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Materials and Methods

The Neely-Kinyon Long-term Agroecological Research (LTAR) site was established in 1998 to study the long-term effects of organic production in Iowa. Treatments at the LTAR site, replicated four times in a completely randomized design, include the following rotations: conventional corn-soybean (C-S), organic corn-soybean-oats/alfalfa (C-S-O/A), organic corn-soybean-oats/alfalfa-alfalfa (C-S-O/A-A) and corn-soybean-corn-oats/alfalfa (C-SB-C-O/A).

On April 29, 2013, Badger oats were underseeded with BR Raven alfalfa at a rate of 90 lb/acre and 15 lb/acre, respectively. Following harvest of the organic corn plots in 2012, winter rye was no-till drilled at a rate of 75 lb/acre on October 29, 2012.

Conventional corn plots were injected with 32 percent UAN on May 14, 2013, at 140 lb N/acre, disked on May 16, and field cultivated on May 24. Chicken manure (S.W. Iowa Egg Cooperative, Massena, IA) was applied to organic corn plots at a rate of 4.6 tons/acre on April 2 in the organic C-S-O/A and C-S-O/A-A plots, and at a reduced rate of 1.9 tons/acre in the C-S-C-O/A plots on April 29. Corn and soybean variety selection and planting methods in 2013 were as follows: Blue River 54B36 corn was planted at a depth of 2.5 in. as untreated seed at a rate of 32,000 seeds/acre in the organic plots and as treated seed in conventional plots, on May 24. Conventional soybean plots were disked on May 18 and 24. Blue River 29AR9 soybeans were planted at a depth of 2 in. in organic and conventional plots at a rate of 160,000 seeds/acre on May 24. Conventional corn plots were sprayed with 1 lb/acre of atrazine and 1.3 pt/acre of Dual™ on June 7, and sprayed again on June 26 with 1.5 lb/acre of Atrazine™, and 1 qt/100 gal crop oil/acre. One of the organic corn plots was mistakenly sprayed with Round-Up™ on June 22 and caused that plot to be removed from certified organic production. Conventional soybeans received applications of 1.3 pt/acre of Dual™ and 6 oz/acre of Pursuit™ on June 7 and were sprayed again on June 26 with 6 oz/acre of Arrow™, 6 oz/acre of Cobra™, 1 qt/100 gallon/acre of crop oil, and 2 lb/acre of AMS.

The alfalfa and compost applied in the organic corn plots was plowed under on May 12, which may have been too close to the planting date of May 24, and as a result of the wet spring and late plowing, seedcorn maggots became an issue and organic corn plots had to be replanted on June 8 with BR 40R73. Organic corn plots were rotary-hoed on June 15 and 19, and row-cultivated on June 27, and July 2 and 10.

Rye was disked in organic soybean plots on May 13, 16, and 24, before soybean planting on May 24. All organic soybean plots were rotary hoed on June 2 before emergence and on June 12, and row-cultivated on June 21, June 27, and July 2. Each organic soybean plot was “walked” twice for large weeds on July 24 and August 13. There was a problem of weeds in conventional plots in 2013, even after repeated herbicide applications, but these were not “walked” in keeping with the protocol of herbicide applications only in conventional plots.

Corn and soybean stands were counted on July 5, and weeds were counted within square meter quadrats at three randomly selected areas within a plot. Soybean plots were sampled for insects on July 19 by sweeping plots 20 times with a 15-in. diameter net, placing contents in a Ziplock™ bag, and freezing until identification was completed. Late-spring soil nitrate tests were conducted on July 5 by sampling at a 6-in. depth in three randomly selected areas in each plot in the corn row. Corn borer sampling was conducted on July 23 by sampling the whorl of three randomly selected corn plants/plot and counting incidence and numbers of corn borers. Corn stalk nitrate samples were collected on September 19, and soybean cyst nematode sampling was completed on October 11. All crop and soil analyses were conducted at the Iowa State University Soil and Plant Analysis Laboratory, Ames, Iowa, and nematode analysis was conducted at the ISU Plant Disease Clinic (Ames, IA).

Alfalfa was baled on June 18, July 18, and August 30. Oat grain was harvested on July 23, and straw was baled on July 26. Soybean plots were harvested on October 13 and corn plots were not harvested until November 2. Grain samples were collected from each corn and soybean plot for grain quality analysis, which was conducted at the ISU Grain Quality Laboratory, Ames, Iowas.

