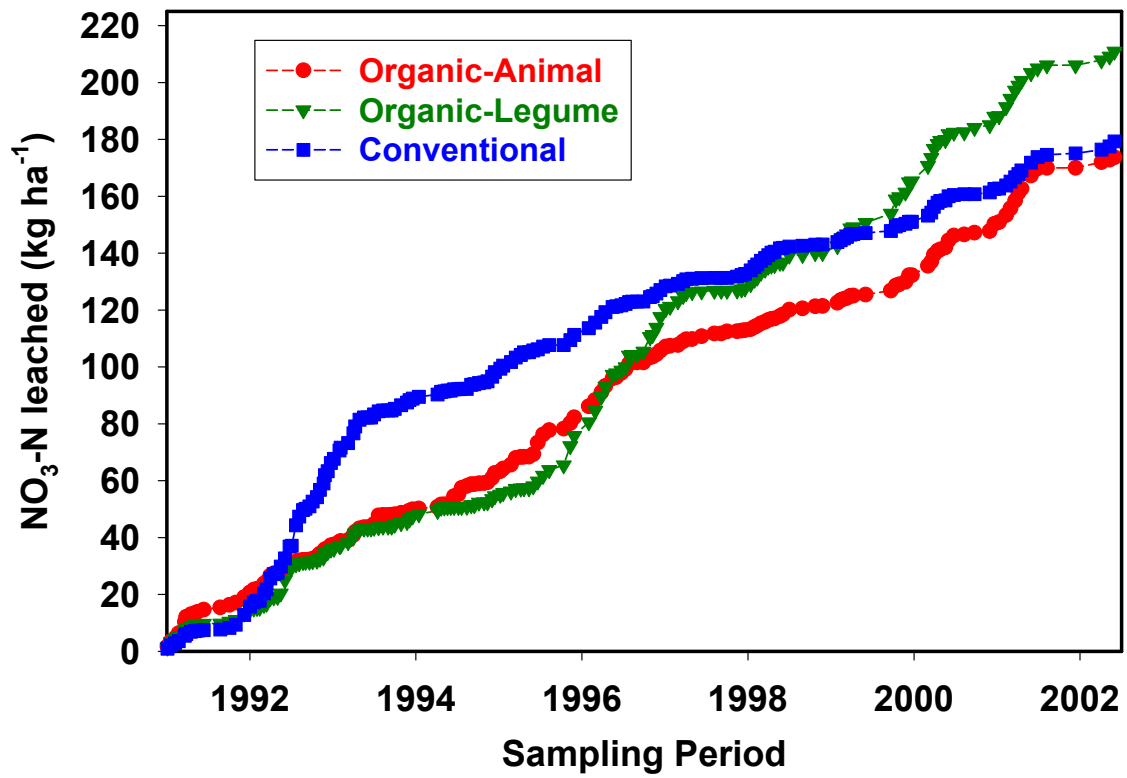


Figure 16: Cumulative nitrate-nitrogen leached, The Rodale Institute Farming Systems Trial 1991-2002.

