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Organic agriculture effect on water use, tile flow, and crop yield

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Abstract

Long-term crop rotations in organic agricultural systems provide N additions through legumes and residual organic materials to improve soil properties. In addition, enhanced pest management and more efficient water use in the spring and fall may result from the plant biodiversity in organic rotations. The purpose of this study was to compare organic and conventional systems in terms of tile flow or water use, and to determine if corn (*Zea mays* L.) or soybean [*Glycine max* (L.) Merr.] yields differed between systems. The experimental plots were in central Iowa and consisted of three treatments: 2-yr conventional rotation (both crops each year in split plot), 4-yr organic rotation (all crops present each year), and organic grass–legume forage. In the fall of 2017, 2018, and 2019, organic forage used more water than the mean of the 4-yr organic rotation, which used more water than the 2-yr conventional rotation. The same trend was shown for the spring of 2017 and 2019. Conventional corn had higher yield than organic for 3 of 8 yr, with 5 yr not significant. Conventional soybean had higher yield than organic for 2 of 8 yr and lower for 1 yr, with 5 yr not significant. Grass weeds were inversely correlated with leaf area index of corn on 3 of 10 measurement dates and for soybean on 5 of 10 measurement dates, but broadleaf weeds only on one date for soybean. Organic agricultural systems had positive benefits for timing of water use in the spring or fall by forage, alfalfa (*Medicago sativa* L.), or oat (*Avena sativa* L.). Some years had comparable yields to conventional corn and soybean.

1 | INTRODUCTION

Farmers chose organic agriculture for a price premium for their crops (Cavigelli et al., 2008), for support of a more ecological system (Bedoussac et al., 2015; Cavigelli et al., 2013), and for better health and communities (Delate, 2002; Reganold & Wachter, 2016). Previous research in Iowa has demonstrated similar yields in organic grain systems, along with economic gains due to price premiums and reduction in production costs (Delate et al., 2013, 2015).

Abbreviations: ET, evapotranspiration; LAI, leaf area index.

Farmers add organic matter to supply nutrients (Cavigelli et al., 2008, 2013) and to improve the physical properties of the soil such as saturated hydraulic conductivity, bulk density, earthworm activity, aggregation, infiltration, water storage, and workability (Jiang et al., 2018; Oquist et al., 2006; Paradelo et al., 2019; Riley et al., 2008; Williams et al., 2017). Often weed control in organic systems is by cultivation, which can degrade soil structure over time (Bell et al., 2012) and result in greater evaporation of water from soil. Longer crop rotations help pest management (disease and insects) by breaking up pest cycles that can develop from monoculture or 2-yr rotations (Brummer, 1998; Lin, 2011; Pimental et al.,

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2005). Legumes in rotation provide N (Bedoussac et al., 2015; Cavigelli et al., 2008). Different plant types have different rooting structure (Basche & Edelson, 2017; Bedoussac et al., 2015) that might result in better soil structure than having just a few plant types. Longer rotations also keep the ground covered for a longer season than do corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] (Basche & Edelson, 2017).

Long-term rotations that include small grains, perennials, or cover crops allow plant water use for a longer season than for corn and soybean. Greater water use may or may not result in significantly less tile outflow. Oquist et al. (2007) showed alternative management (organic or low input, diverse species) had 41% less subsurface drain flow than conventional corn–soybean. Qi et al. (2011) showed that soil water storage was reduced by perennial forage, which suggested higher evapotranspiration (ET) since tile outflow was not significantly reduced compared with conventional corn–soy rotation. Daigh et al. (2014) showed that prairie or winter cover crops had longer lag time to initiate drainage, lower peak drain flow, and lower cumulative drainage compared with corn or soybean, probably due to greater ET for the prairies or cover crop. Goeken et al. (2015) showed that only in May did perennial forage have lower tile outflow than conventional corn–soybean. The extra spring and fall water use could be helpful in drying the soil during extended wet periods, which might reduce flooding (Antolini et al., 2020; Nosetto et al., 2015; Schilling et al., 2014). Early planting of small grains and use of deep-rooted forage crops might reduce waterlogging in soil (Manik et al., 2019).

The purpose of this study was to determine if organic management systems increased water use or decreased tile outflow compared with conventional agriculture, especially during the extended seasons of small grains and forage compared with merely corn and soybean rotation. Crop yield were also compared between conventional and organic corn and soybean in order to determine the effects of weed populations on leaf area index (LAI) and yield.

