Published September, 2004

ORGANIC PRODUCTION

Agroecosystem Performance during Transition to Certified Organic Grain Production

Kathleen Delate* and Cynthia A. Cambardella

ABSTRACT

The 2002 U.S. Farm Bill offers incentives to support the transition from conventional to certified organic production. Research-based recommendations must be developed for suitable crop rotations that provide high yields, grain quality, and adequate soil fertility during the transition. We compared replicated conventional and organic systems, using identical crop varieties, during the 3-yr transition period and the fourth year following a full rotation of organic corn (*Zea mays* L.)–soybean [*Glycine max* (L.) Merr.]–oat (*Avena sativa* L.)–alfalfa (*Medicago sativa* L.) to determine which rotation was associated with the lowest risk during transition. Organic feed corn yields at the Neely–Kinyon long-term agroecological research (LTAR) site in Greenfield, IA, were equivalent to conventional yields in the transition years, and in the fourth year, the organic corn yield of 8.1 Mg ha^{-1} in the longest rotation was greater than the conventional corn yield of 7.1 Mg ha^{-1} in the conventional corn–soybean rotation. Organic and conventional soybean yields were similar in the 3 yr of transition. Organic soybean yield of 3.0 Mg ha^{-1} exceeded the conventional yield of 2.7 Mg ha^{-1} in the fourth year of organic production. Pre- and postharvest soil fertility values were responsive to manure application, but few differences between systems were observed. Grass and broadleaf weed populations varied between the organic and conventional systems each year, but the impact on yield was considered negligible. Corn borer (*Ostrinia nubilalis*) and bean leaf beetle (*Ceratoma trifurcata*) populations were similar between systems, with no effect on yield. We conclude that organic grain crops can be successfully produced in the 3 yr of transition to organic, and additional economic benefits can be derived from expanded crop rotations.

Since 1985, there has been significant growth in the organic food industry, particularly in western countries (Lampkin and Padel, 1994). Sales of organic products reached $8 billion in the USA in 2001, continuing a 20% annual growth rate (Dimitri and Greene, 2002). The USDA-ERS (2003) estimated there were 281 566 ha in organic production in the Midwestern USA in 2001. Averaging across the 12 states in the region, organic grains constituted 37% of organic croplands, or 104 179 ha. In Iowa alone, reported production for all organic crops increased from 5263 ha in 1995 to 40 486 in 2000 (IDALS, 2000a). In various studies of organic grain production across the Midwest, economic premiums for certified organic grains have been driving many transition decisions (Dobbs and Smolik, 1996; Welsh, 1999). New incentives to transition land into certified organic production, including cost sharing and direct payments for conservation practices, such as longer crop rotations, are included in the 2002 Farm Bill.

Organic farming has been described as a complex system (Brumfield et al., 2000) where productivity improves with increasing years under organic management (Lockeretz et al., 1981). Several experimental transition studies have reported initially lower yields, followed by yields similar to conventional production (Liebhardt et al., 1989; MacRae et al., 1990). Developing strategies for lowering the risk of yield loss during the required 3-yr transition period from conventional to a certified organic designation (USDA-AMS, 2003) is the subject of a number of organic research programs in the USA.

Competitive organic yields have been obtained in systems where enhancement of soil organic matter and soil biotic diversity (Drinkwater et al., 1998; Reganold et al., 2001), along with timely weed management (Temple et al., 1994), has occurred. Short- and long-term benefits have been ascribed to longer crop rotations in organic systems (Cavigelli et al., 2000; Drinkwater et al., 1995, 1998; Liebhardt et al., 1989; Mäder et al., 2000; Robertson et al., 2000; Temple et al., 1994; Tilman, 1998) as well as conventional systems (Heichel, 1978; Karlen et al., 1994). In a systems experiment, treatments consist of a suite of practices (soil amendments, tillage, crop selection/rotation) established as a complete management strategy (Drinkwater, 2002). Because short-term changes in nutrient availability and subsequent plant growth have been reported to affect long-term soil quality and system productivity (Sainju et al., 2002), one full crop rotation cycle, in addition to the transition period of 3 yr, is the recommended minimal period for transition experiments (Stanhill, 1990). An examination of the entire agroecosystem is critical in the development of successful organic farming systems (Mäder et al., 2002). Long-term agroecological research sites were established in 1998 in Iowa to examine the short- and long-term physical, biological, and economic outcomes of certified organic and conventional grain-based cropping systems (Delate, 2002). In the LTAR experiments, we are testing the hypothesis that organic systems relying on locally derived inputs are capable of providing stable yields, while maintaining soil quality and plant protection, compared with conventional systems with less diverse crop rotations and greater levels of external, fossil-fuel–based inputs.

K. Delate, Dep. of Hortic. and Dep. of Agron., Iowa State Univ., Ames, IA 50011; and C. Cambardella, USDA-ARS Natl. Soil Tilth Lab., 2150 Pammel Drive, Ames, IA 50011-4420. Joint contribution of the USDA-ARS and the Iowa Agriculture and Home Economics Experiment Station, Ames, IA; Project no. 3801. Received 1 May 2003. *Corresponding author (kdelate@iastate.edu).

Published in Agron. J. 96:1288–1298 (2004).

677 S. Segoe Rd., Madison, WI 53711 USA

Abbreviations: C-S, conventional corn–soybean (rotation); C-S-O/A, organic corn–soybean–oat/alfalfa (rotation); C-S-O/A-A, organic corn–soybean–oat/alfalfa–alfalfa (rotation); SCN, soybean cyst nematode; S-R, soybean–rye (rotation); S-W/CC, soybean–wheat/crimson clover (rotation); TOC, total organic carbon; TN, total nitrogen.

Our objectives in the first segment of the experiment (3-yr transition to organic and 1 yr past certification) were to (i) examine the effects of required organic farming practices, including crop rotation, cover cropping, compost application, and nonchemical weed control, on soil fertility, crop yield, and grain quality compared with a conventional system; (ii) observe relationships within the various crop rotations, including pest status (insects, weeds, and nematodes) and plant response; and (iii) determine which certified organic crop rotations lowered risk, in terms of yields, soil properties, and economic returns, during the transition years.

MATERIALS AND METHODS

Site History

In February 1998, we surveyed producers and agricultural professionals to determine an appropriate design that represented current practices in southwest Iowa for the organic transition experiment (Delate and DeWitt, 1999). Information gained from the survey was used to define the cropping systems that were established at the Iowa State University Neely–Kinyon LTAR site in Greenfield, IA, in 1998. The predominant soil at the LTAR site is a moderately well-drained Macksburg silty clay loam (fine, smectitic, mesic Aquic Argiudolls). The experimental site is located on a 7-ha ridgetop with a uniform slope of 0 to 2%. Research plots are 42 by 21 m in size. The experimental design is completely randomized with four replications of four different cropping system treatments, and all crops in all rotations are planted each year of the experiment. Cropping system treatments consisted of the following crop rotations: conventional corn–soybean (C-S), organic corn–soybean–oat/alfalfa (C-S-O/A), organic corn–soybean–oat/alfalfa–alfalfa (C-S-O/A-A), and organic soybean–rye (*Secale cereale* L.) or wheat (*Triticum aestivum* L.). Following harvest in all organic corn plots from 1998 to 2001, winter rye was planted as a winter cover crop and weed management strategy, per local practices on organic farms. From 1998 to 2000, winter rye followed soybean harvest in the fourth cropping system treatment (S-R), but the rye was destroyed the following spring and soybean planted again. In 2001, the rye component was replaced with winter wheat and a frost seeding of crimson clover (*Trifolium incarnatum* L.) (S-W/CC), and the wheat was taken to harvest the following growing season. This change in crop rotations was initiated to gain organic certification in 2000. When the experiment was established in 1998, the S-R system was permitted on organic farms, but new organic certification rules in 2000 required that a second crop in the rotation be grown an entire season, thus disqualifying the winter rye component as a complete crop year (IDALS, 2000b). Identical crop varieties were planted in organic and conventional systems each year, including food-grade soybean to provide the most economical returns (Delate et al., 2003). A hay crop [alfalfa, red fescue (*Festuca rubra* L.), and oat] was seeded in 1998 in the 9.1-m-strips around each plot and around the perimeter of the experiment to maintain the required buffer (9.1 m) between the certified organic and conventional plots.

Planting Operations

Field operations from 1998–2001 are outlined in Table 1. The entire experimental area was moldboard-plowed, disked, and field-cultivated to prepare a seedbed at the initiation of the experiment in May 1998. Crop varieties were determined on an annual basis, based on the Neely–Kinyon Farm Association's recommendations for varieties with desired market traits. Varieties were changed annually as improved varieties for yield or pest resistance became available. Identical crop varieties and planting dates were used in all treatments each year to minimize initial differences between systems. Corn va-

Table 1. Normal field operations at the Neely–Kinyon Long-Term Agroecological Research (LTAR) site, 1998 to 2001.

