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The Long-Term Agroecological Research (LTAR) Experiment Supports Organic Yields, Soil Quality, and Economic Performance in Iowa

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Abstract

The Long-Term Agroecological Research (LTAR) experiment, at the Iowa State University (ISU) Neely-Kinyon Farm in Greenfield, IA, was established in 1998 to compare the agronomic, ecological, and economic performance of certified organic cropping systems to conventional counterparts. Cropping systems were designed based on local farmer input and practices. In the second LTAR phase (2002 to 2010), equivalent organic and conventional corn (*Zea mays*) and soybean (*Glycine max*) yields were achieved in the organic corn-soybean-oat (*Avena sativa*)/alfalfa (*Medicago sativa*) (C–S–O/A) and corn-soybean-oat/alfalfa-alfalfa (C–S–O/A–A) rotations compared to the conventional corn-soybean rotation (C–S). Organic oat and alfalfa yields, at 103 bu/acre and 4.4 tons/acre, respectively, exceeded county averages of 73 bu/acre and 3.3. tons/acre, for the same period. Similar plant protection occurred in organic crops, without the use of petrochemicals, compared to conventional crops maintained with synthetic pesticides. In Fall 2009, soil organic carbon, total nitrogen, and extractable K and Ca were 5.7%, 9.5%, 14.2%, and 10.8% higher in organic soils, respectively. Soil properties related to biologically active organic matter were up to 40% higher in organic soils. Economic returns to land and management in 2010 were $510/acre in the organic C-S-O/A-A rotation compared to $351/acre in the C-S rotation. The LTAR experiment will be continued as a valuable demonstration of the potential for organic crops to achieve comparable yields while increasing carbon sequestration and economic returns compared to conventional corn and soybean rotations.

Introduction

Driven by consumer demand, organic product sales increased from $3.6 billion in 1997 to $26.6 billion in 2009 (31). In the most recent USDA-ERS survey in 2008, there were 907,916 acres of organic grain crops among the 4.8 million organic acres in the US (45). Several factors propelled the increased consumption of organic foods in the US, including consumer preference for lower pesticide residues in food (2), nutrition and health concerns (43), negative environmental impacts associated with conventional production (48), and consistent federal organic standards (44). Farmers also are interested in producing organic crops that meet the "triple bottom line" of environmental sustainability, economic viability, and social equity. However, organic product supply has lagged market demand owing to the perceived obstacles to successful transition to organic production (15,20).

Adoption of land management strategies fostering soil carbon (C) sequestration will be important in developing new mitigation strategies and technologies reducing C emissions (39). Recommendations fostering C sequestration include reducing tillage intensity and integrating multifunctional cropping rotations including forage legumes, small grains, and animal manure/compost soil amendments. Organic agriculture promotes such practices, as certified organic farming requires "soil-building crop rotations" and soil amendments to optimize production (44). Each of these practices affects soil and water quality, C sequestration, nitrogen (N) cycling, and other functions. Non-point-source contamination is a major water quality concern in the upper Midwest (22) where nutrients, especially nitrate-nitrogen (NO_3-N), are susceptible to leaching (16) due to subsurface draining of highly productive but poorly drained soils (29). A potential strategy for improving water quality by reducing NO_3-N loss is the adoption of practices such as organically managed cropping systems of extended rotations that include small grains and forage legumes that increase soil organic matter content and may improve water and soil nutrient retention (26). When the 2002 and 2007 US Farm Bills offered incentives supporting transition to certified organic production, research-based recommendations were needed to identify suitable crop rotations providing high yields, marketable grain quality, and adequate soil fertility during and beyond transition. The Long-Term Agroecological Research (LTAR) experiment was established to address these issues.

Site Description and Data Collection

Supported by the Leopold Center for Sustainable Agriculture at Iowa State University (ISU), the 17-acre LTAR experiment was established in 1998 at the ISU Neely-Kinyon Farm in Greenfield, IA, as a long-term cropping systems experiment examining the agronomic, soil quality, and economic outcomes from conventional and organic cropping systems typical of the Midwest (10). The LTAR is a systems experiment where treatments consisting of farmer-developed practices (e.g., soil amendments, tillage, crop selection/rotation) form the management strategy (11). The predominant soil at the LTAR site is a moderately well-drained Macksburg silty clay loam (fine, smectitic, mesic Aquic Argiudoll). The experimental site is located on a ridge top with a uniform slope of 0 to 2%. Research plots are 140 × 70 ft. A 2-year conventional corn-soybean (C–S) system is compared to 3-year and 4-year organic systems of corn-soybean-oats/alfalfa (C–S–O/A) and corn-soybean-oats/alfalfa-alfalfa (C–S–O/A–A), using identical crop varieties in each system. The design is completely randomized, due to uniform soil type and slope, with four replications of each cropping system treatment. All crops in each rotation treatment are planted every year of the experiment. A hay crop [alfalfa, red fescue (*Festuca rubra*) and oats] was planted in 30-ft strips around each plot to maintain the required buffer between conventional and organic plots (44).