Core Ideas

- Organic forage had higher evapotranspiration in the fall though tile outflow was unaffected.
- Corn and soybean yields increased as evapotranspiration increased.
- Organic soybean yields were not reduced compared with conventional for 7 of 9 yr.
- Corn and soybean were decreased more by grass weeds than broadleaf weeds.

2 | MATERIALS AND METHODS

2.1 | Experimental plots

The setup of the study was described by Cambardella et al. (2015). The experimental site was 4.1 ha near Boone, IA. There was a weather station 3 m south of the plots under grass–legume forage (Logsdon et al., 2019). Weather station data used in this study were air temperature with relative humidity, rainfall (tipping bucket rain gauge, Campbell Scientific International), barometric pressure, and net solar radiation (CNR1, Kipp and Zonen). The soils on upland parts of the experimental area were Clarion (fine-loamy, mixed, superactive, mesic Typic Hapludoll), and the lowland areas were Webster (fine-loamy, mixed, superactive, mesic Cumulic Endoaquoll) or Canisteo (fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquoll).

In 2011, we planted the whole area to organic grass–legume forage: bromegrass (*Bromus inermis* Leyss.), fescue (*Festuca*), alfalfa (*Medicago sativa* L.), and white clover (*Trifolum repens* L.). In November 2011, we installed tiles 1.22 m deep, plastic barriers between plots and outside study area (1.83 m deep), and tile monitoring equipment. There were 30 plots, each 30.5 by 30.5 m. The study consisted of three treatments: 2-yr conventional corn–soybean rotation (each present each year in one split plot), 4-yr corn–soybean–oat (*Avena sativa* L.)/first-year alfalfa, and second-year alfalfa, all present each year so mean of four plots, and organic grass–legume forage. Although composted beef (*Boa taurus*) manure had been used for organic plot fertility in early years (Cambardella et al., 2015), by 2016, the fertility was supplied by chicken (*Gallus domesticus*) manure to ensure a more rapid N release. There were five blocks, each consisting of six plots (the split conventional plot, each year of the 4-yr organic rotation, and the grass–legume forage). The blocking was based on tile outflow for the fall and winter of 2011–2012.

In the late summer to fall of 2017, we applied lime to the plots with low pH, which disturbed the first-year alfalfa plots. In 2018 we added the beef manure compost to all the organic plots specifically for carbon additions (8,000 kg ha^{-1}), and chiseled and disked it in. Due to the disturbance, we replanted oat and first year alfalfa to what would have been second year alfalfa. Since the forage plot were disturbed from the addition of the compost, they were replanted in August 2018. Chicken manure was added for N (as for all years, 56 kg ha^{-1} N for oat and 168 kg ha^{-1} for corn). A similar amount of urea N was added sidedressed to the conventional corn. See the detailed field activities in the supplemental files. The second-year alfalfa was cut and raked periodically (often monthly), and the mixed forage was cut one to three times a year. Two forage cuttings in 2019 were raked and dry matter measured, but cuttings in 2016 to 2018 were merely left on the field. Supplemental Tables S1–S4 give more specific detail.

2.2 | Crop measurements

We took overhead pictures to determine ground cover fractions as described in Logsdon and Cambardella (2019) . We determined crop cover from the photographic information as in all years using SamplePoint (Booth et al., 2006). In 2018 and 2019, we also measured height of grass and broadleaf weeds as well as crop height. Field operations and weather conditions determined when the overhead pictures could be taken, but generally pictures were taken every 3 wk. When information was given ahead of time, we took pictures both before and after alfalfa and mixed forage were cut; however, often we did not know the date of cutting ahead of time.

We combined ground cover with plant height measurements to determine LAI as described in Logsdon and Cambardella (2019). In 2016 and 2017, we measured crop heights and estimated weed heights. In 2018 and 2019, we determined crop and weed heights on most measurement dates. Weather conditions prevented plant height measurements on a few dates. In 2018 and 2019, we were able to split off LAI into crop, grass weed, and broadleaf weed components. For each measurement date in 2018 and 2019, the LAI of corn or soybean was regressed as a function of grass weed LAI, broadleaf weed LAI, or total weed LAI. We used paired comparison (paired by block) to determine crop yield differences in conventional vs. organic soybean or corn for each year (confidence interval of difference; Saville, 2015).