Operation	Dates
Spring seedbed preparation [moldboard plow (initial year plus years following alfalfa); disk and field cultivate (every year all plots)]	4, 11, 13 May 1998; 31 Mar. 1999; 3, 26 May 1999; 29 Mar. 2000; 5, 14, 18, 28 Apr. 2000; 2 May 2000; 16, 19 Apr. 2001; 10, 16, 17, 21 May 2001
Soil sampling	17 Apr., 2 June, 5 Nov. 1998; 28 May, 12 Nov. 1999; 12 Nov. 2000; 29 Oct. 2001
Oat/alfalfa planting	14 May 1998; 31 Mar. 1999; 29 Mar. 2000; 18 Apr. 2001
Composted manure applied to organic corn	14 May 1998; 21 Apr. 1999; 4 Apr. 2000; 16 Apr. 2001
Corn planting	18 May 1998; 27 May 1999; 4 May 2000; 17 May 2001
Wheat planting	24 Oct. 2000
Herbicides applied to conventional corn and soybean plots	19 May 1998; 26 May 1999; 15, 21 June 1999; 24 Apr. 2000; 16, 25 May 2000; 4 June 2000; 16 May 2001; 6, 20 June 2001; 10 July 2001
Soybean planting	21 May 1998; 28 May 1999; 15 May 2000; 28 May 2001
Organic corn and soybean plots rotary-hoed/harrowed	21, 27 May 1998; 3, 9, 25 June 1999; 10, 22, 30 May 2000; 8, 25 June 2001
Synthetic N applied to corn	5 June 1998; 26 May 1999; 24 Apr. 2000; 16 May 2001
Crop stand counts	9, 29 June 1998; 17 June 1999; 2 June 2000; 8 June, 5 July 2001
Weed populations determined	9 June 1998; 17 June 1999; 7 July 1999; 2, 30 June 2000; 8, 29 June 2001; 5, 31 July 2001
Leafhopper sampling in alfalfa	29 June 1998
Organic corn plots row-cultivated	19, 24 July 1998; 7, 18 June 1999; 6 July 1999; 23 May 2000; 1, 23 June 2000; 8, 11, 13, 26 June 2001
Organic corn plots flame-burned between rows	9 July 1999
Organic soybean plots row-cultivated	17 July 1998; 7, 18 June 1999; 6 July 1999; 7, 19, 30 June 2000; 6, 13, 30 July 2001
Organic soybean plots "walked" for weeds	20 July 1998; 27 Aug. 1998; 8 July 1999; 3 August 1999
Corn insect pest sampling	6 July 1998; 10 July 2000; 12 July 2001
Bean leaf beetle sampling in soybean	28 July 1998; 19, 26 July 2001; 10 Aug. 2001; 13 Sept 2001
Soybean cyst nematode sampling	25 Sept. 1998; 21 Sept. 1999; 30 Aug. 2000; 19 Sept. 2001
Stalk nitrate sampling in corn	25 Sept. 1998; 15 Oct. 1999; 8 Oct. 2000; 4 Oct. 2001
Oat harvest	3 Aug. 1998; 19 July 1999; 14 July 2000; 25 July 2001
Wheat harvest	25 July 2001
Corn harvest	9 Oct. 1998; 15 Oct. 1999; 9 Oct. 2000; 27 Oct. 2001
Soybean harvest	9 Oct. 1998; 15 Oct. 1999; 9 Oct. 2000; 27 Oct. 2001
Alfalfa harvest	3 June, 11 July, 17 Aug. 1999; 22 May, 30 June, 31 July, 25 Aug. 2000; 7 June, 5 July, 8 Aug. 2001

rieties included Pioneer '3489' in 1998, Wilson '1790W' in 1999, and Pioneer '34W67' in 2000 and 2001. In 3 out of 4 yr, a yellow, feed corn variety was grown, but in 1999, a white, food-grade, milling corn was planted, based on local interest in an alternative crop. Corn was planted at a 4.5-cm depth at a rate of 68 000 to 80 000 kernels ha^{-1} over the course of the experiment. Rye ('Rhymin') was no-till drilled at a rate of 63 kg ha^{-1} as a winter cover crop and weed management strategy in all organic corn plots in the C-S-O/A and C-S-O/A-A crop rotations each year. Soybean varieties were 'IA 3006' in 1998, 'IA 2034' in 1999, Pioneer '9305' in 2000, and Northrup-King '2412' in 2001. Soybean seeds were planted at a 5-cm depth in organic and conventional plots at a rate of 400 000 to 500 000 seeds ha^{-1} over the course of the experiment. Due to excessive rains and resulting poor stand in 1998 and 2001, soybean plots were replanted on 2 June 1998 and 16 June 2001.

The O/A component of the organic rotations was planted to oat at 72 kg seed ha^{-1} and underseeded with alfalfa at a rate of 17 kg seed ha^{-1}. Alfalfa in the O/A component of the C-S-O/A rotation remained as a cover throughout the winter of its seedling year and was disked under the following spring, before corn planting. Alfalfa in the A component of the C-S-O/A-A rotation was established in the same manner as the O/A component, but alfalfa remained from spring of the first year of establishment to spring of the third year—a total of two growing seasons—before disking under and corn planting in the third year. Alfalfa and oat seeds were planted with a grain drill set at a 1.3-cm depth. Oat varieties included 'Jerry' and 'Don' from 1998 to 2000 and 'Blaze' in 2001. Alfalfa varieties included 'Nitro', Pioneer '53H81', and Pioneer '54H69', the latter varieties selected for tolerance to potato leafhopper (*Empoasca fabae* Harris). Alfalfa plots that would remain as alfalfa the following year (in the C-S-O/A-A rotation) were overseeded with alfalfa at a rate of 17 kg ha^{-1} on 4 Sept. 1998 to ensure a satisfactory overwintering alfalfa stand in the first year of the experiment. In the following years, fall overseeding was not required in the alfalfa plots because of adequate stands. Alfalfa was harvested each year from all A plots when sufficient alfalfa biomass accumulated while the underseeded alfalfa in the O/A component was left unmowed to supply maximal N to the succeeding corn crop. Alfalfa yields are reported as total amount of hay cut from each plot per year.

Rye (Rhymin) was no-till drilled at a rate of 63 kg seed ha^{-1} in the S-R cropping system treatment following soybean harvest in 1998 and 1999. Winter wheat ('Arapahoe') was then planted in soybean plots on 24 Oct. 2000 to establish the new S-W/CC rotation for 2001. Winter wheat was planted at 100 kg seed ha^{-1}, and crimson clover was frost-seeded on 27 Mar. 2001 into wheat plots at a rate of 11 kg seed ha^{-1}.

Fertilization Regime

Organic corn plots were amended in early spring (1 mo before corn planting) with composted swine manure. The compost was made from a mixture of manure and corn stover that was removed from deep-bedded swine "hoop-house" structures located at the Iowa State University Armstrong Research and Demonstration Farm in Lewis, IA (Richard and Tiquia, 1999). The manure mixture was composted for a 1-yr period before application in the organic system. Average nutrient content of the compost was 7.8, 9.6, and 13.7 g kg^{-1} N, P, and K, respectively, over the course of the experiment. The compost was applied to organic corn plots at rates intended to apply 180 kg N ha^{-1} in 1998 and 134 kg N ha^{-1} in 1999–2001. Organic oat plots received compost at a rate to apply 78 kg N ha^{-1} in 1999–2001. Compost was applied with a manure spreader (New Holland Type 856, New Holland, PA). Conventionally managed corn was fertilized at or immediately before planting with anhydrous ammonia at a rate of 202 N kg ha^{-1} in 1998 and with 28% urea ammonium nitrate at a rate of 134 kg N ha^{-1} in 1999–2001.