During the first LTAR phase (1998-2001), organic corn and soybean yields were equivalent to conventional yields (11). In the fourth year, organic corn yield in the 4-year rotation was 131 bu/acre, compared to the 112-bu/acre conventional yield, and organic soybean yields (45 bu/acre) exceeded conventional yields of 40 bu/acre. Few soil differences were observed between systems, with soil fertility in organic plots sufficient to support high yields, due to manure applications and crop rotations. Grass and broadleaf weed populations varied between the organic and conventional systems each year, but the impact on yield was negligible. Corn borer (*Ostrinia nubilalis*) and bean leaf beetle (*Ceratoma trifurcata*) populations were indistinguishable between systems, with no effect on yield. Our objectives in the second phase (2002-2010) of the LTAR experiment were to: (i) compare yields, soil quality, and pests of organic systems relying on locally derived inputs with the conventional C-S system requiring greater levels of external, fossil-fuel based inputs; and (ii) conduct an economic analysis of the C–S–O/A organic system compared with the C–S system.

Field operations from 2002-2010 are outlined in Table 1. Crop varieties were changed annually as improved varieties for yield or pest resistance became available (12). Identical crop varieties and planting dates were used in all treatments each year to minimize initial differences between systems. Grain and forage varieties were sourced as certified organic seed whenever available. Oats and alfalfa (O/A) were drilled together, with the alfalfa in the 3-year-rotation plots remaining uncut to supply N to the succeeding corn crop. Alfalfa plots in the 4-year-rotation plots remained from spring of the establishment year to spring of the third year, before disking prior to corn planting. Conventional corn plots were injected with 28% urea ammonium nitrate (UAN) at a rate providing 140 lb N/acre. Hoop-house swine compost was applied to organic corn and oat plots to provide 140 lb N/acre and 60 lb N/acre, respectively. Average nutrient content of the compost was 0.78, 0.96, and 1.37% N, P, and K, respectively, over the course of the experiment. Conventional pesticide applications were based on ISU recommendations. All organic corn and soybean plots were rotary hoed and row-cultivated an average of three times each per season.

Grain was harvested using a field-scale combine, while alfalfa was mowed and raked to dry to proper storage moisture (less than 20%) when sufficient biomass accumulated. A field-scale baler was used and bales individually weighed. Oat straw was baled when dry (averaging 12% moisture) and removed from the plots each year.

Corn and soybean stands were enumerated annually after initial cultivations in organic plots, approximately 3 weeks after planting, by counting the number of plants per 17.3 ft of row from three random areas in each plot. Weed populations (grasses and broadleaves) were enumerated in corn and soybean plots at this time within square-foot quadrats at three randomly selected areas within plots. Soybean plots were sampled for insects by sweeping plots 20 times with a 15-inch-diameter net, placing contents in a Ziplock bag, and freezing until identification. The whorl of three corn plants per plot was examined each July for corn borer larvae damage. Soil was sampled at 6-inch depth next to 12-inch corn and analyzed for late-spring nitrate content by the ISU Soil and Plant Analysis Laboratory, Ames, IA. Corn stalk nitrate samples were collected 3 weeks before harvest from three randomly selected corn plants per plot, and analyzed at the same lab (3). Soybean cyst nematode (SCN) (*Heterodera glycines*) sampling was completed before harvest each year by removing four 6-inch-deep soil cores per plot and SCN eggs counted at the ISU Plant Disease Clinic (Ames, IA). Three random 8-oz corn and soybean grain samples were collected at harvest from each plot. Compositional analysis was conducted at the ISU Grain Quality Laboratory, Ames, IA, using a Foss Infratec Model 1229 analyzer (Eden Prairie, MN) to determine grain quality.

Table 1. Field operations at the Long-Term Agroecological Research (LTAR) site, Greenfield, IA, 2002–2010.

