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Agronomic and Economic Performance of Maize, Soybean, and Wheat in Different Rotations during the Transition to an Organic Cropping System

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Abstract: Crop producers transitioning to an organic cropping system must grow crops organically without price premiums for 36 months before certification. We evaluated red clover-maize, maize-soybean, and soybean-wheat/red clover rotations in organic and conventional cropping systems with recommended and high inputs in New York, USA to identify the best rotation and management practices during the transition. Organic compared with conventional maize with recommended inputs in the maize-soybean rotation (entry crop) averaged 32% lower yields, $878/ha higher production costs, and $1096/ha lower partial returns. Organic maize compared with conventional maize with recommended inputs in the red clover-maize rotation (second transition crop) had similar yields, production costs, and partial returns. Organic compared with conventional soybean with recommended inputs in soybean-wheat/red clover or maize-soybean rotations had similar yields, production costs, and partial returns. Organic compared with conventional wheat with recommended inputs in the soybean-wheat/clover rotation had similar yields, $416/ha higher production costs, and $491/ha lower partial returns. The organic compared with the conventional soybean-wheat/red clover rotation had the least negative impact on partial returns during the transition. Nevertheless, all organic rotations had similar partial returns ($434 to $495/ha) so transitioning immediately, regardless of entry crop, may be most prudent. High input management did not improve organic crop yields during the transition.

Keywords: organic cropping system; maize; soybean; wheat; partial returns

1. Introduction

Organically-produced maize (*Zea mays* L.), soybean {*Glycine max* (L.) Merr.} and wheat (*Triticum aestivum* L.) have substantial price premiums, providing market incentives for organic production. Downward trends in prices of all three crops have prompted some crop producers, who practice maize-soybean or maize-soybean-wheat/red clover (*Trifolium pretense* L.) rotations, to contemplate transitioning from conventional to an organic cropping system. The United States Department of Agriculture (USDA), however, requires a 36-month transition period that prohibits the use of genetically modified (GM) crops, synthetic fertilizer, pesticides, etc., before the land can be certified as organic and eligible for the organic price premium [1]. Furthermore, comprehensive survey data indicated that organic compared with conventional maize, soybean or wheat production, despite higher profits, had lower yields and higher/ha production costs [2]. Consequently, a major deterrent for conventional crop producers who wish to transition to an organic cropping system is the potential loss of significant profit during the transition. Identification of the best entry crop (first year transition crop) and subsequent rotation during the transition to an organic cropping system is essential for maintaining cash flow on the farm, especially given the relatively low cash receipts received by maize, soybean and wheat growers in recent years [3].

Numerous studies comparing organic and conventional cropping systems have been conducted. In a study established in 2002 near Morris, Minnesota, USA, organic compared with conventional maize yielded 34% lower, whereas organic compared with conventional soybean yielded statistically similar (but 15% numerically lower) from 2002–2005 when comparing 2-year conventional and organic maize-soybean rotations [4]. Organic maize yielded lower mostly due to lack of available soil N, associated with low N content of the solid dairy manure applied to organic maize. Despite $425/ha lower seed, fertilizer and pesticide costs, the 2-year organic compared with the 2-year conventional rotation had $128/ha higher production costs associated with higher labor, diesel, manure hauling, and machinery ownership costs. Consequently, the organic compared with the 2-year conventional rotation had $511/ha lower net present value during the transition because of lower yields, higher production costs, and the absence of an organic premium [4].

In this same study, the entry crop into an organic cropping system had a major impact on risks and returns during the transition phase [5]. Based on yield data and inputs from the same study, soybean as the entry crop provided a $283 advantage of net present value compared with maize in the maize-soybean organic rotation. In the 4-year organic rotation, wheat as the entry crop provided a $229 advantage over other entry crops [5]. Nevertheless, a simple dynamic adoption model indicated that transitioning to an organic cropping system as rapidly as possible, regardless of the entry crop, would result in the highest expected long-term profit [5].

In another Minnesota study established near Lamberton, organic maize in a maize-soybean-oat (*Avena sativa* L.)/alfalfa-alfalfa (*Medicago sativa* L.) rotation yielded similarly as conventional maize in a maize-soybean rotation from 1993–2009 [6]. Organic compared with conventional soybean, however, yielded 25% lower in their respective rotations over the same period. Organic compared with conventional maize, despite higher machinery costs, had $86/ha lower production costs because of lower seed costs as well as no herbicide costs [7]. Likewise, organic compared with conventional soybean had $101/ha lower production costs, primarily because of lower weed control costs. When factoring in the organic price premium (2.17 price ratio for maize and 2.27 for soybean), the 4-year organic rotation had $527 net revenue compared with $295 for the 2-year conventional rotation [7].

Machinery ownership costs, however, were not included in the first analyses of this study. When comparing the 4-year organic rotation with the 2-year conventional rotation, machinery ownership costs averaged $146/ha across organic farm sizes of 130, 225 and 325 ha compared with $183/ha across conventional farm sizes of 225, 455, and 630 ha [8]. The organic rotation had net returns of $114,000 compared with conventional net returns of $72,000 for a 225-hectare farm [8]. The organic rotation also had net returns of $296,000 for the largest farm size (325 ha), compared with conventional net returns of $220,000 for its largest farm size (630 ha), despite the farm-scale advantage for conventional production.

In a study established in 1990 in Wisconsin, USA, a no-till (NT) conventional maize-soybean rotation compared with an organic maize-soybean-wheat rotation averaged $130 and $408 higher economic mean returns, respectively, in the absence of organic premiums [9]. In the presence of government payments and organic premiums, the organic maize-soybean-wheat rotation had $321 and $165 higher economic mean returns, respectively, compared with the conventional NT maize-soybean rotation [9]. The conventional NT maize-soybean rotation yield trend, however, averaged 151 kg/ha/year compared with 101 kg/ha/year for the organic maize-soybean-wheat rotation from 2009 to 2012 [10], perhaps because of technological advances in the conventional cropping system and/or increased weed competition in the organic cropping system.