Pest Management and Plant Sampling

The following pest management applications were made based on sampling results and Iowa State University recommendations. In the C-S rotation, tefluthrin {*rel*-(2,3,5,6-tetrafluoro-4-methylphenyl)methyl (1*R*,3*R*)-3-[(1*Z*)-2-chloro-3,3,3-trifluoro-1-propenyl]-2,2-dimethylcyclopropanecarboxylate} was applied for control of extended-diapause western corn rootworm (*Diabrotica virgifera* Le Conte) at a rate of 0.05 kg ha^{-1} at planting in 1998 and 1999 only. Herbicides applied in the conventional corn plots included acetochlor [2-chloro-*N*-(ethoxymethyl)-*N*-(2-ethyl-6-methylphenyl)acetamide] at a rate of 2.0 kg ha^{-1} in 1998–2001, atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] at 1.12 kg ha^{-1} in 1999 and 2000 and 0.57 kg ha^{-1} in 2001, and nicosulfuron {2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-*N*,N-dimethyl-3-pyridinecarboxamide} at 0.004 kg ha^{-1} and broxynil (3,5-dibromo-4-hydroxybenzonitrile) at 0.28 kg ha^{-1} in 1999–2001. Sticker spreaders included ammonium sulfate at 1.4 kg ha^{-1} in 2000 and 2001 and a nonionic surfactant at 0.47 L ha^{-1} in 2001. In the conventional soybean plots, trifluralin was applied at a rate of 1.7 kg ha^{-1} in 1998; pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] was applied at a rate 1.4 kg ha^{-1} in 1999 and 2000 and at 1.1 kg ha^{-1} in 2001; sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} was applied at a rate of at 0.28 kg ha^{-1}; and bentazon [3-(1-methylethyl)-1*H*-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide] + acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid} were applied at rates of 0.84 and 0.19 kg ha^{-1}, respectively, in 1999 and 2000. Crop oil concentrate was applied at a rate of at 0.28 kg ha^{-1} in 1999 and 2000, ammonium sulfate at 2.2 kg ha^{-1} and nonionic surfactant at 0.33 L ha^{-1} in 2000 and 2001, and sethoxydim at 0.41 kg ha^{-1} and clethodim at 0.21 kg ha^{-1} in 2001.

Corn and soybean plots in the organic rotations were rotary-hoed and cultivated in the row according to stage of weeds and weather conditions (Table 1). An average of two row cultivations occurred each year. Before harvest, large weeds above the soybean canopy were hand-pulled while walking across each plot, per regional practices for organic soybean crops. An additional weed management tool, a propane flame burner, was used in the organic C-S-O/A and C-S-O/A-A corn plots in 1999. Corn was flamed at 30-cm height, using a Red Dragon propane flame burner (Flame Eng. Inc., LaCrosse, KS), run at 40 psi (≈276 kPa) and a tractor speed of 5 mph (≈2.24 m s^{-1}). Weed counts (grasses and broadleaf weeds per area) were taken in the corn and soybean plots using a 1-m^2 quadrant, randomly placed in three areas of the plot. Weed counts were taken at several periods before and after cultivation events to determine the effectiveness of tillage operations and need for additional weed management. Crop stand counts were determined in corn and soybean plots by counting the number of plants per 6 m of row in three random areas in each plot.

We sampled for potato leafhopper, the key pest of alfalfa crops in 1998, in each O/A plot. Twenty sweeps per plot (40-cm-diam. net) were taken in three random areas of each plot. Soybean insects were collected by sweeping 15 times per plot. Insect samples were placed in zip-lock bags, kept on ice, and transported to the lab for analysis. We monitored for corn borer populations by sampling the whorl of three corn plants at the V-6 stage per plot and recording the presence of corn borer larvae. Samples were treated as described above. In 1999, we monitored for corn earworm (*Helicoverpa zea* Boddie) populations on 31 August by sampling the ear of three plants per plot and recording presence of corn earworm larvae and damage. We sampled for soybean cyst nematode (*Heterodera glycines* Ichinohe) before soybean harvest by removing four soil cores (3.3-cm diam.) to a depth of 15 cm, one core from each of four quadrants in the plot. The four cores were combined into a composite sample, stored in plastic zip-lock bags, and kept cool during transport to the laboratory. Samples were analyzed for soybean cyst nematode (SCN) egg populations at the Plant Disease Diagnostic Laboratory at Iowa State University, Ames.

Corn stalk nitrate sampling was conducted each year 3 wk before harvest, following the methods of Blackmer and Mallarino (1996). All tissue samples were analyzed in the Iowa State University Agronomy and Horticulture Plant Analysis Laboratories, Ames.

Soil Sampling

Five randomly located 3.3-cm-diam. soil cores were collected to a depth of 15 cm from each of six equal-sized sections of the 7-ha field in April 1998 before the establishment of the LTAR plots for standard soil fertility analysis. The five soil cores from each of the six sections were mixed together to form one composite soil sample from each section of the field. Additional soil samples were collected after harvest in 1998 through 2001 and within 2 wk after corn planting in the spring of 1998 and 1999. This report includes data for 2 June 1998, 5 Nov. 1998 (after one season), and 29 Oct. 2001 (4 yr of organic production). For each sampling date, we removed five cores to a depth of 15 cm from each plot, one from each of four quadrants and one core from the plot center. The five cores were combined into one composite sample, stored in plastic zip-lock bags, and kept cool during transport to the laboratory.

Bulk density was estimated by the core method (Blake and Hartge, 1986). A 10-g subsample of field-moist 8-mm-sieved soil was extracted with 50 mL of 2 *M* KCl, and inorganic N ($NO_2 + NO_3$) in the filtrate was quantified using flow injection technology (Lachat Instruments, Milwaukee, WI). Soil water content was determined gravimetrically by oven-drying a 15-g subsample of field-moist 8-mm-sieved soil overnight at 105°C. A subsample of field-moist 8-mm-sieved soil was pushed through a 2-mm sieve, air-dried, stored at room temperature, and later analyzed for P, K, Ca, pH, and electrical conductivity. Phosphorous concentrations (Bray-P) (Knudsen and Beegle, 1988) were measured colorimetrically using ascorbic acid-ammonium molybdate reagents. Exchangeable K, Ca, and Mg were extracted with 1 *M* ammonium acetate (Brown and Warnecke, 1988) and measured using atomic absorption spectrophotometry. Soil pH (Eckert, 1988) and electrical conductivity (Dahnke and Whitney, 1988) were measured using a 1:2 soil-to-water ratio. Five grams of the subsample was ground pass a 250-μm-diam. sieve and used to determine total organic C (TOC) and total N (TN). Total organic C (after removal of carbonates with 1 *M* H_2SO_4) and TN were quantified by dry combustion using a Carlo-Erba NA 1500 NCS elemental analyzer (Haake Buchler Instruments, Paterson, NJ). All analyses were conducted at the USDA-ARS National Soil Tilth Laboratory and the Iowa State University Agronomy Soil Analysis Laboratory, Ames.

Harvest Operations

Oat, corn, wheat, and soybean grain were harvested using a field-scale combine. Alfalfa was mowed and raked and allowed to air-dry. When adequately dried (averaging 15% moisture), alfalfa was baled using a field-scale baler, and bales were individually weighed. An alfalfa harvest was not conducted in 1998 to allow for maximum stand establishment in the first year. Oat straw was baled when dry (averaging 12% moisture) and removed from the plot area each year. Three randomly collected 200-g corn and soybean grain samples were collected at harvest from each plot. Compositional analysis was conducted at the Iowa State University Grain Quality Laboratory, Ames, using a Foss Infratec Model 1229 analyzer (Eden Prairie, MN) to determine grain quality.

Statistical Analysis

All data were subjected to analysis of variance (PROC ANOVA). Means were separated using Fisher's PLSD test at $P \leq 0.05$ (SAS Inst., 1992).

RESULTS

Plant Responses

1998

Average temperature and rainfall during the growing season varied from year to year throughout this study (Table 2), with first-year weather conditions being the most favorable for crop growth. In the first year of transition to organic production, corn yields in the C-S-O/A, C-S-O/A-A and C-S were statistically equivalent, despite lower plant populations at 21 d after planting in the C-S plots (Table 3). Corn yields in the C-S rotation ranged from 10.2 to 11.2 Mg ha^{-1} compared with the organic yield range of 7.3 to 11.1 Mg ha^{-1}. The wider range in corn yields in the C-S-O/A and C-S-O/A-A

Table 2. Monthly mean temperature and precipitation totals for Greenfield, IA, 1998–2001.

	Monthly average air temperature					Monthly precipitation total				
Month	1998	1999	2000	2001	30-yr avg.	1998	1999	2000	2001	30-year avg.
	°C					mm				
Jan.	−3.7	−5.8	−2.4	−4.3	−6.1	26.7	18.5	7.4	47.8	24.6
Feb.	2.3	2.1	2.7	−6.3	−2.8	60.7	35.8	43.4	63.8	29.5
Mar.	0.6	4.1	7.3	0.3	3.9	101.6	30.2	33.0	48.3	56.4
Apr.	11.0	10.9	11.7	13.7	11.1	46.2	164.1	47.8	107.7	95.3
May	19.5	16.3	18.9	17.2	16.7	153.7	167.4	35.8	165.4	108.2
June	20.4	21.5	21.4	21.2	21.7	176.5	103.1	137.4	86.9	108.0
July	24.4	26.2	23.3	25.2	24.4	160.3	77.0	115.8	65.0	112.3
Aug.	24.0	22.5	24.8	24.4	23.3	70.9	83.6	19.3	22.9	90.2
Sept.	22.1	17.6	20.7	17.8	18.9	34.3	66.5	38.9	136.7	103.6
Oct.	13.5	13.0	14.1	11.8	12.2	81.8	9.4	28.2	83.3	64.5
Nov.	6.4	9.1	0.9	10.2	3.9	55.6	36.3	54.4	22.6	56.1
Dec.	−0.1	−1.0	−11.1	0.3	−3.3	9.9	11.4	35.6	10.4	31.5

Table 3. Corn crop performance at the Neely–Kinyon Long-Term Agroecological Research site, 1998–2001.