Operation	**Dates**
Spring seedbed preparation [moldboard plow (initial year plus years following alfalfa); disk and field cultivate (every year all plots)]	5, 16 Apr, 1, 9, 21 May 2002; 31 Mar, 14, 23 Apr, 22, 23 May 2003; 22 Mar, 5, 18 Apr, 6, 10, 16, 24, 25 May 2005; 12, 19 Apr, 8, 15, 22 May 2006; 10, 19, 20, 21 Apr, 15, 19 May 2007; 21, 15 Apr and 20, 11 May 2009; 11, 13, 19 Apr and 24, 25 May 2010
Soil sampling	19 Jun 2002; 19 Jun 2003; 7 Jul 2004; 20 Jun 2005; 7 Jun 2006; 14 Jun, 26 Oct 2007; 18 Jun, 4 Nov 2008; 17 Jul, 4 Nov 2009; 21 May 2010
Oat/alfalfa planting	10 Apr 2002; 1 Apr 2003; 25 Mar 2004; 4, 25 Apr 2005; 13 Apr 2006; 16 Apr 2007; 21 Apr 2008; 16 Apr 2009; 11 Apr 2010
Composted manure applied to organic corn	3 Apr 2002; 2 Apr 2003; 24 Mar 2004; 16 Mar 2005; 6 Apr 2006; 4 Apr 2007; 21 Apr 2008; 20 Apr 2009; 13Apr 2010
Corn planting	14 May 2002; 23 May 2003; 17 May 2004; 16 May 2005; 16 May 2006; 16 May 2007; 20 May 2008; 20 May 2009; 24 May 2010
Herbicides applied to conventional corn and soybean plots	3, 30 May, 12, 26 Jun 2002; 27, 30 May, 27 Jun 2003; 14 Jun 2004; 2 Jun 2005; 26 May, 27 Jun 2006; 21, 25 Jun, 2-10 Aug; 21 May, 23 Jun, 9 Jul 2008; 14, 28 May 2009; 24, 28 May, 24, 30 Jun 2010
Soybean planting	29 May 2002; 28 May 2003; 4 Jun 2004; 25 May 2005; 22 May, 2 Jun 2006; 22 May, 6 Jun 2007; 20 May, 25 Jun 2008; 21 May 2009; 25 May 2010
Organic corn and soybean plots rotary-hoed	20, 28, 31 May, 17 Jun 2002; 30 May, 6, 9, 12 Jun 2003; 16, 28 Jun, 6 Jul 2004; 19, 24 May, 2, 15, 22 Jun 2005; 26 May, 1, 14 Jun 2006; 31 May, 8, 14, 19 Jun 2007; 2 Jun 2008; 24, 29 May, 11 Jun 2009; 28 May, 4, 7 Jun 2010
Synthetic nitrogen applied to corn	3 May 2002; 27 May 2003; 19 May 2004; 20 May 2005; 27 Apr 2006; 17 May 2007; 30 Apr 2008; 21 Apr 2009; 24 May 2010
Weed populations and crop stands determined	19 Jun 2002; 18 Jun 2003; 22 Jun 2004; 27 Jun 2005; 22 Jun 2006; 21 Jun 2007; 13 Jun 2008; 16 Jun 2009; 24 Jun 2010
Organic corn plots row-cultivated	31 May, 14 Jun 2002; 16 Jun, 1 Jul 2003; 8, 17, 28 Jun 2004; 7, 21 Jun 2005; 6, 19 Jun 2006; 5, 21 Jun 2007; 17, 22 Jun, 2 Jul 2008; 17, 23, 26 Jun 2009; 17, 29 Jun 2010
Organic soybean plots row-cultivated	14 Jun, 1, 23 Jul 2002; 20 Jun, 2, 14 Jul 2003; 4, 23 Jun, 12, 20 Jul 2004; 15 Jun, 1 Jul 2005; 12, 27 Jun 2006; 26 Jun, 26 Jul 2007; 22 Jun, 2, 7 Jul 2008; 17, 23, 30 Jun and 13 Jul 2009; 17, 30 Jun, 10 Jul 2010
Organic soybean plots "walked" for weeds	29 Jun, 11 Jul 2005; 29 Jun 2006; 28 Jun, 12 Jul 2007; 1, 14 Aug 2008; 16, 29 Jun 2009; 22 Jul 2010
Corn insect pest sampling	3 Jul 2002; 9 Jul 2003; 6 Jul 2004; 6 Jul 2005; 5 Jul 2006; 5 Jul 2007; 21 Jul 2008; 5 Jul 2009
Bean leaf beetle sampling in soybean	7, 31 Jul, 5 Sep 2002; 7 Aug 2003; 7 Sep 2004; 15 Jun, 13 Jul, 30 Aug 2005; 20 Jul, 3 Aug, 7 Sep 2006; 11 Jun, 13 Jul, 6 Aug 2007; 28 Jul, 4 Sep 2008; 12 Aug 2009; 21 Jul 2010
Soybean cyst nematode sampling	17 Sep 2002; 24 Sep 2003; 11 Oct 2004; 27 Sep 2005; 27 Sep 2006; 26 Sep 2007; 14 Oct 2008; 19 Oct 2009; 27 Sep 2010
Stalk nitrate sampling in corn	4 Oct 2004; 29 Sep 2005; 26 Sep 2006; 21 Sep 2007; 14 Oct 2008; 6 Oct 2009; 27 Sep 2010
Oat harvest	16 Jul 2002; 25 Jul 2003; 27 Jul 2004; 25 Jul 2005; 18 Jul 2006; 17 Jul 2007; 30 Jul 2008; 24 Jul 2009; 26 Jul 2010
Corn harvest	18 Oct 2002; 10 Oct 2003; 9 Nov 2004; 17 Oct 2005; 1 Nov 2006; 29 Oct 2007; 5 Nov 2008; 5 Nov 2009; 16 Oct 2010
Soybean harvest	16 Oct 2002; 9 Oct 2003; 11 Oct 2004; 10 Oct 2005; 24 Oct 2006; 26 Oct 2007; 21 Oct 2008; 28 Oct 2009; 6 Oct 2010
Alfalfa Harvest	31 May, 30 Jun, 30 Jul 2002; 27 May, 7 Jul, 4 Aug 2003; 7 Jun, 12 Jul 2004; 27 Jun, 25 Jul, 2, 19 Sep 2005; 26 May, 1 Jul, 10 Aug, 17 Sep 2006; 6 Jun, 9 Jul, 14 Aug, 17 Sep 2007; 22 Jun, 23 Jul, 4 Aug 2008; 14 Jun, 12 Jul, 11 Aug 2009; 1, 29 Jun, 1 Aug, 30 Sep 2010