Results and Discussion

Oat and alfalfa stands were affected by excessive rains in May, when oat biomass averaged 578 lb/acre on May 29, and alfalfa averaged 3,374 lb/acre (Table 1). Plant populations in the organic grain crop plots also suffered from wet fields, and, in the case of corn, seedcorn maggots infested manure-applied fields with only 12 days between plowing and planting. Therefore, replanting was required on June 8. On July 5, corn stands were similar between re-planted organic C-SB-O/A and conventional plots, at 27,455 plants/acre, compared with higher populations in the other two organic rotations at 30,625 plants/acre (Table 2). Organic soybean populations were some of the lowest ever recorded at the LTAR, averaging only 52,920 plants/acre, less than half of planted seed, compared with 121,080 plants/acre in the conventional plots (Table 2). Weed populations were highest in the organic C-S-O/A corn plots, similar in the C-S-O/A-A and C-S-C-O/A plots, and lowest in the conventional corn plots (Table 2). In the soybean plots, the organic C-S-C-O/A rotation had the highest amount of weeds, with no difference in weeds between the organic C-S-O/A and C-S-O/A-A plots and the conventional plots (Table 2). Weeds in general were greater in organic plots, averaging 11 weeds/sq. meter, compared with <1/sq. meter in conventional corn plots, and 15 weeds/sq. meter in organic soybean plots compared with 2 weeds/sq. meter in conventional soybean plots. This difference could be attributed to wet fields in spring, which created poor conditions leading to a delay of 7 and 9 days between planting and the first rotary-hoeing in corn and soybeans, respectively. For good weed management in organic crops, the first rotary-hoeing should occur within 2–3 days after planting.

Although there was no statistical difference between late-spring soil nitrate levels, conventional corn plots averaged 33 ppm NO_3-N, and organic soils averaged 15 ppm NO_3-N (Table 3). Corn borers were again low in all fields, showing the high degree of tolerance/resistance in conventionally bred (non-GMO) corn varieties. Incidence of corn borer damage and presence averaged less than 1 percent of plants sampled (Table 4). Corn stalk nitrate levels were high at harvest, reflecting a crop with green leaves. The highest levels were in the organic C-S-O/A-A corn, averaging 5,263 ppm nitrate-N, compared with 1,130 ppm in the conventional C-S, and the organic C-S-C-O/A and C-S-O/A rotations (Table 5).

Oat yields averaged 97 bushels/acre and oat straw averaged 3 tons/acre (Table 6). There was no difference in oat yield between the three- and four-year rotations.

Organic corn yields averaged 143 bushels/acre compared with conventional yields of 135 bushels/acre (Table 7). Statistical differences were observed with the highest corn yield in the organic four-year rotation (C-S-O/A-A) at 159 bushels/acre, compared with the lower yields in the three-year rotation (C-S-O/A) at 143 bushels/acre, the conventional rotation (135 bu/acre), and the rotation with two years of corn within three years (C-S-C-O/A) at 127 bushels/acre. The poor stands, delayed weed management and subsequent high weed populations, along with drought in July and August, affected organic soybean yields, which averaged 31 bushels/acre compared with 40 bushels/acre in the conventional plots (Table 8). The C-S-C-O/A soybean yield was significantly lower at 28 bushels/acre, and the other organic three- and four-year rotation soybean yields averaged 33 bushels/acre. The organic soybean yields were 26 percent lower than the 2012 average organic soybean yields after a more severe drought, highlighting the importance of weed management over dry weather for organic soybean yields.

Alfalfa growth was impacted by the wet spring followed by drought, yielding an average of 1.8 tons/acre (Table 9), down from 4.3 tons/acre in 2011, but more than the drought of 2012, when alfalfa plots yielded 0.77 tons/acre.