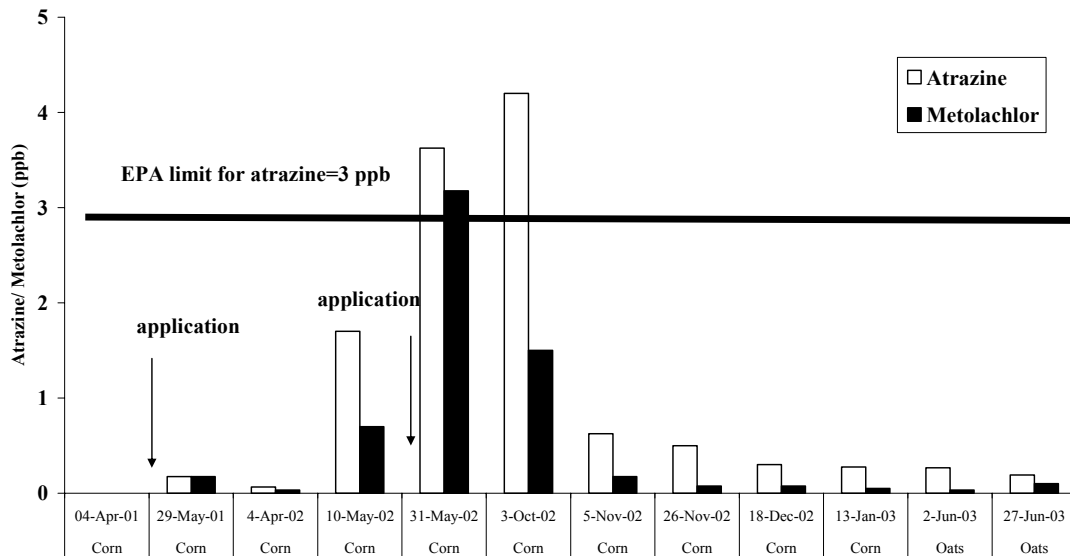


Figure 17: Trends of atrazine and metolachlor concentrations in leachate found in corn after corn plots of the conventional system, The Rodale Institute Farming Systems Trial, 2001-2003.

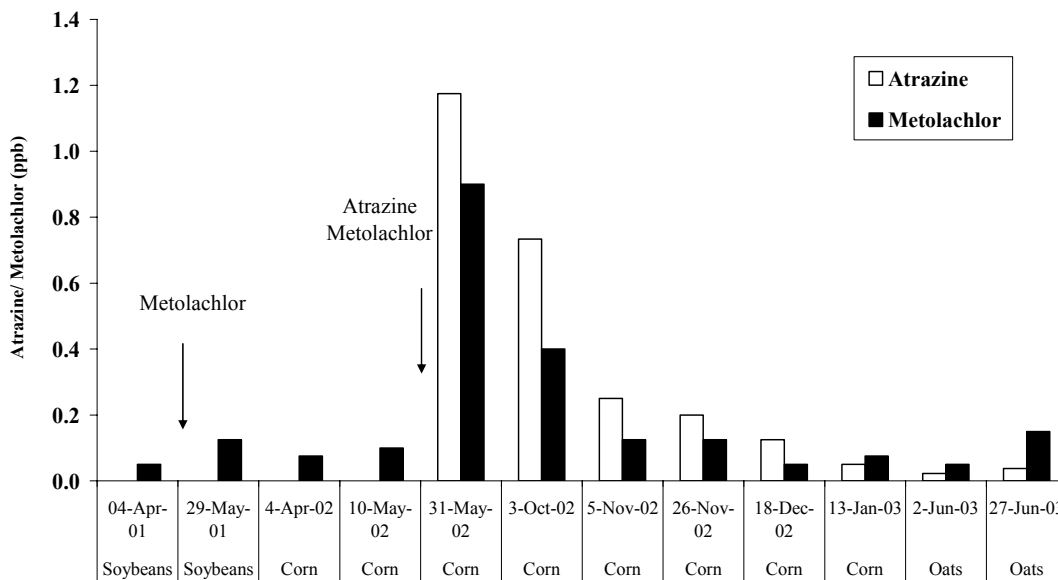


Figure 18: Trends of atrazine and metolachlor concentrations in leachate found in corn after soybean plots of the conventional system, The Rodale Institute Farming Systems Trial, 2001-2003

	Yield potential (kg/ha)	Yield loss per unit of weeds	R ²
Corn			
Organic-animal	7753	0.59	0.35
Organic-legume	7619	0.62	0.33
Conventional	7384	2.92	0.17
Soybeans			
Organic-animal	3058	0.36	0.90
Organic-legume	2985	0.36	0.82
Conventional	2901	0.75	0.11

Table 1: Yield potential, yield loss per unit of weeds and correlation between weed biomass and yield potential in corn and soybeans, The Rodale Institute Farming Systems Trial, 1981-2001 (years with outliers for yields – transition years and crop failures – were not part of the analysis).

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