Soil analysis. Five 1.5-inch-diameter soil cores (from each plot quadrant and the plot center) were collected at a 6-inch depth from all plots each fall after harvest, prior to any tillage/planting, and mixed together to form one composite soil sample. Samples were stored in Ziplock bags and kept cool during transport to the laboratory. Bulk density was calculated using the volume of soil associated with the 5 core samples, the dry weight of soil, and the water content measurements (1,4). Field-moist samples were pushed through a 0.03-inch-diameter sieve. A sub-sample of the 0.03-inch-sieved soil was air-dried and another sub-sample was pushed through a 0.008-inch-diameter sieve. All air-dried samples were stored at room temperature prior to analysis. Soil water content, inorganic N, and microbial biomass C (MBC) were quantified using field-moist 0.03-inch-sieved soil. Soil water content was determined gravimetrically after oven drying overnight at 105°C. After extraction with 2 M KCl, inorganic N [(NO_3 +NO_2) and NH_4] in the filtrate was determined using flow injection technology (Lachat Instruments, Milwaukee, WI). Microbial biomass C (40) was measured with standard soil fumigation (23) and chemical extraction (41,47). Nitrogen mineralization potential was measured by aerobic incubation using a modification of Keeney and Bremner's (24) method in Drinkwater et al. (17). Total organic C (TOC), soil inorganic C (SIC), soil organic C (SOC), total N, N mineralization potential, and particulate organic matter (POM) C and N were determined for the air-dried 0.008-inch-sieved samples. Soil organic C (SOC) and total N (TN) were measured using dry combustion methods. Particulate organic matter (POM) fractions were isolated using a modification of the method of Cambardella and Elliott (5) and POM fraction C and N quantified using dry combustion. Macroaggregation was assessed for 0.03-inch-sieved, air-dried samples (6), and calculated as percentage of total soil >250 µm in diameter (macroaggregates). Electrical conductivity (EC), pH, Bray P, and extractable K, Ca, and Mg were quantified for air-dried 0.008-inch-sieved samples. Phosphorous soil test levels (Bray-P) (19) were measured colorimetrically using ascorbic acid-ammonium molybdate reagents. Exchangeable K, Ca, and Mg were extracted with 1M ammonium acetate (49) and measured using atomic absorption spectrophotometry. Soil pH (50) and EC (51) were measured using a 1:2 soil-to-water ratio. All results were expressed on a dry weight basis. Data for plant growth, yields, pest populations, grain quality and soil quality were subjected to analysis of variance and mean separation using Fisher's Protected LSD at $P \le 0.05$.

Economic analysis. An enterprise budget, including an estimate of the costs and returns for certified organic crops, was developed for this study, following methods of Chase et al. (9). Enterprise budgets allocate costs for land, labor, and capital to the most appropriate use, as prioritized by the producer. The economic analysis was a two-part analysis, which included fixed and variable costs for inputs (e.g., machinery operations, equipment depreciation, fuel, seeds, crop fertility sources, pesticides), and a second analysis which included all inputs, labor costs, subsequent yields, and selling price of conventional and organic crops (13). Revenue was determined by multiplying conventional and certified organic prices received for the crop as an organic feed crop by the average yield obtained in the study for each system.

Weather Effects

Although high temperatures during some months of the second LTAR phase exceeded 30-year averages, the overall average growing-season temperature was identical to the 30-year average (Table 2). Two flood years, 2008 and 2010, brought June rainfall exceeding 30-year averages by 8 and 7 inches, respectively. Five of the nine years of the study had above-average annual rainfall.