2.3 | Water measurements

We manually collected tile water flow data approximately weekly from each plot. We cumulated each quarterly tile outflow amount, excluding any measurement interval in which one or more tile overflowed and did not have reliable data. Excluded intervals were 28 Jan. to 11 Feb. 2016, 8–13 Sept. 2016, 17–22 Feb. 2017, 27 Apr. to 22 May 2017, 28 Apr. to 4 May 2018, 14–19 July 2018, 6 Oct. to 10 Nov. 2018, and 17–29 May 2019. Then, each two-sample treatment set (2-yr conventional, 4-yr organic, organic forage) was paired by block. We determined the 95% confidence interval of the difference between each two-treatment pair, and the treatments were declared significantly different if the confidence interval did not include zero (Saville, 2015).

We calculated crop ET as described by Logsdon et al. (2019). The change in calculation for ET was that we did not include a subsoil water stress component for transpiration since the stress would be shown by smaller plants. We did the same paired comparison described above (each set of two treatments) on the quarters in which we had calculated ET for at least 3 wk of the quarter.

TABLE 1 Quarterly precipitation

Year	Jan.–Mar.	Mar.–June	July–Sept.	Oct.–Dec.
	mm			
2012	102	259	212	116
2013	80	422	115	108
2014	46	418	365	136
2015	15	403	515	334
2016	67	232	500	94
2017	129	327	161	89
2018	89	372	457	248
2019	51	336	269	210

TABLE 2 Quarterly tile outflow (excluding intervals with tile overflow, which caused unknown exact outflow), and mean treatment difference

Quarter	2-yr conventional	4-yr organic	Organic forage
	mm		
2016-1	66a	73a	81a
2016-2	43a	56a	37a
2016-3	30a	28ab	18b
2016-4	16a	26a	14a
2017-1	26a	49a	68a
2017-2	52a	63a	45a
2018-1	4b	12ab	14a
2018-2	40a	38a	35a
2018-3	63a	67a	50a
2018-4	57a	63a	47a
2019-1	4b	13a	28ab
2019-2	49a	55a	47a
2019-3	5a	8a	7a
2019-4	19a	33a	27a

Note. January–March was Quarter 1, April–June was Quarter 2, July–September was Quarter 3, October–December was Quarter 4. Within each row, means followed by the same letter are not significantly different at $p = .05$. There was no or insignificant mean outflow for the third and fourth quarter of 2017.

3 | RESULTS AND DISCUSSION

3.1 | Water comparisons

Rainfall (Table 1) was minimal for the second quarter of 2016 and for the third and fourth quarters of 2017. There was more rainfall for the third quarter of 2016 and 2018. Quarterly tile outflow was rarely significantly different among the three treatment means (Table 2), mainly due to variability among the blocks. The few differences did not show any trends. Quarterly ET for organic forage was greater than for the 4-yr organic rotation, which was greater than the 2-yr

TABLE 3 Quarterly crop evapotranspiration (quarters with at least 3 wk of calculated data) and mean treatment difference

Quarter	2-yr conventional	4-yr organic	Organic forage
	mm		
2016-3	409a	394a	441a
2017-2	28c	150b	352a
2017-3	388a	297b	400a
2017-4	1c	19b	60a
2018-2	149b	179a	148ab
2018-3	442a	264c	319b
2018-4	2c	9b	30a
2019-2	47c	115b	303a
2019-3	387a	306c	356b
2019-4	8c	33b	63a

Note. April–June was Quarter 2, July–September was Quarter 3, October–December was Quarter 4. Our calculation procedure could not determine evapotranspiration for the first quarter, and in some years there were not enough data to report for the fourth quarter. We did not start the experiment in 2016 until the end of June. Within each row, means followed by the same letter are not significantly different at $p = .05$.

conventional rotation for the second and fourth quarters of 2017 and 2019 and for the fourth quarter of 2018 (Table 3). The same trend was not shown for the second quarter of 2018 due to soil and plant disturbance when applying composted manure, and delayed replanting of mixed forage until August. The third quarter showed inconsistent results since ET was usually high for all treatment means. The organic 4-yr rotation usually had significantly lower ET after oat harvest since it took time to replant and establish the first-year alfalfa, and ET was reduced until the alfalfa finally grew in the fall. Also, the second-year alfalfa was cut periodically, which stunted ET until regrowth occurred. Avice et al. (1997) showed a slow rebound after alfalfa was cut (around 2 wk). If there are too many cuttings, forage may not completely recover (Ergon et al., 2016; Ventroni et al., 2010).

Small grains, alfalfa, and forages are expected to use more water in the spring and fall than corn and soybean (Goeken et al., 2015; Hatfield et al., 2009; Qi et al., 2011) since corn and soybean do not have plant growth at that time. Since 3 of the 4 yr of our study had wet portions of the extended season, extra water use could be beneficial to reduce runoff (Woodley et al., 2018), downstream flooding (Antolini et al., 2020; Nosetto et al., 2015; Schilling et al., 2014), or waterlogged soil (Manik et al., 2019).