Soybean cyst nematodes remained low across all rotations, averaging 15 eggs/100 cc of soil, with no differences between conventional and organic plots (Table 10). Soybean insect pests also were low in 2013, and bean leaf beetles did not substantially affect soybean staining

Corn grain quality remained high despite the drought. Protein levels were equivalent between conventional and organic C-S-O/A-A corn (averaging 8.8%), with the organic rotation containing two years of corn among the lowest, at 7.7 percent protein (Table 9). Corn density was greater (1.26%) in the organic rotations compared with 1.24 percent in the conventional. Moisture was high (18.6%) at harvest, with no difference between systems. Corn starch was greater in the organic rotations (73%) compared to 71 percent in the conventional corn. Corn oil content was greater (4.3%) in conventional corn compared with an average of 4.2 percent across all organic rotations.

Soybean moisture levels were not different between systems, averaging 11 percent (Table 10). Protein levels also were equivalent among all rotations at 35 percent. Soybean carbohydrate levels averaged 23 percent, with no differences between systems. Oil levels (19%) were similar across all rotations.

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Table 1. Oat and alfalfa biomass and plant populations in the LTAR experiment, Neely-Kinyon Farm, 5/29/2013.

	Oat		Alfalfa	
Rotation	Population (plants/acre)[y]	Dry weight (lb/acre)[y]	Population (plants/acre)	Dry weight (lb/acre)
Org. C-SB-O/A[z]	1,684,321	594	-	-
Org. C-SB-O/A-A	1,680,689	562	2,123,550	3,374
$LSD_{0.05}$	NS	NS	-	-
P value (α=0.05)	0.98	0.59	-	-

[z]C=corn, S=soybean, O=oat, and A=alfalfa.
[y]Means in a column followed by the same letter are not significantly different at P≤0.05 (Fisher's protected LSD test). NS=not significant.

Table 2. Stand and weed populations in corn and soybean plots in the LTAR experiment, Neely-Kinyon Farm, 7/5/2013.

	Corn		Soybean	
Rotation	Plant population (plants/acre)[y]	Weed population (plants/m^2)[y]	Plant population (plants/acre)[y]	Weed population (plants/m^2)[y]
Conventional C-SB[z]	27,830 b	0.42 c	121,080 a	2.1 b
Org. C-SB-O/A	27,080 b	15.7 a	56,250 b	7.7 b
Org. C-SB-O/A-A	30,830 a	9.3 b	53,920 b	9.0 b
Org. C-SB-C-O/A	30,420 a	8.9 b	48,580 b	27.3 a
$LSD_{0.05}$	2,280	4.9	12,890	13.5
P value (α=0.05)	0.0029	0.0001	0.0001	0.0032

[z]C=corn, S=soybean, O=oat, and A=alfalfa.
[y]Means in a column followed by the same letter are not significantly different at P≤0.05 (Fisher's protected LSD test). NS=not significant.

Table 3. LSNT soil analysis in the LTAR experiment, Neely-Kinyon Farm, 7/5/2013.

Rotation	NO_3-N (mg/kg)[y]
Conventional C-SB[z]	32.5
Org. C-SB-O/A	12.0
Org. C-SB-O/A-A	22.5
Org. C-SB-C-O/A	11.5
$LSD_{0.05}$	NS
P value (α=0.05)	0.053

[z]C=corn, S=soybean, O=oat, and A=alfalfa.
[y]Means in a column followed by the same letter are not significantly different at P≤0.05 (Fisher's protected LSD test). NS=not significant.

Table 4. Corn borer damage and presence in the LTAR experiment, Neely-Kinyon Farm, 7/23/2013.

Rotation	Damage (%)[y]	Presence (%)[y]
Conventional C-SB[z]	0.33	0.17
Org. C-SB-O/A	0.08	0.08
Org. C-SB-O/A-A	0.08	0.08
Org. C-SB-C-O/A	0.08	0.00
$LSD_{0.05}$	NS	NS
P value (α=0.05)	0.2218	0.558

[z]C=corn, S=soybean, O=oat, and A=alfalfa.
[y]Means in a column followed by the same letter are not significantly different at P≤0.05 (Fisher's protected LSD test). NS=not significant.

Table 5. Corn stalk nitrate in the LTAR experiment, Neely-Kinyon Farm, 9/19/2013.