Table 2. Monthly growing season precipitation totals and mean temperature and for Greenfield, IA, 2002–2010.

	Monthly precipitation (inches)										**Avg air temp** (F°)	
Month	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**30-year avg**	**2002-2010**	**30-year avg**
Mar	0.90	1.12	4.40	1.12	3.99	2.68	2.22	4.02	2.04	2.21	40	39
Apr	3.21	5.39	1.42	2.73	4.37	4.57	4.69	4.81	2.91	3.64	53	52
May	3.97	5.63	8.1	4.48	3.26	7.58	5.56	1.68	7.41	4.65	62	62
Jun	1.82	4.43	3.41	3.64	1.26	2.4	12.81	4.77	11.19	4.62	71	71
Jul	3.86	2.54	5.24	4.22	3.70	2.36	6.07	4.62	7.39	4.89	75	75
Aug	3.67	0.74	5.37	2.01	6.80	10.8	0.75	5.69	3.71	3.79	73	74
Sep	1.53	3.59	1.18	1.05	3.85	4.32	4.15	1.70	5.75	3.60	66	66
Oct	3.47	1.03	1.25	0.96	1.69	5.8	4.01	6.38	0.97	2.50	53	54
Total annual precipitation (2002–2010) & seasonal avg air temp	24.1	32.9	36.7	25.6	34.5	45.9	45.1	38.8	46.4	35.5	61.6	61.6

Plant Growth and Yields

From 2002-2010, average corn yields were statistically equivalent in the conventional C-S rotation and in the organic C-S-O/A and C-S-O/A-A rotations (Table 3). There was a trend towards higher corn yields in the 4-year rotation (178 bu/acre), following two years of alfalfa, compared to the 3-year rotation (166 bu/acre). Due to high variability, there were no statistical differences between systems in late-spring soil nitrate and corn stalk nitrate levels at season's end (Table 3). However, the use of slow-release organic amendments in the organic system may have been associated with nutrient cycling differences (21,35) and more variable soil nitrate levels, which averaged 13 ppm, compared to the conventional system at 23 ppm. Despite lower nitrate levels in organic plots in the first and second LTAR phases, organic yellow dent corn yields were equivalent or greater than conventional counterparts during transition (11), and organic corn yields steadily increased from the first-phase average yield of 130 bu/acre to the second-phase average yield of 172 bu/acre across the C-S-O/A and C-S-O/A-A rotations.

Table 3. Grain crop performance at the Long-Term Agroecological Research (LTAR) site, 2002-2010.

	Corn				**Soybean**		**Oat**		**Alfalfa**
Rotation	**Yield** (bu/acre)	**Plant population** (plants/acre)	**LSNT** (ppm NO3-N)	**Stalk nitrate** (ppm NO3-N)	**Yield** (bu/acre)	**Plant population** (plants/acre)	**Yield** (bu/acre)	**Straw yield** (ton/acre)	**Yield** (ton/acre)
Conventional C-S	180	27,439	23.4	1,573	49	116,837	–	–	–
Organic C-S-O/A	167	25,977	14.5	1,788	52	100,871	102	1.24	–
Organic C-S-O/A-A	178	23,289	11.4	893.5	51	102,417	104	1.25	4.37
LSD 0.05	NS[x]	NS	NS	NS	NS	NS	NS	NS	–

C = corn, S = soybean, O = oat, and A = alfalfa. Corn yields at 15.5% moisture; soybean at 13% moisture; LSNT = Late Spring Nitrate Test.

[x] Means (9–year) within a column are not significant (NS) at $P \le 0.05$ (Fisher's protected LSD test).

Corn plant populations were similar between systems, averaging 25,568 plants/acre across all rotations (Table 3). These results mirrored those observed in the fourth year of the LTAR experiment, when rotary hoeing operations were balanced by higher seeding rates, and organic plant populations were equivalent to conventional for the first time in that phase (11). Despite a trend towards lower stands in organic soybean plots, plant populations were statistically equivalent in organic and conventional systems, averaging 106,708 plants/acre.

Second-phase LTAR organic oat yields averaged 103 bu/acre, with no difference between the 3- and 4-year rotations (Table 3), contrasting with the 68-bu/acre average oat yield in the first phase (11). Increased soil fertility from additional years of composted manure and alfalfa may have led to increased yields, along with more favorable weather. Organic alfalfa yields averaged 4.4 tons/acre over 9 years, compared to 2.9 tons/acre in the first four years (11), presumably due to higher rainfall in the second phase. Organic oat and alfalfa yields met or exceeded county averages, with 9-year average yields of 73.4 bu/acre and 3.3 tons/acre, respectively (46).