Year	Rotation†	Stalk nitrate	Corn yield	Corn population	Weed population	
					Grasses	Broadleaves
		mg kg^{-1} N-NO_3	Mg ha^{-1}	plants ha^{-1}	plants m^{-2}	
1998	C-S	4415	10.6	50 121	0.0	3.7
	C-S-O/A	434	9.0	60 102	11.6	12.4
	C-S-O/A-A	948	9.0	62 572	4.1	17.8
	$LSD_{0.05}$	3219‡	NS	5 122	NS	NS
1999	C-S	1568	10.1	66 278	0.0	0.9
	C-S-O/A	287	7.6	50 430	7.8	1.6
	C-S-O/A-A	551	7.5	46 518	3.8	3.1
	$LSD_{0.05}$	1029	0.8	7 304	5.7	NS
2000	C-S	5105	8.8	66 485	0.7	4.8
	C-S-O/A	7613	8.9	58 457	15.9	7.3
	C-S-O/A-A	7225	9.3	61 338	14.7	6.6
	$LSD_{0.05}$	NS	NS	4 918	7.6	NS
2001	C-S	5543	7.1	71 013	1.8	3.4
	C-S-O/A	2665	8.0	71 828	5.5	0.8
	C-S-O/A-A	3430	8.2	74 520	4.8	13.8
	$LSD_{0.05}$	NS	0.7	NS	NS	7.0

† C = corn, S = soybean, O = oat, and A = alfalfa.
‡ Means within a year and within a column are not significant (NS), or significant at $p \leq 0.05$ (Fisher's protected LSD test).

rotations may have been associated with the less readily available N in the initial year of transition as nutrient cycling processes in first-year organic systems change from inorganic N fertilization to organic amendments (Harris et al., 1994; Reider et al., 2000). Corn stalk nitrate content (4415 mg kg^{-1}) was also greater in the C-S rotation compared with the organic rotations (averaging 691 mg kg^{-1}) (Table 3). Grass and broadleaf populations in corn plots did not differ among systems in the first year of transition (Table 3). Reported weed counts (Tables 3 and 4) are those obtained in the last counting event after all tillage operations were completed and represented weeds most likely to reduce corn and soybean yield potential.

Soybean plant populations were equal in the C-S, C-S-O/A, C-S-O/A-A, and S-R rotations, averaging 308 750 plants ha^{-1} (Table 4). Soybean yields were also equivalent among all rotations, averaging 3.3 Mg ha^{-1}. Weed density did not differ between C-S and C-S-O/A and C-S-O/A-A rotations (Table 4). Organic oat grain yields averaged 1.5 Mg ha^{-1} with a test weight of 412 kg m^{-3}. An average of 2.4 Mg ha^{-1} of straw (12% moisture) was harvested from oat plots. Alfalfa was not harvested in the seedling year to ensure maximum overwintering for a second-year crop.

1999

When the corn variety was changed to a white, food-grade, milling type in 1999, corn yields in the C-S-O/A and C-S-O/A-A rotations averaged 7.6 Mg ha^{-1} compared with 10.1 Mg ha^{-1} in the C-S rotation (Table 3). Several factors may have contributed to the reduction of corn yields in these rotations, including lower plant populations at 21 d after planting, averaging 48 474 plants ha^{-1} compared with 66 278 plants ha^{-1} in C-S system (Table 3). Poor germination and damage from rotary hoeing also occurred in the C-S-O/A and C-S-O/A-A

Table 4. Soybean crop performance at the Neely–Kinyon Long-Term Agroecological Research site, 1998–2001.

Year	Rotation†	Soybean yield	Soybean population	Weed population	
				Grasses	Broadleaves
		Mg ha^{-1}	plants ha^{-1}	plants m^{-2}	
1998	C-S	3.3	312 042	0.17	2.2
	C-S-O/A	3.2	314 821	0.17	1.6
	C-S-O/A-A	3.3	317 943	0.33	2.2
	S-R	3.5	306 280	0.17	4.2
	$LSD_{0.05}$	NS‡	NS	NS	1.6
1999	C-S	3.3	284 873	0.00	0.00
	C-S-O/A	3.0	235 267	0.00	0.50
	C-S-O/A-A	3.3	229 505	0.33	0.42
	S-R	3.2	223 123	0.25	0.42
	$LSD_{0.05}$	NS	24 055	NS	NS
2000	C-S	2.7	282 610	2.20	1.5
	C-S-O/A	2.4	288 167	16.4	6.7
	C-S-O/A-A	2.5	276 949	16.9	4.5
	S-R	2.6	293 209	3.80	1.5
	$LSD_{0.05}$	NS	NS	10.0	2.8
2001	C-S	2.7	307 095	0.0	2.6
	C-S-O/A	2.9	276 838	0.7	1.0
	C-S-O/A-A	3.2	299 693	1.0	1.7
	S-R	–§	–§	–§	–§
	$LSD_{0.05}$	0.1	NS	NS	NS

† C = corn, S = soybean, O = oat, A = alfalfa, and R = rye.
‡ Means within a year and within a column are not significant (NS) or significant at $p \leq 0.05$ (Fisher's protected LSD test).
§ Crop not planted in this system. In 2001, all soybean plots in S-R rotation were planted to wheat to meet new certification rules.

rotations. In addition, grass weeds were more prevalent in these plots (Table 3). Similar to 1998, corn stalk nitrate content at the end of the season was greater in the C-S system than in either the C-S-O/A or C-S-O/A-A rotation (Table 3).

Soybean crop stands in the C-S-O/A, C-S-O/A-A, and S-R rotations averaged 229 298 plants ha^{-1}, which was significantly lower than the C-S rotation (284 873 plants ha^{-1}) (Table 4). Despite lower stands, soybean yields were not significantly lower in the C-S-O/A, C-S-O/A-A, and S-R rotations compared with the C-S rotation. In the second year of transition, soybean yields in all rotations averaged 3.2 Mg ha^{-1} (Table 4). In contrast to corn plots, weed populations were similar in all soybean plots (Table 4). Organic oat grain yields averaged 3.1 Mg ha^{-1}, with a test weight of 412 kg m^{-3} and 4.0 Mg ha^{-1} of straw. Over three cuttings in 1999, 7.2 Mg ha^{-1} of alfalfa hay was harvested from alfalfa plots in the C-S-O/A-A rotation.

2000

There were no significant differences in corn and soybean yields across all rotations in the third year of transition (Tables 3 and 4). Corn yields averaged 9.1 Mg ha^{-1} in the C-S-O/A and C-S-O/A-A rotations compared with 8.8 Mg ha^{-1} in the C-S rotation (Table 3). Though grain yields were similar, corn plant stands were less in the C-S-O/A and C-S-O/A-A rotations (averaging 59 898 plants ha^{-1}) than the C-S rotation (66 485 plants ha^{-1}). Grass weed populations were again greater in corn plots in the C-S-O/A and C-S-O/A-A rotations compared with the C-S rotation, but broadleaf populations were similar (Table 3). In the third year of transition, corn stalk nitrate levels in the C-S-O/A and C-S-O/A-A rotations exceeded 7000 mg kg^{-1} but were not significantly different from those in the C-S rotation (Table 3). This luxury consumption of N could be the result of increased compost mineralization rates or high soil moisture in the grain-filling period.

Soybean stands were not significantly different among any of the rotations and averaged 285 234 plants ha^{-1} (Table 4). Soybean yields in the C-S-O/A, C-S-O/A-A, and S-R systems averaged 2.5 Mg ha^{-1} compared with 2.7 Mg ha^{-1} in the C-S system (Table 4). Grass and broadleaf weed populations were greater in the C-S-O/A and C-S-O/A-A rotations; however, there were no differences between the S-R and C-S systems (Table 4). Oat yields averaged 2.2 Mg ha^{-1} with 1.4 Mg ha^{-1} of straw. Organic alfalfa hay yielded an average of 6.3 Mg ha^{-1} over four harvest dates.