3.2 | Plant comparisons

Over the 3 yr (2017–2019, Figure 1), soybean yield was correlated with season ET as long as one high weed plot in 2018

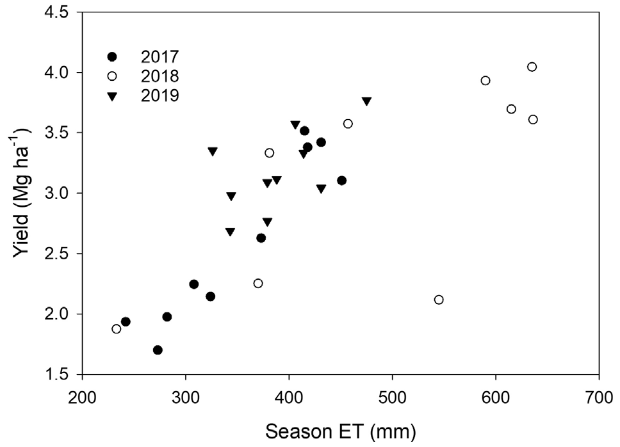

FIGURE 1 Soybean yield as a function of seasonal evapotranspiration (ET) for 2017 through 2019

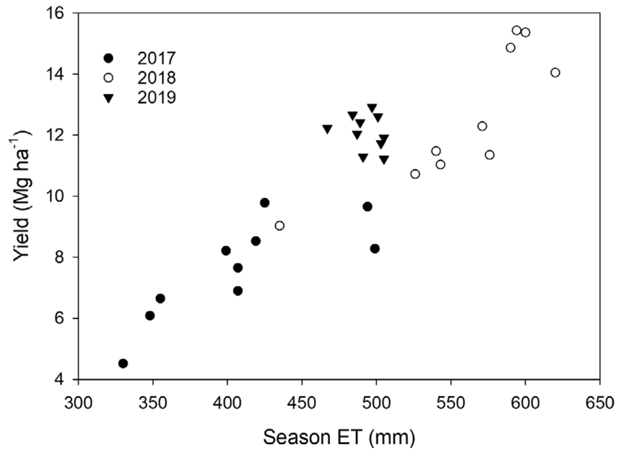

FIGURE 2 Corn yield as a function of seasonal evapotranspiration (ET) for 2017 through 2019

was considered an outlier (yield = 1.13 + 0.0045ET, $r^2 = .51$, $p < .001$). Over the 3 yr, corn yield (Figure 2) was correlated with season ET (yield = −4.70 + 0.0312ET, $r^2 = .77$, $p < .001$). On the other hand, neither oat nor alfalfa dry matter correlated with seasonal ET, and neither did oat grain yields correlate with ET over the 3 yr (not shown).

Since the experiment was started (Table 4), grain yield of conventional corn was significantly higher than for organic corn in 3 of the 8 yr. Grain yield of conventional soybean was significantly higher than for organic soybean in 2 of the 8 yr, and significantly less than organic soybean for 1 yr. Yield variability from year-to-year was beyond the scope of the current study. The first few years of the study, composted beef manure was used rather than poultry manure, but the N release from the compost was not sufficient for the year it was applied. This resulted in lower corn yields in the early years. Nitrogen release from the poultry manure was more useable in the applied year. Timing of rain (Table 4) played a role in yield

TABLE 4 Paired (by block) comparison of conventional vs. organic corn and soybean grain yields

Year	Conventional corn	Organic corn	Conventional soybean	Organic soybean
	Mg ha^{-1}			
2012	9.01a	8.57a	2.79a	2.99a
2013	8.11a	6.60b	2.13a	2.21a
2014	7.30a	7.19a	3.12a	3.79a
2015	9.28a	8.79b	3.44a	3.47a
2016	12.78a	12.32a	3.22a	2.10b
2017	8.77a	6.50b	3.11a	2.10b
2018	14.40a	10.72b	3.50a	2.76a
2019	12.13a	12.08a	3.03b	3.31a

Note. Within each row set, means followed by the same letter are not significantly different at $p = .05$.