Table 4. Pest status (weeds and corn borer damage) at the Long-Term Agroecological Research (LTAR) site, 2002-2010.

	Corn			Soybean	
Rotation	**Grass weeds** (plants/ft²)	**Broadleaf weeds** (plants/ft²)	**Corn borer** (% plants damaged)	**Grass weeds** (plants/ft²)	**Broadleaf weeds** (plants/ft²)
Conventional C-S	1.16	4.96	2.84	2.05	5.06
Organic C-S-O/A	5.96	8.11	2.82	3.70	4.03
Organic C-S-O/A-A	6.87	5.33	0.97	3.98	3.36
LSD 0.05	NS[x]	NS	NS	NS	NS

C = corn, S = soybean, O = oat, and A = alfalfa.

[x] Means (9–year) within a column are not significant (NS) at $P \leq 0.05$ (Fisher's protected LSD test).

Weed, Insect, and Nematode Pest Status

From 2002 to 2010, grass and broadleaf weeds most likely to reduce corn and soybean yield potentials following tillage operations did not differ between systems (Table 4). While there was a trend towards lower weed populations in the conventional plots, rotary hoeing and row- cultivation operations in organic corn plots were successful in maintaining corn grass and broadleaf weeds under 5 and 7 plants/ft², respectively. Grass and broadleaf weeds in soybeans were less than 4 and 5 plants/ft², respectively, across all rotations, with no statistical differences between conventional and organic plots. These results contrasted with first-phase weed populations, which were greater overall in organic plots. Improved management and rotational effects may have led to decreased weeds in organic plots.

Corn insect pest populations were similar among the three rotations (Table 4). Damage from corn borers averaged 2%, similar to corn borer damage in the first phase (11), and did not reach the economic threshold level (5% damaged plants) when synthetic or biological insecticides would be required to avoid yield loss. Soybean cyst nematode populations, averaging 31 eggs per 100 cc of soil across all rotations (Table 5), were in the low range reported throughout Iowa, and less than first-phase average population levels of 149 eggs per 100 cc of soil. Bean leaf beetle populations, averaging 16 beetles per 20 sweeps (Table 5), percentage of stained soybeans, total pest insects, and beneficial insect populations were equivalent in conventional and organic rotations over this period, similar to first-phase results (11).

Table 5. Soybean pest status (insects and nematodes) at the Long-Term Agroecological Research (LTAR) site, 2002-2010.

Rotation	**Bean leaf beetle populations** (numbers/ 20 sweeps)	**Stained soybeans** (%)	**Pest insect populations** (numbers/ 20 sweeps)	**Beneficial insect populations** (numbers/ 20 sweeps)	**Soybean cyst nematodes** (eggs/100 cc)
Conventional C-S	8.70	4.90	20.77	3.52	23.6
Organic C-S-O/A	20.18	4.14	33.61	3.70	23.6
Organic C-S-O/A-A	17.97	4.90	27.44	3.32	38.9
LSD 0.05	NS[x]	NS	NS	NS	NS

C = corn, S = soybean, O = oat, and A = alfalfa.

[x] Means (9–year) within a column are not significant (NS) at $P \leq 0.05$ (Fisher's protected LSD test).

Grain Quality

Corn protein content was equivalent between the conventional and organic rotations during the LTAR second phase, averaging 9.8% (Table 6), which contrasted with first-phase results, where conventional corn protein levels exceeded organic in two of the first four years. Corn oil (3.4%) and starch (61%) content were similar among the three rotations over the second phase. Soybean protein, oil, and carbohydrate content also were equivalent across all rotations in the second phase, averaging 36%, 23% and 18%, respectively. In 1 of 4 years of the first phase, soybean protein levels were lower in the C-S rotation compared to the organic rotations, but overall protein differences were indistinguishable, averaging 37% (11). The 1% decrease in protein levels can be explained by the change from food-grade, tofu-type soybeans in the first LTAR phase to feed-grade soybeans in the second phase.

Table 6. Grain quality in the Long-Term Agroecological Research (LTAR) site, 2002-2010.

Rotation	**Corn**			**Soybean**		
	Protein (%)	**Carbohydrates** (%)	**Oil** (%)	**Protein** (%)	**Carbohydrates** (%)	**Oil** (%)
Conventional C-S	9.71	60.7	3.44	36.3	23.0	18.0
Organic C-S-O/A	9.65	61.0	3.42	35.9	23.3	18.1
Organic C-S-O/A-A	10.05	61.0	3.40	36.0	23.3	18.0
LSD 0.05	NS[x]	NS	NS	NS	NS	NS

C = corn, S = soybean, O = oat, and A = alfalfa.

[x] Means (9–year) within a column are not significant (NS) at $P \leq 0.05$ (Fisher's protected LSD test).