2001

Corn and soybean yields in the fourth year of the C-S-O/A-A rotation exceeded yields in the C-S rotation (Tables 3 and 4). Corn yield averaged 8.1 Mg ha^{-1} across the C-S-O/A and C-S-O/A-A rotations compared with 7.1 Mg ha^{-1} in the C-S rotation, despite similar plant populations in the three rotations (Table 3). Four years after the cropping systems were established, grass weed populations were similar among the three systems that contained corn, but broadleaf weeds were significantly greater in the C-S-O/A-A rotation than the other two rotations (Table 3). Corn stalk nitrate levels were not statistically different in the C-S (5543 mg kg^{-1}), C-S-O/A, and C-S-O/A-A (3048 mg kg^{-1}) rotations, suggesting luxury consumption of N in all systems.

Soybean yields in the C-S rotation averaged 2.7 Mg ha^{-1} compared with 3.0 Mg ha^{-1} in the C-S-O/A and C-S-O/A-A rotations (Table 4). Soybean plant populations were similar across all rotations, averaging 294 542 plants ha^{-1}. Soybean weed populations were similar among the three rotations (Table 4).

Wheat yields averaged 2.6 Mg ha^{-1}, and oat grain yields averaged 3.0 Mg ha^{-1}. Straw was not measured

Table 5. Grain quality at the Neely–Kinyon Long-Term Agroecological Research site, 1998–2001.

Year	Rotation†	Corn				Soybean		
		Density	Starch	Oil	Protein	Fiber	Oil	Protein
		g kg^{-1}						
1998	C-S	12.6	602.2	43.0	80.5	44.0	164.8	395.8
	C-S-O/A	12.5	609.5	44.7	68.5	43.7	165.5	397.0
	C-S-O/A-A	12.3	609.5	45.7	66.2	45.0	164.3	393.0
	S-R	–‡	–‡	–‡	–‡	44.0	165.5	394.5
	$LSD_{0.05}$	NS§	NS	NS	9.1	NS	NS	NS
1999	C-S	12.6	610.0	41.0	73.0	46.7	155.2	407.5
	C-S-O/A	12.5	613.0	38.2	71.7	46.2	156.7	410.7
	C-S-O/A-A	12.5	613.2	38.5	72.5	46.5	156.7	413.0
	S-R	–‡	–‡	–‡	–‡	46.5	155.2	418.0
	$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS
2000	C-S	12.8	605.8	29.3	83.3	47.1	193.6	358.3
	C-S-O/A	13.1	606.3	29.0	84.8	46.9	187.9	369.3
	C-S-O/A-A	13.1	604.5	29.0	86.5	46.2	186.5	373.7
	S-R	–‡	–‡	–‡	–‡	48.0	184.9	371.5
	$LSD_{0.05}$	NS	NS	NS	NS	1.1	4.1	5.6
2001	C-S	13.1	596.8	36.3	90.0	46.3	206.0	327.8
	C-S-O/A	13.1	601.0	37.3	84.3	46.3	207.0	326.0
	C-S-O/A-A	13.2	599.3	37.0	86.0	45.8	200.5	338.8
	S-R	–‡	–‡	–‡	–‡	–‡	–‡	–‡
	$LSD_{0.05}$	NS	NS	NS	3.0	NS	NS	NS

† C = corn, S = soybean, O = oat, A = alfalfa, and R = rye.
‡ Crop not planted in this system. In 2001, all soybean plots in S-R rotation were planted to wheat to meet new certification rules.
§ Means within a year and within a column are not significant (NS), or significant at $p \leq 0.05$ (Fisher's protected LSD test).

in 2001. Alfalfa yields averaged 5.7 Mg ha^{-1} over three harvest dates.

Grain Analysis

Protein content of corn in the C-S rotation exceeded levels from the C-S-O/A and C-S-O/A-A rotations in 2 out of 4 yr (Table 5). Over the 4 yr, corn grain protein in the C-S rotation averaged 82 g kg^{-1}, and the combined average of the C-S-O/A and C-S-O/A-A rotations was 78 g kg^{-1}. When white milling corn was grown in 1999, protein content (73 g kg^{-1}) was substantially less than the yellow dent corn grown in other years. Corn density and oil and starch content were similar among the three rotations over 4 yr (Table 5).

Soybean grain protein content was similar in 3 out of 4 yr, averaging 372 g kg^{-1} in the C-S rotation and 378 g kg^{-1} across the C-S-O/A, C-S-O/A-A, and S-R rotations (Table 5). Oil and fiber content were also similar in those years (Table 5). In the year where grain composition differed (2000), protein content was significantly less and oil content significantly greater in the C-S rotation (Table 5). All grain quality levels compared favorably to reported average Iowa values each year of the experiment (Hurburgh, 1997–2001).

Insect and Nematode Responses

From 1998 to 2001, corn insect pest populations were similar among the three rotations (Table 6). Lepidopterous larvae did not reach the economic threshold level (5% of plants showing damage) when synthetic or biological insecticides would be required to avoid yield loss. Soybean cyst nematode populations were in the low-to-moderate range reported throughout Iowa, according to Iowa State University laboratory analysis (Tylka, 2002). The average SCN population over 4 yr was 157 eggs per 100 cm^3 of soil in the C-S-O/A, C-S-O/A-A, and S-R rotations compared with 140 eggs per 100 cm^3 of soil in the C-S rotation. Due to high variability in SCN population numbers, significant differences were not detected among rotations (Table 6). Bean leaf beetle populations were similar in C-S, C-S-O/A, C-S-O/A-A, and S-R rotations in 2000 and 2001 when populations averaged 21 beetles per 15 sweeps (Table 6).

Soil Fertility Changes

Before field operations in April 1998, the site average soil TOC concentration was 24.1 g C kg^{-1}, and average soil pH was 6.2. Soil test levels for Bray P and K were both very high, averaging 30 and 313 mg kg^{-1}, respectively. Soil samples taken 2 mo after plowing and seedbed preparation, and 1 mo after compost application in June 1998, showed little change in soil TOC content (Table 7). There were no significant differences among rotations on this sample date for any of the soil fertility parameters except NO_3–N (Table 7). The higher inorganic N content observed in the S-R rotation probably reflected the legacy of 3 yr of alfalfa production at this site since three of the four replicates for this rotation were randomly placed on former alfalfa ground.

In November of 1998, after one field season of organic production, the average soil TOC concentration was 26.1 g C kg^{-1}, and there were no significant differences in soil TOC among the four rotations (Table 8). Soil pH averaged 6.5 for all rotations in the fall of 1998. All plant nutrients were present at optimal or near-optimal concentrations for crop production, and there were no significant differences among the rotations except for P. Bray P concentrations in the top 15 cm were significantly greater in the C-S-O/A and C-S-O/A-A rotations, reflecting the application of composted swine manure in these systems.

In October 2001, after 4 yr of organic production,

Table 6. Insect and nematode response at the Neely–Kinyon Long-Term Agroecological Research site, 1998–2001.

Year	Rotation†	Corn	Soybean	
		Corn larvae	Soybean cyst nematode	Bean leaf beetles
		injured stalks, %	eggs cm^{-3} soil	no./15 sweeps
1998	C-S	0.50	100.0	–‡
	C-S-O/A	1.00	12.50	–‡
	C-S-O/A-A	1.25	12.50	–‡
	S-R	–§	1325.0	–‡
	$LSD_{0.05}$	NS¶	NS	
1999	C-S	1.88	0.00	–‡
	C-S-O/A	1.79	38.0	–‡
	C-S-O/A-A	1.50	62.0	–‡
	S-R	–§	25.0	–‡
	$LSD_{0.05}$	NS	NS	
2000	C-S	0.20	75.0	20.3
	C-S-O/A	0.20	0.00	21.8
	C-S-O/A-A	0.05	62.5	16.0
	S-R	–§	50.0	11.5
	$LSD_{0.05}$	NS	NS	NS
2001	C-S	0.22	387.5	33.3
	C-S-O/A	0.18	62.50	24.3
	C-S-O/A-A	0.17	150.0	20.3
	S-R	–§	–§	–§
	$LSD_{0.05}$	NS	NS	NS

† C = corn, S = soybean, O = oat, A = alfalfa, and R = rye.
‡ Bean leaf beetles monitored in 2000 and 2001 only.
§ Crop not planted in this system. In 2001, all soybean plots in S-R rotation were planted to wheat to meet new certification rules.
¶ Means within a year and within a column are not significant (NS), or significant at $p \leq 0.05$ (Fisher's protected LSD test).

Table 7. Soil fertility at the Neely–Kinyon Long-Term Agroecological Research site, 2 June 1998.