In a cropping system study established in 1996 in Maryland, USA, organic maize in a maize-soybean-wheat/vetch (*Vicia vilossa* Roth) rotation yielded 28% lower compared with conventional NT maize in a maize-soybean-wheat/soybean rotation during the transition years from 1996 to 1998 [11]. After the transition period, organic compared with conventional maize yielded 40% lower in their respective 3-crop rotations [11]. The lower organic maize yields were associated mostly with low soil N availability (73%) and weed competition (23%). After the transition period, organic soybean compared with NT conventional soybean yielded 24% lower in their respective 3-crop rotations because of greater weed competition [11]. In the 3-year period (2000–2002) following the transition, the organic compared with the conventional cropping system, despite lower maize and soybean yields, had $514/ha greater net returns [11]. Economic risk in the 3-year organic system, however, was 3.9 times greater compared with a 6-year organic rotation (maize/rye (*Secale cereale* L.)-soybean-wheat-alfalfa-alfalfa-alfalfa).

In a study, established in Iowa, USA, maize and soybean in an organic maize-soybean-oat/alfalfa-alfalfa rotation compared with a conventional maize-soybean rotation yielded similarly during the transition [12], resulting in higher profitability for the organic cropping system because of lower production costs [13]. In the second phase of the study, maize and soybean again yielded similarly between cropping systems so the organic cropping system was far more profitable because of lower production costs in maize and higher prices received for organic maize and soybean [14].

Long-term cropping system experiments, though beneficial, are somewhat limited in the analyses of conventional vs. organic cropping systems because management practices are fixed, and the "human" management factor of organic production is missing [2]. Agricultural Resource Management Survey (ARMS) data from 2010 was used for maize (794 conventional and 451 organic farms); 2009 ARMS data for wheat (1641 conventional and 1458 organic farms); and 2006 ARMS data for soybean (748 conventional and 478 organic farms) to compare conventional and organic crop production [2]. Organic maize, soybean, and wheat had higher economic costs ($205 to $242/ha; $261 to $309/ha; and $135 to $153/ha higher, respectively) because increased costs for fuel, repair, capital, and labor offset lower seed, fertilizer and chemical costs. Furthermore, organic maize, soybean, and wheat compared with conventional crops yielded much lower (27%, 34%, and 32%, respectively). Consequently, organic compared with conventional producers had higher average economic costs per metric ton or Mg ($76 to $89/Mg, $143 to $164/Mg, and $243 to $287/Mg higher, respectively). Nevertheless, net economic returns were greater for organic compared with conventional maize and soybean producers ($126 to $163/ha, and $54 to $101/ha higher, respectively) because of the organic price premiums (~2.85 and ~2.25 ratios, respectively). Net economic returns for organic compared with conventional wheat, however, were slightly lower ($−5 to $−23/ha), despite the organic price premium (~2.4 price ratio). The survey data indicate that the price premium is crucial for profitability in organic maize, soybean, and wheat production because of lower yields and higher production costs.

A major deterrent to adoption of organic crop production is the uncertainty associated with selection of the best first year transition (entry) crop and subsequent rotation during the 36-month period when organic premiums do not exist [5]. Another deterrent is that novice organic crop producers are uncertain of the best organic management practices to use during the transition and beyond [5]. Two objectives of this study are: (a) to identify the best entry crop and subsequent organic rotation that results in the best partial economic returns to the organic cropping system during the transition, and (b) to evaluate recommended and high input organic management practices (organic seed treatment, and high seeding and high N rates) to determine if high input management increases weed competitiveness and improves soil N availability for organic crops.

2. Materials and Methods

We initiated a 4-year cropping system study at a Cornell University research farm near Aurora, NY, USA (42°44′ N, 76°40′ W) in 2015 to evaluate different sequences of the maize-soybean-wheat/red clover rotation. Winter wheat was not planted in the fall of 2014 before the onset of the study. Instead, red clover was seeded in mid-July of 2015 into bare soil to insure a green manure crop for the subsequent maize crop in 2016. Our three sequences during the transition thus included red clover-maize, soybean-wheat/red clover, and maize-soybean in 2015 and 2016 when organic crops were not eligible for an organic price premium. The 36-month transition period consisted of only two growing seasons in this study because the previous crops before the transition did not receive any prohibited inputs after June of 2014. Thus the 2017 crops were eligible for the organic price premium because they were harvested in July (wheat), October (soybean) and November (maize).

Three contiguous experimental fields (220 m × 40 m) with similar tile-drained silt loam soil (fine-loamy, mixed, mesic, Glossoboric Hapludalfs) but different previous crops in 2014 (spring barley, maize, and soybean) were used in the study. The experimental design is a split-split plot (four replications) with previous crops as whole plots, cropping systems (conventional and organic) as sub-plots, and management inputs (recommended and high inputs) as sub-sub plots. The entire 40 m lengths were planted to maize, soybean or winter wheat in each field, but plot length was shortened to 30 m to allow for 5 m borders on the north and south sides of the plots. Also, 3 m borders were inserted between sub-plots (cropping systems) to minimize spray drift or fertilizer movement from conventional into organic plots. Likewise, 3 m border plots were inserted between each sub-subplot to minimize border effects from each crop, which differed in height. To ensure that the 3 m border plots between sub-plots were adequate to minimize spray drift from conventional to organic plots, we only sprayed the conventional plots early in the morning when wind speed was less than 5 km/h. We did not plan to market the crops produced organically as organic in future years, so the 5 m borders were adequate for our study. Whole plot dimensions were 216 m wide and 30 m long, sub-plot dimensions were 27 m wide and 30 m long, and sub-subplot dimensions were 3 m wide and 30 m long.

Maize and soybean strips were moldboard plowed from 18–20 May in both years, followed by secondary tillage the following day. Maize and organic soybean were planted in 0.76 m row spacing immediately after secondary tillage in both years. Conventional soybean strips were also planted on the same day but in the typical 0.38 m row spacing. The maize and soybean planting dates, which were delayed so some early-season weeds could emerge before plowing in the organic cropping system, were just after the optimum planting dates for both crops (25 April–20 May for maize and 6 May–17 May for soybean) at this site.