Soil Quality Effects

In Fall 2009, at the last soil-sampling period in the second phase, soil quality indicators were consistently higher in the organic rotations relative to the C-S rotation (Table 7). Organic soils had more SOC and total TN, lower soil acidity, and higher extractable P, K, Ca, and Mg concentrations than conventional soils, although the comparison was not statistically significant for Mg. Soil quality parameters related to biologically-active organic matter, including MBC, particulate organic matter POMC, and potentially mineralizable N (PMN), were up to 40% greater in organic than conventional soils. The 3-year organic rotation had more inorganic P and K than the 4-year organic rotation, reflecting the greater manure application intensity in the 3-year rotation. Potentially mineralizable N was significantly greater in the 4-year organic rotation compared to the 3-year rotation, reflecting the greater organic N inputs from the additional year of alfalfa. Soil quality enhancement was particularly evident for biologically-active forms of organic matter, which are critical for maintenance of N fertility in organic systems, and for basic cation concentrations, which control nutrient availability through the relationship with cation exchange capacity (CEC).

Table 7. Soil quality in the Long-Term Agroecological Research (LTAR) experiment–Fall 2009 (0-6-inch depth)

Rotation	SOC	TN	POM-C	POM-N	MBC	PMN	P	K	Mg	Ca	EC	pH	AGG STAB
	(g/kg)				(mg/kg)						(mS/cm)		(%)
Conv C-S	22.9	2.20	2.41	0.17	296	41	13.7	218	312	2797	168	6.4	24.2
Org C-S-O/A	24.4	2.29	3.32	0.22	344	50	40.6	359	348	3104	213	6.8	23.3
Org C-S-O/A-A	24.0	2.32	3.39	0.25	361	60	28.6	338	344	3094	215	6.7	27.8
LSD 0.05	1.3[x]	0.11	0.92	NS	47	10	6.8	102	NS	176	18	0.16	NS

SOC = Soil organic carbon; TN = Total nitrogen; POM-C = Particulate organic matter carbon; POM-N = Particulate organic matter nitrogen; MBC = Microbial biomass carbon; PMN = Potentially mineralizable nitrogen; AGG STAB = Aggregate stability; Conv = Conventional; Org = Organic; C = corn, S = soybean, O = oat, and A = alfalfa.

[x] Means within a column are not significant (NS), or significant (LSD) at *P* ≤ 0.05 (Fisher's protected LSD test).

Economic Comparisons

Since 1998, the LTAR organic crop rotations have displayed greater economic performance than the conventional rotation (13,14). This economic advantage persisted in the second LTAR phase despite large price swings for conventional and organic crops and rising production costs. In 2010, for example, total input production costs, including machinery, seed, pesticides, fertilizer, crop insurance, and interest, for the organic C-S-O/A-A rotation averaged $120/acre less than the conventional C-S rotation, based on 2010 input costs (18) (Table 8). The overall lower costs in the organic rotation were due to the absence of petroleum-based fertilizers and pesticides. Manure, obtainable at no cost other than the cost of application, was applied on organic plots for fertilization.

Table 8. Costs of production ($/acre) between conventional and organic systems at the Long-Term Agroecological Research (LTAR) site, Greenfield, Iowa, 2006–2010.

		2006	2007	2008	2009	2010
Conventional C-S	Corn	257.01	319.44	326.69	370.87	427.70
	Soybeans	99.89	152.46	159.47	158.30	215.75
	Rotational average[x]	178.45	235.95	243.08	264.59	321.73
Organic C-S-O/A-A	Corn	221.64	246.44	249.18	334.41	346.88
	Soybeans	120.17	233.22	146.50	167.99	180.03
	Oats/Alfalfa	134.51	142.88	156.06	156.47	165.18
	Alfalfa	89.66	97.25	80.46	83.65	112.97
	Rotational average	141.50	179.95	158.05	185.63	201.27

Conventional C–S = Conventional corn-soybean system; Organic C–S–O/A–A = organic corn-soybean-oat/alfalfa-alfalfa system.

[x] Production costs include all input production costs (i.e., seed, machinery use, fertilizer, pesticides). Labor is excluded from this analysis.

Additionally, economic returns for LTAR organic crops have been consistently greater than conventional crops (8) despite an average doubling of labor for field operations. In 2010, returns to land and management averaged across all crops in the organic C-S-O/A-A rotation (including all labor charges) were $510/acre, compared to $351/acre for the conventional C-S rotation, based on 2010 prices for all crops (Table 9). The return to land and management is the net income that is available to pay land and management costs after deducting production costs. Land charges would be equivalent to local land rental rates and would be identical across every crop in each system, varying by year only.

Because the LTAR is conducted at an Experiment Station, management charges would be identical across both systems. In the first 4-year analysis of LTAR returns, organic corn increased average revenues by a factor of 3.54 over conventional corn, while organic soybean returns were 4.84 times greater than conventional soybean revenues (14). Even during the first two transition years, returns were greater in the organic system because of lower costs of production (8, 13).