Rotation	NO_3–N (mg/kg)[y]
Conventional C-SB[z]	1,291 b[y]
Org. C-SB-O/A	1,533 b
Org. C-SB-O/A-A	5,263 a
Org. C-SB-C-O/A	566 b
$LSD_{0.05}$	1,198
P value (α=0.05)	0.0001

[z]C=corn, S=soybean, O=oat, and A=alfalfa.
[y]Means in a column followed by the same letter are not significantly different at P≤0.05 (Fisher's protected LSD test). NS=not significant.

Table 6. Oat and oat straw yields in the LTAR experiment, Neely-Kinyon Farm, 7/23/2013.

Rotation	Yield (bu/acre)[y]	Straw (tons/acre)[y]
Org. C-SB-O/A[z]	101	3.28
Org. C-SB-O/A-A	92	2.89
$LSD_{0.05}$	NS	NS
P value (α=0.05)	0.268	0.281

[z]C=corn, S=soybean, O=oat, and A=alfalfa.
[y]Means in a column followed by the same letter are not significantly different at P≤0.05 (Fisher's protected LSD test). NS=not significant.

Table 7. Corn and soybean yields in the LTAR experiment, Neely-Kinyon Farm.

Rotation	Corn (bu/acre)[y]	Soybean (bu/acre)[y]
Conventional C-SB [z]	135 bc	39.8 a
Org. C-SB-O/A	143 b	33.6 b
Org. C-SB-O/A-A	159 a	31.6 b
Org. C-SB-C-O/A	127 c	27.5 c
$LSD_{0.05}$	12.2	4.03
P value (α=0.05)	0.0006	0.0002

[z]C=corn, S=soybean, O=oat, and A=alfalfa.
[y]Means in a column followed by the same letter are not significantly different at P≤0.05 (Fisher's protected LSD test). NS=not significant.

Table 8. Soybean cyst nematode populations and stained soybeans in the LTAR experiment, Neely-Kinyon Farm.

Rotation	SCN eggs per 100 cc[y]	Stained soybeans (%)[y]
Conventional C-SB[z]	12.5	1.16
Org. C-SB-O/A	37.5	1.09
Org. C-SB-O/A-A	12.5	1.00
Org. C-SB-C-O/A	0.0	0.27
$LSD_{0.05}$	NS	NS
P value (α=0.05)	0.642	0.108

[z]C=corn, S=soybean, O=oat, and A=alfalfa.
[y]Means in a column followed by the same letter are not significantly different at P≤0.05 (Fisher's protected LSD test). NS=not significant.

Table 9. Corn grain quality analysis in the LTAR experiment, Neely-Kinyon Farm.

Rotation	Moisture (%)[y]	Protein (%)[y]	Oil (%)[y]	Starch (%)[y]	Density (g/cc)[y]	Ethanol yield (gal/bu)[y]
Conventional C-SB[z]	18.15	9.03 a	4.33 a	70.88 c	1.24 c	2.76 b
Org. C-SB-O/A	20.03	8.13 bc	4.13 b	72.5 ab	1.26 ab	2.82 a
Org. C-SB-O/A-A	18.48	8.58 ab	4.10 b	71.90 b	1.26 a	2.80 ab
Org. C-SB-C-O/A	18.73	7.65 c	4.00 b	72.65 a	1.25 bc	2.84 a
$LSD_{0.05}$	NS	0.84	0.18	0.72	0.01	0.05
P value (α=0.05)	0.138	0.02	0.011	0.001	0.003	0.010

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

[y]Means in a column followed by the same letter are not significantly different at P≤0.05 (Fisher's protected LSD test). NS=not significant.

Table 10. Soybean grain quality analysis in the LTAR experiment, Neely-Kinyon Farm.

Rotation	Moisture (%)[y]	Protein (%)[y]	Oil (%)[y]	Fiber (%)[y]	Carbohydrates (%)[y]
Conventional C-SB[z]	11.55	35.30	19.30	4.73	22.68
Org. C-SB-O/A	11.23	34.98	19.38	4.70	22.95
Org. C-SB-O/A-A	11.23	34.95	19.33	4.70	23.03
Org. C-SB-C-O/A	11.40	35.55	19.10	4.70	22.65
$LSD_{0.05}$	NS	NS	NS	NS	NS
Interaction P value (α=0.05)	0.3840	0.0805	0.4112	04262	0.0959

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

[y]Means in a column followed by the same letter are not significantly different at P≤0.05 (Fisher's protected LSD test). NS=not significant.