Table 1 lists the management inputs for maize, soybean, and wheat for both years. Major differences between conventional and organic maize include (a) a treated (insecticide/fungicide seed treatment) GM (genetically modified) hybrid, P9675AMXT (Optimum®AcreMax®XTreme), with the AMXT, LL (Liberty Link) and RR2 (Roundup Ready 2) traits, versus the non-GM isoline, P9675 (no seed treatment in recommended input but an organic seed treatment, Sabrex, mixed in the seed hopper in the high input treatment), (b) 280 kg/ha of 10-20-20 (N-P-K analysis, respectively) versus 365 kg/ha of composted manure (5-4-3 analysis) as starter fertilizer, (c) 135 to 180 kg N/ha side-dressed in 2015 and 0 to 56 kg N/ha when following red clover in 2016 (recommended and high input treatments, respectively) with a liquid N source (32-0-0 analysis) versus the same N rates in organic maize with composted chicken manure applied pre-plant and (d) a single Glyphosate herbicide application for weed control in conventional versus tine weeding, followed by a close cultivation to the row, followed by two additional cultivations between the rows for organic maize. We estimated that 50% of the N from the composted poultry manure would be mineralized and available to organic maize. Seeding rates of 73,000 kernels/ha were used in recommended input and 86,500/ha in high input treatments of both cropping systems. We selected a non-GM isoline for organic maize instead of an organically developed and produced hybrid so we could determine how management practices (and not hybrid selection) affected yield and partial returns.

Table 1. Soil texture/drainage, planting rate, hybrid/cultivar, tillage, starter and N fertilizer practices, and weed control practices for maize, soybean, and wheat in conventional and organic cropping systems with two management treatments (recommended and high input) at a Cornell Research Farm near in central NY in 2015 and 2016.

Descriptor	Crop					
	Maize		Soybean		Wheat	
	Rec.	High	Rec.	High	Rec.	High
	Conventional					
Soil texture/Drainage	Well- drained silt loam					
Planting rate (seeds/ha)	73,100	87,700	370,500	494,000	2,964,000	4,200,000
Seed Treatment	Fungicide/insecticide		Fungicide/insecticide		Fungicide/insecticide	
Cultivar	GM hybrid	GM hybrid	GM variety	GM variety	Soft white (P24R46)	Soft white (P24R46)
Tillage	Moldboard Plow		Moldboard Plow		No-Till	
Starter Fertilizer (kg/ha)	280 kg/ha (10-20-20)		None		225 kg/ha (10-20-20)	
N fertilizer-side-dress (kg N/ha)	2015: 90–160 kg N/ha (liquid) 2016: none	2015: 135–200 kg N/ha (liquid) 2016: 56 kg N/ha	None	None	80 kg N/ha (33-0-0)	56 + 56 kg N/ha (33-0-0)
Herbicide application	Glyphosate	Glyphosate	Glyphosate	Glyphosate	None	Yes
Fungicide application	None	None	None	Yes	None	Yes
	Organic					
Soil texture/Drainage	Well- drained Honeoye silt loam					
Planting rate (kernels/acre)	73,100	87,700	370,500	494,000	2,964,000	4,200,000
Seed Treatment	None	Organic	None	Organic	None	Organic
Cultivar	Non-GM Isoline	Non-GM Isoline	Non-GM variety	Non-GM variety	Soft white (P24R46)	Soft white (P24R46)
Tillage	Moldboard Plow		Moldboard Plow		No-Till	
Starter Fertilizer	350 kg/ha composted chicken manure (5-4-3)		None		170 kg N/ha composted chicken manure (5-4-3)	
Pre-plant N fertilizer (kg N/ha)	2015: 90–160 kg N/ha composted manure 2016: none	2015: 56–200 kg N/ha composted manure 2016: 56 kg	None	None	80 kg N/ha composted manure	56 + 56 kg N/ha composted manure
Tine weeding	1×		1×		None	
Cultivate	3×		4×		None	

Maize was harvested with a small plot Almaco combine (Nevada, IA, USA) in November in both years when grain moistures were ~18%. An approximate 1000 g sample was collected from each sub-subplot to determine grain moisture and grain N% concentrations (by combustion with a LECO CN628 Nitrogen Analyzer, LECO Corporation, St. Joseph, MI, USA). Yields were adjusted to 15.5% moisture. Grain moisture differences were less than 1% between cropping systems so will not be reported.

Major differences between conventional and organic soybean include (a) treated (insecticide/fungicide seed treatment) GM variety, P22T41R2 with the RR2Y and SCN traits versus a non-GMO variety, 92Y21 (organic seed treatment mixed in the seed hopper of the high input treatment), (b) 0.38 m versus 0.76 m row spacing (for cultivation of weeds in organic soybean), and c) a single Glyphosate herbicide application for weed control versus tine weeding, followed by close cultivation to the row, followed by three additional cultivations between the rows, respectively (Table 1). Seeding rates of 370,500 and 494,000 seeds/ha were used for recommended and high input treatments in both cropping systems. Conventional soybean in the high input treatment also received a fungicide (Fluxapyroxad + Pyraclostrobin at ~300 mL/ha) application at the early pod stage (R3 stage) in late July for potential disease problems and overall plant health. We did not fertilize soybean because conventional soybean growers typically do not use fertilizer on soybean.

Soybean was harvested on 23 September 2015 at ~11% moisture wheat was no-tilled into soybean stubble with a 1590 John Deere no-till drill (Molina, IL, USA) in 0.19 m rows the following day in 2015. We decided to no-till wheat because of the paucity of visible weeds, especially winter perennial weeds, in both cropping systems. Soybean developed green stem in 2016 and was not harvested until November 9, too late to plant wheat after soybean in this environment.

Major differences between conventional and organic wheat include (a) a treated (insecticide/fungicide seed treatment) soft red winter wheat variety, 25R46, versus the untreated 25R46, (b) 225 kg/ha of 10-20-20 (N-P-K analysis) versus 175 kg/ha of composted chicken manure (5-4-3, N-P-K analysis) as starter fertilizer, (c) and top-dressing with 80 kg N/ha in late March or 56 kg N/ha in late March + 56 kg N/ha in late April in the recommended and high input treatments, respectively with ammonium nitrate (33-0-0) versus 80 kg N/ha (late March) or 56 kg N/ha (pre-plant) + 56 kg N/ha in late April in recommended and high input treatments, respectively with composted chicken manure (Table 1). We also applied an herbicide (thifensulfuron + tribenuron) in the fall and a fungicide (Prothioconazole + Tebuconazole) in the spring in high input conventional wheat. We frost-seeded red clover at ~30 kg/ha into all the wheat treatments in early March to provide N to the subsequent maize crop in 2017. Wheat was harvested on 7 July of 2016.