Table 9. Returns to land and management ($/acre) between conventional and organic systems at the Long-Term Agroecological Research (LTAR) site, Greenfield, Iowa, 2006–2010.

		2006	2007	2008	2009	2010
Conventional	Corn	256.72	470.74	493.85	373.08	334.89
	Soybeans	170.65	467.62	322.76	450.05	367.89
	Rotational average^{x}	213.69	469.18	408.31	411.56	351.39
Organic C-S-O/A-A	Corn	589.62	1014.29	1433.61	1092.57	542.05
	Soybeans	382.71	537.46	967.33	1118.14	814.85
	Oats	165.89	228.96	530.13	228.66	185.14
	Alfalfa	158.45	305.51	536.66	424.07	499.59
	Rotational average	324.17	521.55	866.93	715.86	510.41

Conventional C–S = Conventional corn-soybean system; Organic C–S–O/A–A = organic corn-soybean-oat/alfalfa-alfalfa system.

[x] Returns to land and management are based on prices received for conventional and certified organic crops each year, and include all costs of production (listed in Table 8) and labor charges.

Discussion

Over the 13 years of the LTAR experiment, organic corn and soybean yields have been equivalent or greater than conventional counterparts in the initial four years (11) and in the second nine years reported here. Results from the LTAR experiment have been similar to other comparisons of organic and conventional systems across the US, although LTAR organic yields have often exceeded those reported in the literature. During the first LTAR phase, corn yields in the organic system (C-S-O/A and C-S-O/A-A rotations) were 91.8% of conventional corn yields in the C-S rotation, while organic soybean yields were 99.6% of conventional soybean yield (11). In the second phase, the advantage of the longer organic rotation was demonstrated by the numerically higher corn yields in the C-S-O/A-A rotation, which averaged 99% of the average conventional corn yield, compared to 92% in the C-S-O/A rotation. Organic soybean yields over the 9-year period were 5% and 4% greater in the C-S-O/A and the C-S-O/A-A rotation, respectively, than conventional soybean yields. These results compare to those obtained by Posner et al. (34), who found, over a combined 13- and 8-year trial at two sites in Wisconsin, organic corn, soybean, and winter wheat yields were 90% of conventional counterparts, and organic forage crop yields and quality were equivalent or greater than conventional counterparts. For 34% of site-years, organic yields were lower, due to inadequate weed management. Similar results were obtained in Minnesota when weeds affected organic yields and organic soybean yields were 16 to 19% lower than conventional yields (33). Organic corn yields, however, were only 7 to 9% lower than the conventional system.

Soil quality, as evidenced by higher soil microbial diversity, has been shown to be greater in organic relative to conventional systems (27). In Maryland, despite the use of tillage in organic systems, soil combustible C and N were higher after 9 years in an organic system that included cover crops compared with three conventional no-till systems, two of which included cover crops, suggesting that organic practices can potentially provide greater long-term soil benefits than conventional no-till (42). In a 4-year Montana study, PMN was 23% higher in the organic system, with equal or greater winter wheat yields and superior grain quality than the conventional no-till system (30). Increases in soil organic matter pools also were reported in a transitional organic system in Michigan, as measured by increases in total and labile C and N (37). With the development of carbon markets and payments for carbon sequestration, additional revenue could accrue to organic producers who increase their soil quality (38). Research has shown significantly lower environmental costs, lower energy requirements, and higher carbon sequestration rates in organic systems relative to conventional counterparts in other long-term comparisons (25,28,32,36).

While conventional corn and soybean prices and revenues have been historically high since 2008, fertilizer, pesticide, seed, and fuel costs also have increased dramatically, reducing net economic returns to conventional production. Organic production is portrayed as a classic risk/reward situation in which producers assume crop production and marketing risk to receive higher average returns. An economic comparison of conventional and organic crops in a long-term trial in Maryland showed that production costs were greatest in conventional tilled systems, while the organic systems' costs were similar to the conventional no-till system (7). Returns from the organic systems were greater than conventional systems, similar to LTAR results, and the lowest variability of returns occurred in the longer, more diverse organic rotation. Producers using organic practices that lead to higher rates of soil carbon sequestration and greenhouse gas (GHG) emission reduction will be better positioned for carbon-offset markets and potentially derive more profit by selling their emission credits. Thus, economic and environmental benefits from GHG reduction and enhanced soil quality could incentivize increased conversion from conventional to organic production. In the next LTAR phase, we will examine more closely the combined ecological and economic benefits of organic systems based on crop productivity, carbon sequestration, nutrient balance, reduction of nitrate leaching, and GHG mitigation.

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