Rotation†	TOC‡	TN§	NO_3–N	P	K	Ca	Mg	BD¶	pH	EC#
	g kg^{-1}		mg kg^{-1}					g cm^{-3}		μS cm^{-1}
C-S	23.8	1.7	14.5	35	331	2973	294	1.15	6.32	289
C-S-O/A	25.0	1.7	10.4	51	361	2972	281	1.12	6.41	283
C-S-O/A-A	24.6	1.8	11.0	45	355	3133	270	1.07	6.44	285
S-R	23.4	1.9	24.4	28	248	3241	336	1.09	6.34	363
$LSD_{0.05}$	NS††	NS	NS	NS	NS	NS	NS	NS	NS	NS

† C = corn, S = soybean, O = oat, A = alfalfa, and R = rye.
‡ TOC, total organic carbon. Collected 2 June 1998 to a depth of 15 cm.
§ TN, total nitrogen.
¶ BD, bulk density.
# EC, electrical conductivity.
†† Means within a year and within a column are not significant (NS), or significant at $p \leq 0.05$ (Fisher's protected LSD test).

average soil TOC concentration was 25.7 g C kg^{-1}, and there were no significant differences in soil TOC among the four rotations (Table 9). Soil fertility parameters continued to reflect the legacy of continued application of composted swine manure to the corn and small grain plots in the C-S-O/A and C-S-O/A-A rotations. This effect was especially true for P in the C-S-O/A rotation where Bray P was three times as great as in April 1998. Bray P in the C-S-O/A and C-S-O/A-A rotations was 85 and 61 mg kg^{-1}, respectively, and both rotations had significantly more P than the C-S rotation or the S-R (1998–1999) and S-W/CC rotation (2000).

DISCUSSION

The first phase (4 yr) of the Neely–Kinyon LTAR experiment consisted of the 3-yr transition period and 1 yr of certified organic production. During the first phase, corn yield in the organic system (C-S-O/A and C-S-O/A-A rotations) was 91.8% of conventional corn yield in the C-S rotation. Soybean yield in the organic system (C-S-O/A, C-S-O/A-A, and S-R) was 99.6% of conventional soybean yield. Results obtained here compare with those of Mäder et al. (2002) where organic crop yields were 80 to 100% of conventional yields for all crops in the organic rotation [wheat, potato (*Solanum tuberosum* L.), grass–clover hay] over 21 yr. Other studies in the Midwestern USA have reported similar organic and conventional grain yields (Welsh, 1999), but none have reported such consistent yields in a transition organic system as obtained in this study. Porter et al. (2003) reported corn yields that were 7 to 9% lower in organic systems and organic soybean yields 16 to 19% lower than conventional yields. Organic yellow feed corn yields in our study (1998, 2000, and 2001) were similar to conventional yields, which supports U.S. survey results reported by the Organic Farming Research Foundation (OFRF, 2001) where organic corn yields averaged 95% of conventional yields. Organic white corn, grown in 1999 for a specialty food market, is generally a lower-yielding hybrid without additional fertilization and did not perform as well as conventionally grown white corn fertilized with 134 kg N ha^{-1} from urea.

The importance of a soil-building cover crop or le-

Table 8. Soil fertility at the Neely–Kinyon Long-Term Agroecological Research site, 5 Nov. 1998.

Rotation†	TOC‡	TN§	NO_3–N	P	K	Ca	Mg	BD¶	pH	EC#
	g kg^{-1}		mg kg^{-1}					g cm^{-3}		μS cm^{-1}
C-S	25.5	2.2	6.9	34	244	3509	304	1.10	6.40	239
C-S-O/A	26.2	2.2	4.4	48	290	3653	301	1.15	6.46	228
C-S-O/A-A	26.3	2.2	3.8	42	276	3684	317	1.15	6.47	234
S-R	26.5	2.2	6.6	31	209	3706	348	1.12	6.37	256
$LSD_{0.05}$	NS††	NS	NS	12	NS	NS	NS	NS	NS	NS

† C = corn, S = soybean, O = oat, A = alfalfa, and R = rye.
‡ TOC, total organic carbon. Collected 5 Nov. 1998 to a depth of 15 cm.
§ TN, total nitrogen.
¶ BD, bulk density.
# EC, electrical conductivity.
†† Means within a year and within a column are not significant (NS), or significant at $p \leq 0.05$ (Fisher's protected LSD test).

Table 9. Soil fertility at the Neely–Kinyon Long-Term Agroecological Research site, 2001.

Rotation†	TOC‡	TN§	NO_3–N	P	K	Ca	Mg	BD¶	pH	EC#
	g kg^{-1}		mg kg^{-1}					g cm^{-3}		μS cm^{-1}
C-S	24.9	2.2	7.7	40	267	3297	308	1.23	6.59	233
C-S-O/A	26.3	2.3	7.1	85	308	3657	315	1.25	6.85	244
C-S-O/A-A	26.1	2.4	7.7	61	320	3740	340	1.21	6.80	230
S-R	25.7	2.3	5.7	34	215	3831	389	1.22	6.79	229
$LSD_{0.05}$	NS††	NS	NS	21	63	NS	54	NS	NS	NS

† C = corn, S = soybean, O = oat, A = alfalfa, and R = rye.
‡ TOC, total organic carbon. Collected 29 Oct. 2001 to a depth of 15 cm.
§ TN, total nitrogen.
¶ BD, bulk density.
# EC, electrical conductivity.
†† Means within a year and within a column are not significant (NS), or significant at $p \leq 0.05$ (Fisher's protected LSD test).

gume–grass mixture, such as a grass–clover hay (Mäder et al., 2002), or the oat–alfalfa mixture in the LTAR experiment, was demonstrated in the fourth year of the LTAR when corn and soybean yields in the C-S-O/A-A rotations were significantly greater than conventional corn and soybean yields. In the initial year of organic transition, an economic advantage may be gained by planting legume hay crops or crops with a lower N demand (such as small grains or soybean) in fields with low productivity to increase soil fertility for the following corn crop (Liebhardt et al., 1989). As an example, when corn was grown on former alfalfa ground (land in alfalfa in 1997, before the initiation of the LTAR experiment), yields were greater than corn grown on former soybean ground (data not shown). By the second year of the experiment, however, yield differences from the 1997 crop history (soybean vs. alfalfa) were mitigated by rotation effects (all 1999 organic corn plots followed 1998 oat–alfalfa plots) and compost applications (Tables 3 and 4).

The recommended corn stalk nitrate level of 750 to 2000 mg kg^{-1} (Blackmer and Mallarino, 1996) was consistently achieved in the organic system after the first 2 yr of the rotation, suggesting that compost applications and cover crop additions can provide sufficient nutrients for organic grain crops. We believe that both timely weed management and sufficient levels of N, P, and K in the organic system contributed to successful organic yields during the transition. Our results contrast with those of Lockeretz et al. (1981), MacRae et al. (1990), and Hanson et al. (1997) where lower agronomic productivity was cited in transitioning organic systems compared with conventional cropping systems. Yield increases were obtained, however, after the 3-yr rotation as N availability from organic amendments increased within the organic system (Clark et al., 1999; Drinkwater et al., 1998; Liebhardt et al., 1989). Soil fertility in organic production systems is controlled by organic amendments, such as the composted swine manure used in this study and the inclusion of forage legumes and other green manures in extended crop rotations. Nitrogen fertility is maintained through the synchronization across space and time of net N mineralization from soil organic N pools and plant uptake of inorganic N. This process depends on the constant renewal of biologically available N to soil organic N pools. Over the long term, soil organic C and N levels have been shown to be consistently higher when forage legumes and small grains are rotated with corn and soybean (Dick et al., 1986a, 1986b; Johnston, 1986; Karlen and Doran, 1991; Kuo and Jellum, 2002; Odell et al., 1984). However, statistically significant short-term changes in TOC and TN are difficult to detect since we are looking for relatively small changes in a very large reservoir of total soil organic matter. In our study, during the 3 yr of transition to organic production and 1 yr beyond transition, soil TOC concentration in the top 15 cm of soil increased by 9% (from 24.1 g C kg^{-1} in 1998 to an average of 26.2 g C kg^{-1} in 2001) in the organic system that contained forage legumes and were amended with composted swine manure. Total organic C in the conventional system changed only minimally, from 24.1 g C kg^{-1} in 1998 to 24.9 g C kg^{-1} in 2001. Converting the TOC and TN concentration data for the 3- and 4-yr organic rotations to an aereal basis (i.e., kg C ha^{-1}) indicates that the extended organic rotations have accumulated 5.4 Mg C ha^{-1} and 457 kg N ha^{-1} over a 4-yr period. This translates into an average yearly TN input of 114 kg N ha^{-1}, which is adequate to maintain organic N pools in these systems. While not all of the newly inputted N will be readily labile, nor does this reflect a complete N budget, our research indicates that extended organic rotations containing forage legumes have the potential to at least maintain TOC and TN despite the relatively high tillage intensity. It is our goal to adjust future compost rates to more accurately reflect crop needs, always mindful of potential adverse environmental effects from excessive N and P applications.