Maize densities were taken immediately before tine weeding (~1–2 days after 90% emergence) and again at the 9th leaf or V9 stage, after the completion of mechanical weed control practices, by counting all the plants along the 30 m plot length of the two harvest rows. The first maize density measurement was taken to determine if the treated GMO maize hybrid and non-treated non-GMO maize isoline differed in emergence rates and plant establishment. The second measurement was taken to determine the extent of maize damage by mechanical weed control practices (tine weeding, a close cultivation, and three in-row cultivations) in organic maize. Soybean densities were also taken immediately before tine weeding (~1–2 days after 90% emergence) to determine emergence rates and again a few days before harvesting to determine final soybean densities by counting all the soybean plants in three 1.52 m^2 regions along the 30-m harvest rows (2 center rows in organic soybean and 4 center rows in organic soybean). Weed densities were determined in maize by counting all the weeds taller than 5 cm in height along the 30 m length of the two harvest rows at the V14 stage, the end of the critical weed-free period for maize in this environment [15]. Weed densities were also determined in soybean by counting all visible weeds along the 30 m length of the entire 3.3 m wide soybean plot at the pod-filling stage (R4 stage), the end of the critical weed-free period for soybean in this environment. Predominant weed species in both crops included *Polygonum convovulus*, *Chenopodium album*, *Echinochloa crus-galli*, *Polygonum pensylvanicum* L., *Setaria vidis*, *Ambrosia artemisifolia* and *Amaranthus retroflexus.*

Wheat densities were taken about a week after emergence by counting all wheat plants in three 1.52 m^2 regions along the 30-m harvest rows (8 center rows). Weed densities were also determined in wheat by counting all visible weeds along the 30 m length of the entire 3.3 m wide wheat plot in early April, during the active spring tillering period in this environment. Predominant weed species, which not differ among previous crops or between cropping systems, included *Taraxacum officinale* F.H. Wigg, *Malva neglecta* Wallr., *Stellaria media* (L.) Vill., and *Lamium amplexicaule* L. Wheat was harvested with a small plot Almaco combine (Nevada, IA, USA) in early July. An approximate 1000 g sample was collected from each sub-subplot to determine grain moisture and grain N concentrations by combustion (LECO CN628 Nitrogen Analyzer, LECO Corporation, St. Joseph, MI, USA). Yields were adjusted to 13.5% moisture.

Costs for the different management inputs for the three crops in the two cropping systems are listed in Table 2. Production costs for organic maize and wheat will be somewhat inflated because of the use of composted chicken manure as the major N source (~13× higher cost/kg of N compared with liquid N in conventional maize and ammonium nitrate in wheat). We used composted chicken manure in organic maize and wheat because of its known analyses of N-P-K and its ease in calibration and application with a fertilizer spreader. We wished to avoid the problems with the use of solid animal manure in previous studies, which did not accurately estimate the N content [4,8]. Also, conventional maize received only a single application of Glyphosate compared with the typical two or more herbicide applications used by most growers because moldboard plowing reduced the need for supplemental weed control chemicals. Most maize growers use reduced tillage or no-till, which results in more chemical use and higher weed control costs. Our weed control costs were thus significantly lower than typical in conventional maize. Consequently, production costs are skewed in favor of conventional maize and wheat.

Table 2. Costs of variable inputs, including seed, hopper seed treatments, (inoculant for conventional soybean and Sabrex for organic crops), starter fertilizer, N fertilizer, herbicide, and fungicide in conventional and/or organic soybean, maize, and wheat.

Input	Conventional	Organic
	$	
	Soybean	
Seed/140,000	81.95 (including seed treatment)	50.95
Seed Treatment	48.80/g (Cell-Tech inoculant)	200/g (Sabrex)
Herbicide	280/L (Glyphosate)	-
Fungicide	2130/L (Fluxapyroxad + Pyraclostrobin)	-
	Maize	
Seed/80,000	330 (including seed treatment)	240
Seed Treatment	-	200/g (Sabrex)
Starter Fertilizer	448/tonne (Mg)	325/tonne (Mg)
Side-dress N	0.99/kg N	12.76/kg N
Herbicide	280/L (Glyphosate)	-
	Wheat	
Seed/bag	31 (including seed treatment)	24
Seed Treatment	-	200/g (Sabrex)
Starter Fertilizer	448/tonne (Mg)	325/tonne (Mg)
Herbicide	276/mL	-
Top-dress N	0.99/kg N	12.76/kg N
Fungicide	1325/L (Prothioconazole + Tebuconazole)	-

Soybean prices received by NY farmers averaged $0.345/kg in 2015 and 2016, maize prices averaged $0.156/kg in 2015 and 2016, and the wheat price averaged $0.149/kg in 2016 [16]. Economic analyses focused on enterprise budget items that differed among the treatments, namely the value of production associated with yield differences as well as cost differences for inputs for maize, soybean and wheat. Returns to variable and fixed inputs that do not differ between conventional and organic soybean production under recommended and high input management were calculated for the three crops. Our selected variable inputs include: Seed, fertilizer, and other inputs (inoculant, organic seed treatment, herbicide, and fungicide); labor and machinery operating inputs (repairs and maintenance, fuels and lubricants), excluding tillage, planting and harvesting tasks, except for hauling, where hauling cost is a function of yield [17]. Cost of production values reported for fixed inputs exclude farm machinery ownership costs for tillage, planting and harvest, land charges, and values of management inputs. Grain moistures did not differ between organic and conventional maize, and grain drying is not required for soybean and wheat, so we did not include those production costs in maize.

Previous crop (2014 crops), cropping systems (conventional and organic), and management inputs (recommended and high) were considered fixed and replications m (and years) random for statistical analyses for individual years and averaged across years using the REML function in the MIXED procedure of SAS (version 9.4; SAS Institute Inc., Cary, NC, USA). For statistical analyses of the partial returns data for the 2-year transition, rotations were considered a fixed variable and a sub-sub plot within cropping systems. Fields with different previous crops (2014 crops) had yield differences for maize and soybean in 2015 but did not have any interactions with cropping systems and rotations. Consequently, the data will be pooled across previous crops (the three contiguous fields) for each year. Least square means of the main effects (cropping system and management inputs) were computed and means separations were performed on significant effects using Tukey's HSD (Studentized Range) test, with statistical significance set at $p < 0.05$. Differences among least square means for cropping system interactions were calculated also using Tukey's HSD test. Two-way interactions (cropping system by management inputs) were detected for some variables so the interaction comparisons will be presented. Simple correlations (Pearson) among all measurements within each year were calculated using CORR in SAS.