TABLE 5 Mean leaf area index (LAI) of corn crop and significance of negative correlation with weeds

Year	Measurement day	Corn LAI	Grass LAI	Broadleaf LAI
2018	18 June	0.76	0.20*	0.04ns†
2018	9 July	3.85	0.21*	0.03ns
2018	31 July	5.06	0.13*	0.02ns
2018	23 Aug.	4.77	0.40*	0.03ns
2018	11 Sept.	2.11	0.16ns	0.03ns
2019	27 June	0.33	0.04ns	0.01ns
2019	15 July	3.65	0.05ns	0.02ns
2019	5 Aug.	5.06	0.06ns	0.01ns
2019	28 Aug.	4.99	0.04ns	0.02ns
2019	16 Sept.	3.56	0.06ns	0.01ns

*Significant at the .05 probability level.
†ns, not significant.

TABLE 6 Mean leaf area index (LAI) of soybean crop and significance of negative correlation with weeds

Year	Measurement day	Soybean LAI	Grass LAI	Broadleaf LAI
2018	18 June	0.80	0.21ns†	0.03ns
2018	9 July	2.29	0.53ns	0.15ns
2018	31 July	3.24	0.70*	0.04*
2018	23 Aug.	2.85	1.18*	0.08ns
2018	11 Sept.	1.41	0.86*	0.10ns
2019	27 June	0.30	0.14ns	0.02ns
2019	15 July	1.70	0.19ns	0.02ns
2019	5 Aug.	3.52	0.49*	0.09ns
2019	28 Aug.	3.60	0.60*	0.22ns
2019	16 Sept.	1.30	0.56ns	0.18ns

*Significant at the .05 probability level.
†ns, not significant.

variability, as shown by dry conditions in 2017 and wet conditions in 2018.

Overall, economics were not considered since corn and soybean together made up both years of the 2-yr conventional treatment but only 2 of 4 yr of the 4-yr organic rotation (Kirchmann et al., 2016). Badgley et al. (2007) reviewed literature that showed the ratio of organic to conventional grain yield was 0.92 for developed countries, and legume yield ratio was 0.82 for developed countries. Weather has a large effect on year-to-year variation in yield (Cavigello et al., 2008). de Ponti et al. (2012) showed a mean yield ratio of 0.89 for corn and 0.92 for soybean with organic yield losses attributed to weeds, diseases, and lower fertility.

Across conventional and organic plots (Table 5), corn LAI increased as grass or total weed LAI decreased for 3 of the 10 measurement dates in 2018 and 2019 but was not affected by broadleaf weed LAI. Across conventional and organic plots (Table 6), soybean LAI increased as grass and total LAI decreased for 5 of the 10 measurement dates, and as broadleaf LAI decreased for only one of the measurement dates. So overall, soybean growth was reduced more by grass weed growth than was corn growth, and broadleaf growth rarely directly reduced either corn or soybean growth. Weed pressure was a problem for organic soybean in 2018 when wet conditions hampered mechanical weeding. Flame cultivation in corn was very effective in organic corn for 2019, reducing weed pressure near to zero, similar to conventional corn (not shown). Karlen et al. (2007) documented weed pressure in organic soybean. Posner et al. (2008) observed weed pressure in both organic soybean and corn when there was a wet spring.

4 | CONCLUSIONS

In the fall of 2017–2019, organic forage used more water than the 4-yr organic rotation, which used more water than the 2-yr conventional rotation. The same trend was shown for the spring of 2017 and 2019, but not in 2018 due to soil disturbance. Three of the four years had wet periods within the growing season, so using more water might be useful in reducing flooding, runoff, and leaching. The other year was dry, so extra water use might not be as useful.

Generally increased seasonal water use resulted in increased yield for corn and soybean. Conventional corn had higher yield than organic for 3 of 8 yr. Other factors affecting yield could be the more available synthetic N applied in conventional corn plots. Conventional soybean had higher yield than organic for 2 of 8 yr and lower yield for 1 yr. Weedy grass was inversely correlation with LAI of corn on 3 of 10 measurement dates and for soybean on 5 of 10 measurement dates, but broadleaf weeds only on one date for soybean.

Overall, this study showed that organic agricultural systems have positive benefits for timing of water use and, in some years, have comparable yields to conventional corn and soybean. Dry years or years with weed pressure sometimes resulted in lower yields in the organic system.

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AUTHOR CONTRIBUTIONS

Sally D. Logsdon: Formal analysis; Investigation; Methodology; Resources; Software; Visualization; Writing-original draft; Writing-review & editing. Cindy Cambardella: Conceptualization; Funding acquisition; Investigation; Project administration; Resources. Kathleen Delate: Funding acquisition; Project administration; Writing-review & editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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