In the first phase of the LTAR experiment, weed pressure in the organic corn and soybean systems was manageable, contrary to other studies (Clark et al., 1999; Liebhardt et al., 1989; Porter et al., 2003) where weed pressure was associated with lower yields in the organic systems. Although weed pressure in LTAR organic plots often exceeded competitive loads for corn and soybean production (Kappler, 2003), yields in organic and conventional systems were competitive. Weed management was considered less of a problem in organic soybean compared with corn plots where rye was not used as a cover crop. Allelopathic effects from rye in soybean systems have been reported by others (Ateh and Doll, 1996; LeMahieu and Brinkman, 1990; Liebl et al., 1992; Minton, 1992). Weed densities in the S-R rotation in our study were equivalent to conventional systems in the first 2 yr of transition and significantly less in the third year. The inclusion of rye for a longer period in the S-R plots, where rye was grown for a total of 12 mo in the same plot over a 3-yr period, compared with 4 mo in the C-S-O/A and C-S-O/A-A plots, may have led to significantly less weed pressure in this rotation. Although we assumed a suppressive effect of the legume cover crop (alfalfa) on weed populations in subsequent crops based on previous research (Dyck et al., 1995; Liebman and Dyck, 1993), greater numbers of grass weeds in the third year of transition (2000), and broadleaf weeds in the fourth year of organic production (2001), were observed in corn plots in the C-S-O/A-A rotation (Table 3).

Economic returns in the C-S-O/A and C-S-O/A-A rotations were significantly greater than returns in the C-S rotation (Delate et al., 2003). In this economic analysis of specific LTAR rotations, organic soybean was grown once every 3 (C-S-O/A) or 4 (C-S-O/A-A) yr. Currently, organic soybean commands the greatest return in the organic rotation and will remain as the economic cornerstone of any organic rotation in the Midwestern USA (Welsh, 1999). Despite the presence of soybean staining in LTAR soybean, a complex of viral and fungal diseases associated with bean leaf beetle populations (Rice, 2001) first observed in 2000, premium prices were obtained for stained organic soybean because of high demand from 1999–2001. Although it has been suggested that the lower costs of production from reduced fertilizers and pesticides in organic systems may be offset by increased machinery fossil fuel use in tillage operations, Mäder et al. (2002) found that enhanced soil fertility and higher biodiversity were correlated with less dependence on inputs in the organic systems, reducing fertilizer and energy inputs by 44% and pesticides by 97%. Heichel (1978) also found that the crop energy yield to fossil fuel energy flux ratio were similar in a two- and four-crop rotation system.

While pest loads were similar between systems in the initial years of the study, we will continue to examine the effect of crop sequence and length on long-term pest disruption and attraction of beneficial insects into the organic system. Greater biological control should occur in organic systems that maintain diverse biota through minimal pesticide applications (Altieri, 1995; Letourneau, 1997). Beneficial insects, such as parasitic wasps and predacious lady beetles, and competitive soil microorganisms (Workneh and van Bruggen, 1994) have been reported in greater abundance in organic sites. In a similar organic grain system as the LTAR, epigaeic predacious arthropods, such as carabids, staphylinids, and spiders, which regulate lepidopterous pests in corn, were found to be twice as high as in conventional fields (Pfiffner and Niggli, 1996).

The minor differences in food quality attributes between conventional and organic corn and soybean grain correspond with results obtained by Offermann and Neiberg (2000). Because differences in taste, texture, and nutrient profile have been obtained in other organic systems (Reganold et al., 2001; Asami et al., 2003), we will continue to monitor for potential food quality changes over time.

ACKNOWLEDGMENTS

We gratefully acknowledge the help of the following individuals who assisted with this research: B. Burcham, H. Friedrich, N. Wantate, B. Boehm, Heartland Organic Marketing Cooperative, A. McKern, and C. Collins. We also thank the Leopold Center for Sustainable Agriculture and the USDA-IFAFS (Initiative for Future Agriculture and Food Systems) program for funding this project and Iowa State University College of Agriculture for its support of this research and education program.

REFERENCES

Altieri, M.A. 1995. Agroecology. Westview Press, Boulder, CO.

Asami, D., Y.J. Hong, D.M. Barret, and A.E. Mitchell. 2003. Comparison of the total phenolic and ascorbic acid content of freeze-dried and air-dried marionberry, strawberry and corn grown using conventional, organic, and sustainable agricultural practices. J. Agric. Food Chem. 51:1237–1241.

Ateh, C.M., and J.D. Doll. 1996. Spring planted winter rye (*Secale cereale*) as a living mulch to control weeds in soybean (*Glycine max*). Weed Tech. 10:347:353.

Blackmer, A.M., and A.P. Mallarino. 1996. Cornstalk testing to evaluate nitrogen management. I.S.U. PM-1584. Iowa State University, Ames, IA.

Blake, G.R., and K.H. Hartge. 1986. Bulk density. p. 363–375. *In* A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Brown, J.R., and D. Warnecke. 1988. Recommended cation tests and measures of cation exchange capacity. p. 15–19. *In* W.C. Dahnke (ed.) Recommended chemical soil test procedures for the North Central region. NCR Publ. No. 221 (Revised). North Dakota Agric. Exp. Stn., Fargo, ND.

Brumfield, R.G., A. Rimal, and S. Reiners. 2000. Comparative cost analyses of conventional, integrated crop management, and organic methods. HortTechnology 10:785–793.

Cavigelli, M.A., J.R. Teasdale, K.A. Nichols, C. Shuey, S. Liang, T.H. Dao, J. Radhakrishnan, and J.E. Buyer. 2000. The USDA-ARS Farming Systems Project: Developing sustainable agriculture systems for the Mid-Atlantic region. p. 83. *In* 2000 Agronomy abstracts. ASA, Madison, WI.

Clark, M.S., W.R. Horwath, C. Shennan, K.M. Scow, W.T. Lanini, and H. Ferris. 1999. Nitrogen, weeds and water as yield-limiting factors in conventional, low-input, and organic tomato systems. Agric. Ecosyst. Environ. 73:257–270.

Dahnke, W.C., and D.A. Whitney. 1988. Measurement of soil salinity. p. 32–34. *In* W.C. Dahnke (ed.) Recommended chemical soil test procedures for the North Central region. NCR Publ. No. 221 (Revised) North Dakota Agric. Exp. Stn., Fargo, ND.

Delate, K.M. 2002. Using an agroecological approach to farming systems research. HortTechnology 12(3):345–354.

Delate, K.M., and J. DeWitt. 1999. Organic focus groups in Iowa. Leopold Center for Sustainable Agriculture Annual Report, LCSA, Iowa State University, Ames, IA.

Delate, K.M., M. Duffy, and C. Chase. 2003. An economic comparison of organic and conventional grain crops. Am. J. Altern. Agric. 35:1–11.

Dick, W.A., D.M. Van Doren, Jr., G.B. Triplett, and J.E. Henry. 1986a. Influence of long-term tillage and rotation combinations on crop yields and selected soil parameters. I. Results obtained for a Mollic Ochraqualf soil. Res. Bull. No. 1180. Ohio Agric. Res. and Development Ctr., Ohio State Univ., Wooster, OH.

Dick, W.A., D.M. Van Doren, Jr., G.B. Triplett, and J.E. Henry. 1986b. Influence of long-term tillage and rotation combinations on crop yields and selected soil parameters. I. Results obtained for a Typic Fragiudalf soil. Res. Bull. No. 1181. Ohio Agric. Res. And Development Ctr., Ohio State Univ., Wooster, OH.

Dimitri, C., and C. Greene. 2002. Recent growth patterns in the U.S. organic food market. USDA-ERS Agriculture Information Bulletin No. AIB777. U.S. Department of Agriculture-Economic Research Service, Washington, DC.

Dobbs, T.L., and J.D. Smolik. 1996. Productivity and profitability of conventional and alternative farming systems: A long-term on-farm paired comparison. J. Sustain. Agric. 9(1):63–79.

Drinkwater, L.E. 2002. Cropping systems research: Reconsidering agricultural experimental approaches. HortTechnology 12(3):355–361.

Drinkwater, L.E., D.K. Letourneau, F. Workneh, A.H.C. Van Bruggen, and C. Shennan. 1995. Fundamental differences between conventional and organic tomato agroecosystems in California. Ecol. Appl. 5:1098–1112.

Drinkwater, L.E., P. Wagoner, and M. Sarrantonio. 1998. Legume-based cropping systems have reduced carbon and nitrogen losses. Nature 396:262–265.