3. Results and Discussion

3.1. Agronomic

Table 3 shows the agronomic maize data for 2015 and 2016. Organic compared with conventional maize in the maize-soybean rotation yielded 32% lower as an entry crop in 2015 when averaged across management input treatments. Organic compared with conventional maize had ~8% lower plant densities at the 9th leaf stage (V9), when all cultivations to organic maize had been completed, mostly due to cultivation damage [18]. Despite the close and repeated cultivations, organic compared with conventional maize had almost 5x higher weed densities. In addition, organic maize had very low grain N% concentrations (1.06%) compared with conventional maize (1.32%). Excessive precipitation (276 mm) from planting on 21 May to silking on 27 July probably leached or denitrified a considerable amount of the N in the pre-plow application of composted chicken manure [18].

In contrast, the experimental site received 98 mm of precipitation from the side-dressing N application (26 June) to silking, allowing for most of the side-dressed N to be available to conventional maize. Grain yield had a strong positive correlation with grain N% concentrations ($r = 0.81$, $n = 48$) and a strong negative correlation with weed densities ($r = -0.78$, $n = 48$). These results agree with findings that have reported lower organic maize yields during the transition because of limited soil N availability and weed competition [4,11].

In 2016, however, organic maize as the second-year transition crop in the soybean-maize rotation yielded similarly as conventional maize and input management did not influence yields. Maize yields were very low, however, because of exceedingly dry conditions from April through July (222 mm), which greatly reduces maize yields in northern latitudes of the USA [19]. It was also the driest (75 mm) 19 May (planting date) through 20 July (silking date) period in 61 years of record keeping at the experimental site [19]. Maize and weed densities were much lower in 2016 compared with 2015 undoubtedly because the exceedingly dry soil conditions reduced maize and weed emergence. Grain N% concentrations, however, were much greater because there was no leaching or denitrifying of applied N, as well as the concentration effect of grain N% associated with low yields. Grain yield did not correlate with weed densities nor grain N concentrations in 2016. Grain yield did correlate with maize densities (r = 0.45, n = 48) because plant densities were below threshold plant densities where yields decline, even in dry years [19].

Table 3. Maize densities at the 9th leaf stage (V9), weed densities at the V14 stage, yield, grain N content and revenue of maize in 2015 in 2016 under conventional and organic cropping systems at recommended and high input management in central NY.

	Year		
Treatment	**2015**	**2016**	**Mean**
	Maize densities-V9 stage (plants/ha)		
Conventional			
Recommended	72,158 b [+]	56,566 c	64,362 c
High Input	86,391 a	65,606 a	75,999 a
Organic			
Recommended	64,750 c	51,472 d	58,111 d
High Input	80,819 ab	60,648 b	70,734 b
	Weed densities-V14 stage (weeds/m^2)		
Conventional			
Recommended	0.47 a	0.27 b	0.37 a
High Input	0.39 a	0.18 b	0.29 a
Organic			
Recommended	2.41 b	0.99 a	1.70 c
High Input	2.13 b	0.64 a	1.39 b
	Yield (kg/ha)		
Conventional			
Recommended	10,321 a	7156 a	8739 a
High Input	10,545 a	7783 a	9164 a
Organic			
Recommended	6905 b	7093 a	6999 b
High Input	7281 b	7156 a	7219 b
	Grain N (%)		
Conventional			
Recommended	1.32 a	1.56 ab	1.44 a
High Input	1.33 a	1.68 a	1.51 a
Organic			
Recommended	1.05 b	1.51 b	1.28 b
High Input	1.06 b	1.61 a	1.34 b
	Revenue ($/ha)		
Conventional			
Recommended	1611 a	1116 a	1364 a
High Input	1645 a	1214 a	1430 a
Organic			
Recommended	1077 b	1107 a	1092 b
High Input	1136 b	1116 a	1127 b

[+] Treatment interaction means within the same column followed by the same letter are not significantly different according to Tukey's HSD (Studentized Range) test at the 0.05 level.

Table 4 shows the agronomic data for soybean in 2015 (soybean-wheat/red clover rotation) and 2016 (maize-soybean rotation). Organic and conventional soybean with recommended inputs yielded similarly in both years, but there was a cropping system × management input interaction in 2015.

Organic soybean did not respond to high inputs, but conventional soybean showed a 9% yield increase in 2015. Conventional soybean with recommended inputs had plant densities above the threshold for maximum yield in this environment [20] and very low weed densities so neither should have contributed greatly to the yield increase in the high input treatment in 2015. Nevertheless, seed yields in 2015 had a weak correlation with plant densities ($r = 0.31$, $n = 48$) and a weak negative correlation with weed densities ($r = -0.36$, $n = 48$). There was a cropping system × input management interaction for seed mass in 2015 with a 6 mg increase in seed mass for conventional soybean with high inputs, but no increase in seed mass for organic soybean with high inputs. The fungicide application to high input conventional soybean may have improved overall plant health resulting in greater seed mass and the 9% yield increase. Seed yield did not correlate with soybean densities or weed densities during the dry 2016 growing season. The organic soybean yield data agree with a Minnesota, USA study that showed that organic and conventional soybean yielded similarly during the transition [4].

Table 4. Harvest plant densities, weed densities at the full pod stage (R4), seed yield, and revenue of soybean in 2015 and 2016 under conventional and organic cropping systems at recommended and high input management in central NY.

	Year		
Treatment	**2015**	**2016**	**Mean**
	Soybean densities (plants/ha)		
Conventional			
Recommended	307,967 c +	318,167 c	313,067 c
High Input	417,912 a	442,750 a	429,971 a
Organic			
Recommended	338,083 b	284,667 d	311,375 c
High Input	419,258 a	383,250 b	401,254 b
	Weed densities-R4 stage (weeds/m^2)		
Conventional			
Recommended	0.24 a	0.44 a	0.34 b
High Input	0.11 a	0.27 a	0.19 b
Organic			
Recommended	0.40 a	0.77 b	0.58 a
High Input	0.61 a	0.60 ab	0.60 a
	Yield (kg/ha)		
Conventional			
Recommended	2977 b	2711 a	2844 a
High Input	3239 a	2806 a	3023 a
Organic			
Recommended	2851 b	2631 a	2741 a
High Input	2952 b	2655 a	2804 a
	Revenue ($/ha)		
Conventional			
Recommended	1005 b	960 a	982 a
High Input	1093 a	994 a	1044 a
Organic			
Recommended	962 b	939 a	951 a
High Input	996 b	932 a	964 a

+ Treatment means within the same column followed by the same letter are not significantly different according to Tukey's HSD (Studentized Range) test at the 0.05 level.

Table 5 shows the agronomic data for wheat in 2016. Wheat yields also had a cropping system x management input interaction. Organic wheat as the second-year transition crop in the soybean-wheat/red clover rotation yielded 11.5% lower than conventional wheat with recommended inputs. Conventional and organic wheat yielded the same with high inputs not because organic wheat responded to high inputs but because conventional wheat showed an 8.7% yield decrease with high inputs. It is not clear why conventional wheat yields actually declined with the use of high inputs. Yields were low because dry conditions (150 mm of precipitation, prevailed from the early tillering stage (1 April) until harvest (7 July). Surprisingly, organic compared with conventional wheat in the recommended input treatment had greater early plant establishment and fewer fall and spring weeds (Table 5). Conventional wheat, however, had an average grain N% of 2.03% compared to only 1.66% N in organic wheat, suggesting less available soil N for organic wheat. Grain yield, however, did not correlate with grain N% probably because dry soil conditions and not soil N availability was the major yield driver in 2016.

Table 5. Percent stand (early plant establishment), spikes/m^2 at harvest, weed densities in the early spring, grain yield, grain N%, and revenue of wheat in 2015–2016 under conventional and organic cropping systems at recommended and high input management in central NY.

	Wheat-2016		
Treatment	**Stand/%**	**Spikes/m^2**	**Weeds/m^2**
Conventional			
Recommended	88 b +	500 a	0.46 a
High Input	78 c	509 a	0.01 b
Organic			
Recommended	98 a	503 a	0.05 b
High Input	99 a	563 b	0.04 b
	Yield (kg/ha)	**Grain N (%)**	**Revenue ($/ha)**
Conventional			
Recommended	4314 a	1.95 b	642 a
High Input	3938 b	2.11 a	586 b
Organic			
Recommended	3817 b	1.65 c	568 b
High Input	3828 b	1.66 c	570 b

+ Treatment means within the same column followed by the same letter are not significantly different according to Tukey's HSD (Studentized Range) test at the 0.05 level.

3.2. Economic

Maize revenue, a direct function of yield, had similar statistical relationships as yield so conventional compared with organic maize generated more revenue in 2015, but similar revenue in 2016 (Tables 3 and 6). Organic compared with conventional maize, averaged across the 2 years, had higher selected production costs when comparing their respective recommended and high input management treatments because of higher variable and fixed costs (Table 6). As expected, organic compared with conventional maize had lower seed costs because of the lack of seed treatment and GM traits. Organic compared with conventional maize, however, had higher fertilizer costs because of the much greater cost for composted chicken manure relative to conventional starter fertilizer and N fertilizer. A green manure crop was not in place for the 2015 maize crop so most of the composted chicken manure as an N source was applied in 2015 (none to the recommended input treatment and 56 kg N/acre in the high input treatment in 2016). Most organic crop producers in New York, USA do not use composted manure as an N source but rather use solid manure from their own livestock or from a neighbor's livestock, which is far less expensive. Organic compared with conventional maize also had higher labor, repair and maintenance, and fuel and lubricant costs because of the 4-time use of labor and equipment for mechanical weed control in organic maize compared with the 1-time use of labor and equipment for herbicide application in conventional maize. Organic compared with conventional maize thus had higher total selected variable costs ($190 to $687 in recommended and high input treatments, respectively).

Organic compared with conventional maize also had greater fixed costs because of greater wear and tear with the 4-time use of tractors and equipment for weed control purposes. Overall, organic compared with conventional maize had much higher total selected costs ($248 and $744/ha higher in recommended and high input treatments, respectively) compared to a Minnesota, USA study ($87/ha lower organic maize production costs) that used solid dairy manure [4]. In 2016, when composted chicken manure was not applied to organic maize with recommended inputs as an N source, organic compared to conventional maize had $75/ha lower total selected costs, similar to the Minnesota study.

Table 6. Income, selected costs, and partial returns for conventional maize with recommended management (M1) and high input management (M2), and organic maize with recommended management (M3) and high input management (M4) at a Cornell Research Farm in central NY averaged across the 2015 and 2016 growing seasons [1].

	Maize Treatments			
Production Value, Income	**M1**	**M2**	**M3**	**M4**
	$/ha			
Grain	1364	1430	1092	1127
Selected Production Costs [1]				
Variable Inputs				
Fertilizers	194.92	240.51	455.57	992.63
Seeds	301.07	360.84	219.07	262.49
Sprays & Other Crop Inputs	106.53	143.10	79.81	124.25
Labor	1.16	1.16	20.87	20.87
Repairs & Maintenance				
Tractor	0.22	0.22	5.53	5.53
Equipment	0.86	0.86	6.07	6.07
Fuels & Lubricants	0.73	0.73	12.09	12.09
Interest on Operating Capital	13.38	17.54	9.75	28.26
Total Selected Variable Input Costs	618.37	764.96	808.76	1452.1
Fixed Inputs				
Tractors	1.60	1.60	32.80	32.80
Equipment	4.47	4.47	30.23	30.23
Land charge	-	-	-	-
Value of management	-	-	-	-
Total Selected Fixed Input Costs	6.07	6.07	63.03	63.03
Total Selected Costs	624.44	771.03	871.79	1515.2
Partial Returns	739	659	220	−388

[1] This reporting of costs focused on those costs that differed among the four maize treatments. The land charge, and value of management input did not differ among treatments, so items are blank. Likewise, grain moistures did not differ among treatments so drying costs are not included. Seed costs differed among treatments due to price per unit differences between non-GMO and GMO hybrids, and seeding rate differences for recommended versus high input management. Spray and other crop inputs that differed included pest and disease management materials, and hauling as a function of yield. Labor costs reported included only those attributed to sprays for treatments C1 and C2, and those attributed to weeding tasks for C3 and C4. Labor costs reported do not include labor associated with tillage, planting and harvesting tasks considered constant, not differing among treatments. Similar explanations underlie estimates for the remaining cost items that differ. Costs for M3 and M4 were much higher in 2015 compared with 2016 because the use of composted chicken manure as an N source in 2015 vs. red clover in 2016.