Dyck, E., M. Liebman, and M.S. Erich. 1995. Crop-weed interference as influenced by a leguminous or synthetic fertilizer nitrogen source: I. Doublecropping experiments with crimson clover, sweet corn, and lambsquarters. Agric. Ecosyst. Environ. 56:93–108.

Eckert, D.J. 1988. Recommended pH and lime requirement tests. p. 6–8. *In* W.C. Dahnke (ed.) Recommended chemical soil test procedures for the North Central region. NCR Publ. No. 221 (Revised). North Dakota Agric. Exp. Stn., Fargo, ND.

Hanson, J.C., E. Lichtenberg, and S.E. Peters. 1997. Organic versus conventional grain production in the mid-Atlantic: An economic and farming system overview. Am. J. Altern. Agric. 12:2–9.

Harris, G.H., O.B. Hesterman, E.A. Paul, S.E. Peters, and R.R. Janke. 1994. Fate of legume and fertilizer nitrogen-15 in a long-term cropping systems experiment. Agron. J. 86(5):910–915.

Heichel, G.H. 1978. Stabilizing agricultural energy needs: Role of forages, rotations, and nitrogen fixation. J. Soil Water Conserv. 33:279–282.

Hurburgh, C.R. 1997–2001. Quality of corn and soybeans produced in Iowa: Results of strip-plot sampling, 1997–2001. Iowa Grain Quality Initiative Prog. Iowa State University, Ames, IA.

[IDALS] Iowa Dep. of Agriculture and Land Stewardship. 2000a. Annual survey on organic production. IDALS, Des Moines, IA.

[IDALS] Iowa Dep. of Agriculture and Land Stewardship. 2000b. Organic certification standards—State of Iowa. IDALS, Des Moines, IA.
Johnston, A.E. 1986. Soil organic matter: Effects on soils and crops. Soil Use Manage. 2:97–105.
Kappler, B. 2003. Guide for Weed Management in Nebraska–2003. University of Nebraska, Dep. of Agronomy and Horticulture, Lincoln, NE.
Karlen, D.L., and J.W. Doran. 1991. Cover crop management effects on soybean and corn growth and nitrogen dynamics in an on-farm study. Am. J. Altern. Agric. 6:71–82.
Karlen, D.L., G.E. Varvel, D.G. Bullock, and R.M. Cruse. 1994. Crop rotations for the 21st Century. Adv. Agron. 53:1–45.
Knudsen, D., and D. Beegle. 1988. Recommended phosphorus tests. p. 12–14. *In* W.C. Dahnke (ed.) Recommended chemical soil test procedures for the North Central region. NCR Publ. No. 221 (Revised). North Dakota Agric. Exp. Stn., Fargo, ND.
Kuo, S., and E.J. Jellum. 2002. Influence of winter cover crop and residue management on soil nitrogen availability in corn. Agron. J. 94:501–508.
Lampkin, N.H., and S. Padel. 1994. Organic farming and agricultural policy in Western Europe: An overview. p. 437–454. *In* P. Midmore and N.H. Lampkin (ed.) The economics of organic farming: An international perspective. CAB International, Wallingford, UK.
LeMahieu, P.J., and M.A. Brinkman. 1990. Double cropping soybean after harvesting small grains as forage in the north central USA. J. Prod. Agric. 3:385–389.
Letourneau, D.K. 1997. Plant arthropod interactions in agroecosystems. p. 239–291. *In* L.E. Jackson (ed.) Ecology in agriculture. Academic Press, San Diego, CA.
Liebhardt, W.C., R.W. Andrews, M.N. Culik, R.R. Harwood, R.R. Janke, J.K. Radke, and S.L. Rieger-Schwartz. 1989. Crop production during conversion from conventional to low-input methods. Agron. J. 81:150–159.
Liebl, R., F.W. Simmons, L.M. Wax, and E.W. Stoller. 1992. Effect of rye (*Secale cereale*) mulch on weed control and soil moisture in soybean (*Glycine max*). Weed Technol. 6:838–846.
Liebman, M., and E. Dyck. 1993. Crop rotation and intercropping as strategies for weed management. Ecol. Appl. 3:92–122.
Lockeretz, W, G. Shearer, and D. Kohl. 1981. Organic farming in the Corn Belt. Science 211:540–547.
MacRae, R.J., S.B. Hill, G.R. Mehuys, and J. Henning. 1990. Farm-scale agronomic and economic conversion from conventional to sustainable agriculture. Adv. Agron. 43:155–198.
Mäder, P., S. Edenhofer, T. Boller, A. Wiemken, and U. Niggli. 2000. Arbuscular mycorrhizae in a long-term field trial comparing low-input (organic, biological) and high-input (conventional) farming systems in a crop rotation. Biol. Fertil. Soils 31:150–156.
Mäder, P., A. Fließbach, D. Dubois, L. Gunst, P. Fried, and U. Niggli. 2002. Soil fertility and biodiversity in organic farming. Science 296: 1694–1697.
Minton, M.A. 1992. Nematode management in minimum- tillage soybean with resistant cultivars, rye rotation, and aldicarb. Nematropica 22:21–28.
Odell, R.T., S.W. Melsted, and W.M. Walker. 1984. Changes in organic carbon and nitrogen of Morrow Plot soils under different treatments, 1904–1973. Soil Sci. 137:160–171.
Offermann, F., and H. Neiberg. 2000. Economic performance of organic farms in Europe. Univeritat Hohenheim, Institut fur Landwirtschaftliche Betriebslehre, Stuttgart, Germany.
[OFRF] Organic Farming Research Foundation. 2001. OFRF Newsletter, Vol. 10. OFRF, Santa Cruz, CA.
Pfiffner, L., and U. Niggli. 1996. Effects of bio-dynamic, organic and conventional farming on ground beetles (Col. Carabidae) and other epigaeic arthropods in winter wheat. Biol. Agric. Hortic. 12:353–364.
Porter, P.M., D.R. Huggins, C.A. Perillo, S.R. Quiring, and R.K. Crookston. 2003. Organic and other management strategies with two- and four-year crop rotations in Minnesota. Agron. J. 95:233–244.
Reganold, J.P., J.D. Glover, P.K. Andrews, and H.R. Hinman. 2001. Sustainability of three apple production systems. Nature 410: 926–929.
Reider, C., W. Herdman, L.E. Drinkwater, and R. Janke. 2000. Yields and nutrient budgets under composts, raw dairy manure and mineral fertilizer. Compost Sci. Util. 8:328–339.
Rice, M. 2001. Bean leaf beetle in Iowa. Integrated Crop Management Newsletter. Iowa State University, Ames, IA.
Richard, T.L., and S.M. Tiquia. 1999. In-barn composting system plus a warm bed for pigs. BioCycle 40(10):44.
Robertson, G.P., E.A. Paul, and R.R. Harwood. 2000. Greenhouse gases in intensive agriculture: Contributions of individual gases to the radioactive forcing of the atmosphere. Science 289:1922–1925.
Sainju, U.M., B.P. Singh, and S. Yaffa. 2002. Soil organic matter and tomato yield following tillage, cover cropping and nitrogen fertilization. Agron. J. 94:594–602.
SAS Institute. 1992. SAS/STAT guide for personal computers. Version 6.03. SAS Inst., Cary, N.C.
Stanhill, G. 1990. The comparative productivity of organic agriculture. Agric. Ecosyst. Environ. 30:1–26.
Temple, S.R., O.A. Somasco, M. Kirk, and D. Friedman. 1994. Conventional, low-input, and organic farming systems compared. Calif. Agric. 48:14–19.
Tilman, D. 1998. The greening of the green revolution. Nature 396: 211–212.
Tylka, G. 2002. Soybean cyst nematode-resistant soybean varieties for Iowa. I.S.U. PM-1649. Iowa State University Extension, Ames, IA.
[USDA-AMS] U.S. Department of Agriculture-Agriculture Marketing Service. 2003. National Organic Program. Final Rule: 7 CFR Part 205 [Online]. Available at http://www.ams.usda.gov/nop (accessed 10 April 2003; verified 12 December 2003). USDA-AMS, Washington, DC.
[USDA-ERS] U.S. Department of Agriculture–Economic Research Service. 2003. [Online]. Available at http://www.ers.usda.gov/data/Organic/(accessed 10 April 2003; verified 12 December 2003). USDA-ERS, Washington, DC.
Welsh, R. 1999. The economics of organic grain and soybean production in the midwestern United States. Policy Studies Report No. 13. Henry A. Wallace Institute for Alternative Agriculture. Greenbelt, MD.
Workneh, F., and A.H.C. van Bruggen. 1994. Suppression of corky root of tomatoes in soil from organic farms associated with soil microbial activity and nitrogen status of soil and tomato tissue. Phytopathology 84:688–694.