Conventional compared with organic maize had much greater partial returns in 2015 because of higher yields and lower production costs (Table 7). If cash flow is of a major concern to the grower, maize should not be the entry crop in the transition to organic crop production unless there is animal manure on the farm (or close by) or a green manure crop in place. In 2016, when maize followed red clover, partial returns had a cropping system × management input interaction. Organic and conventional maize with recommended inputs had similar partial returns. In contrast, organic maize with high inputs (organic seed treatment, high seeding rates and 56 kg N/ha of composted manure), had lower partial returns compared with both conventional maize input treatments. Again, the 13× higher N/kg cost of composted chicken manure is almost solely responsible for the lower partial returns of organic maize with high input management. Organic maize with recommended inputs, which only received composted chicken manure as a starter fertilizer, had greater partial returns compared with conventional maize with high inputs, a management practice frequently used by conventional growers. If the grower wishes to plant maize during the transition, the partial returns data indicate that the grower should plant a green manure crop first, followed by maize with recommended inputs as the second crop. This strategy, however, would eliminate maize as the first crop eligible for the organic premium in 2017, which could reduce long-term economic benefits [6].

Table 7. Estimated partial returns of maize, soybean and wheat in conventional and organic cropping systems with recommended and high input management in 2015 (maize and soybean) and 2016 (all three crops) in central NY.

	Crop		
	Maize	**Soybean**	**Wheat**
Treatment	**2015 Estimated partial returns ($/ha)**		
Conventional			
Recommended	928 a [+]	706 a	-
High Input	844 a	664 a	-
Organic			
Recommended	−168 b	662 a	-
High Input	−562 c	630 a	-
Treatment	**2016 Estimated partial returns ($/ha)**		
Conventional			
Recommended	550 a	699 a	303 a
High Input	475 b	601 a	24 b
Organic			
Recommended	607 a	648 a	−188 c
High Input	−215 c	579 a	−588 d

[+] Treatment means within the same column followed by the same letter are not significantly different according to Tukey's HSD (Studentized Range) test at the 0.05 level.

Conventional soybean with high input management in 2015 had the highest revenue, but revenue did not differ between cropping systems nor management inputs in 2016 (Tables 4 and 8). Organic compared with conventional soybean had $50 to $105 lower total selected variable costs when comparing respective treatments (Table 8). Organic compared with conventional soybean had lower seed and other input costs (inoculant in conventional, organic seed treatment in organic high input, herbicide and fungicide in conventional high input), which offset higher remaining variable costs (labor, repairs and maintenance, and fuels and lubricants). As with maize, organic compared with conventional soybean had higher fixed input costs, associated with the greater use of tractor and equipment (tine weeder and cultivator) for repeated cultivations for weed control.

Organic compared with conventional soybean had slightly higher ($13/ha) total selected production costs with recommended input management but slightly lower ($47/ha) costs in high input management. Other cropping system studies have also reported similar or lower total production costs for organic soybean [7,8,13] mostly because of lower seed and pesticide costs. A Minnesota, USA study, however, reported $128/ha higher production costs in organic compared with conventional soybean because lower seed and pesticide costs did not offset higher labor, diesel, and machinery ownership costs [4]. Likewise, the USDA survey data [2] also reported that organic soybean producers had higher economic costs ($262 to $309/ha) compared with conventional producers.

Table 8. Income, selected costs, and partial returns for conventional soybean with recommended management (S1) and high input management (S2); and organic soybean with recommended management (S3) and high input management (S4) at a Research Farm in central NY averaged across the 2015 and 2016 growing seasons [1].

	Soybean Treatments			
Production Value, Income	**S1**	**S2**	**S3**	**S4**
	$/ha			
Seed	967	1028	932	953
Selected Production Costs [1]				
Variable Inputs				
Fertilizers	-	-	-	-
Seeds	216.94	289.25	134.90	179.88
Sprays & Other Crop Inputs	31.74	77.86	9.95	33.90
Labor	1.09	2.71	25.45	25.45
Repairs & Maintenance				
Tractor	0.22	0.45	6.08	6.08
Equipment	0.81	1.79	8.39	8.39
Fuels & Lubricants	0.75	1.52	17.69	17.69
Interest on Operating Capital	6.27	9.32	5.05	6.78
Total Selected Variable Input Costs	257.82	382.90	207.51	278.13
Fixed Inputs				
Tractors	1.58	3.18	35.40	35.40
Equipment	4.33	8.67	34.31	34.31
Land charge	-	-	-	-
Value of management	-	-	-	-
Total Selected Fixed Input Costs	5.91	11.85	69.71	69.71
Total Selected Costs	263.73	394.75	277.22	347.84
Partial Returns	703	633	655	605

[1] See Table 6 for an explanation of selected production costs.

Soybean partial returns in 2015 and 2016 did not differ among cropping systems nor management inputs because of mostly similar yields and production costs (Table 7). Organic soybean, especially with recommended inputs (no organic seed treatment to improve plant establishment or higher seeding rates to improve weed control) thus is an excellent entry or second year crop in the transition to an organic cropping system. Our economic data agree with another study that indicated that soybean is the preferred entry crop compared to maize [4]. A major advantage of using soybean as the entry crop is that soybean does not require N fertilizer so the prospective organic grower who does not own livestock will not have to find an organic N source, as in the case of maize or wheat.

Wheat revenue had a cropping system x management input interaction, similar to yield (Tables 5 and 9). Total selected production costs were more than 2-fold greater in organic compared with the respective conventional wheat management treatments (Table 9). The use of composted manure as starter fertilizer but more importantly as an N source is the major reason for the much greater variable and total production costs in organic wheat. As with maize, most organic growers in New York, USA would probably not use composted manure as an N source. Consequently, the $416 to $595/ha higher production costs for organic compared with conventional wheat in our study are much higher than the $243 to $257/ha higher production costs in the USDA survey report [2].

Table 9. Income, selected costs, and partial returns for conventional wheat with recommended management (W1) and high input management (W2), and organic wheat with recommended management (W3) and high input management (W4) at a Research Farm in central NY in 2015–2016 [1].

	Wheat Treatments			
Production Value, Income	**W1**	**W2**	**W3**	**W4**
	$/ha			
Grain	643	587	569	570
Selected Production Costs [1]				
Variable Inputs				
Fertilizers	165.49	198.84	601.15	891.61
Seeds	125.52	200.84	97.17	155.49
Sprays & Other Crop Inputs	41.74	131.03	40.01	82.25
Labor	0	2.42	0	0
Repairs & Maintenance				
Tractor	0	0.45	0	0
Equipment	0	0.88	0	0
Fuels & Lubricants	0	1.36	0	0
Interest on Operating Capital	8.35	13.41	18.45	28.26
Total Selected Variable Input Costs	341.08	550.24	756.78	1157.60
Fixed Inputs				
Tractors	0	3.29	0	0
Equipment	0	9.19	0	0
Land charge	-	-	-	-
Value of management	-	-	-	-
Total Selected Fixed Input Costs	0	12.47	0	0
Total Selected Costs	341.08	562.72	756.78	1157.60
Partial Returns	303	24	−188	−588

[1] See Table 6 for an explanation of selected production costs.

Organic compared with conventional wheat had much lower partial returns when comparing their respective management treatments because of similar or lower yields and much higher total selected production costs (Table 7). Many wheat growers in New York, USA, however, manage wheat with high inputs (high seeding rates, fall herbicide, high split-applied N rates, and late spring fungicide). Organic wheat with recommended inputs compared more favorably with typical conventional wheat management with high inputs ($212/ha lower partial returns). Organic wheat compared with organic maize and soybean as second-year crops in the transition had much lower partial returns. Conventional wheat compared with conventional maize or soybean, also had lower partial returns, which explains in part the record low hectares of wheat planted in the USA in 2017 [3]. Winter wheat, however is an ideal rotation crop that disrupts weed and insect cycles in maize and soybean [21] so must be evaluated in context of its benefits to an organic rotation.

When comparing partial returns of the three crop rotations (red clover-maize, maize-soybean, and soybean-wheat/red clover) during the transition, the organic red clover-maize rotation with recommended inputs had similar partial returns as the conventional red clover-maize rotation with recommended inputs and greater partial returns compared with the high input treatment (Table 10). Most conventional growers, however, who do not transition to organic production, would not practice such a rotation so comparisons should be made between the organic red clover-maize rotation with the conventional maize-soybean rotation. The organic red/clover-maize rotation with recommended inputs had $1127/ha lower partial returns compared with the conventional maize-soybean rotation with recommended inputs and $1024/ha lower partial returns compared with the high input treatment. We did not apply composted chicken manure as an N source to organic maize with recommended inputs in 2016, but rather utilized red clover as the N source. Therefore, production costs are not inflated and partial returns not deflated when comparing the organic clover-maize rotation with recommended inputs with the conventional maize-soybean rotation with recommended and high inputs.

The organic maize-soybean rotation with recommended inputs had similar partial returns ($434) as the organic red clover-maize rotation with recommended inputs ($441, Table 10). Consequently, partial returns of both organic rotations were similar when compared with the conventional maize-soybean rotation. The substitution of a green manure crop for maize as an entry crop instead of continuing a maize-soybean rotation during the transition thus did not improve partial returns.

The organic compared with the conventional soybean-wheat/red clover rotation with recommended inputs had $548/ha lower partial returns (Table 10). Many soybean and wheat growers in New York, USA, however, use high input management on both crops. The organic soybean-wheat/red clover rotation with recommended inputs compares more favorably with the conventional soybean-wheat red clover rotation with high inputs ($229/ha lower partial returns). If cash flow is of major concern to the grower during the transition, soybean was the best entry crop followed by wheat in this study. This agrees with the findings in a Minnesota USA study [5]. When comparing partial returns of all three organic rotations with recommended inputs, however, differences were only $54 to $61 /ha. Consequently, the red clover-maize, maize-soybean, and soybean-wheat/red clover rotations would essentially have the same cash flow impact on the farm during the transition. This agrees with the findings of Archer et al. [5] who reported that transitioning growers should begin the transition process immediately, regardless of the entry crop.

Table 10. Estimated partial returns of three rotations (red clover-maize, maize-soybean, and soybean-wheat) during the transition period (2015 and 2016) in conventional and organic cropping systems with recommended and high input management in central New York.

	Sequence during Transistion		
Treatment	**Clover-Maize**	**Maize-Soybean**	**Soybean-Wheat**
		Total Costs ($/ha)	
Conventional			
Recommended	741 +	958 +	605
High Input	909	1211	956
Organic			
Recommended	666	1556	1035
High Input	1503	2077	1505
		Total Revenue ($/ha)	
Conventional			
Recommended	1116 a	2526 a	1647 a
High Input	1214 a	2610 a	1679 a
Organic			
Recommended	1107 a	1990 b	1530 a
High Input	1116 a	2041 b	1567 a
		Total Partial Returns ($/ha)	
Conventional			
Recommended	375 a	1568 a	1043 a
High Input	305 b	1399 a	724 b
Organic			
Recommended	441 a	434 b	495 c
High Input	−387 c	−36 c	62 d

+ Treatment means within the same column followed by the same letter are not significantly different according to Tukey's HSD (Studentized Range) test at the 0.05 level; [1] Maize costs in 2015 are much greater than costs in 2016 because of the use of composted chicken manure as the main N source in 2015 vs. red clover in 2016.

Organic maize and wheat had greater production costs than typical because of the use of composted chicken manure to ensure comparable N rates applied to organic and conventional maize and wheat. In addition, conventional weed control costs in maize are much lower than typical because most conventional maize growers in the USA do not moldboard plow their fields so they use more weed control chemicals than the single glyphosate application used in this study. Consequently, input costs of organic compared with conventional maize, soybean and wheat during the transition were much higher than typical, especially in maize and wheat. On the other hand, delaying the planting of conventional maize and soybean to just after the optimum planting dates probably reduced their yields and revenue somewhat. Likewise, the exceedingly dry 2016 growing season, probably contributed to the similar yields and revenue between organic and conventional maize and soybean and only an 11.5% lower organic wheat yield with recommended inputs during the second transition year [22]. In addition, we used untreated Pioneer varieties with no GMO traits in maize, soybean, and wheat instead of organic varieties, which probably also favored organic compared to conventional yields and revenue. Consequently, partial returns between organic and conventional cropping systems in our study during the transition did not differ greatly from other studies [4,8].

4. Conclusions

The two major constraints to organic field crop production are soil N availability and weed competition. Soybean was thus an excellent entry crop in the transition to organic production because it provided its own N, and tine weeding followed by four cultivations provided satisfactory weed control in this study. In contrast, maize as an entry crop, was more problematic because providing available soil N in the absence of a green manure crop was a challenge, and maize was less competitive with weeds (compared with wheat or soybean) in this study.

Organic wheat no-tilled into soybean stubble had very low weed densities in this study. Organic wheat in a maize-soybean-wheat/red clover rotation, however, must rely on an organic N source for its N uptake. Wheat takes up most of its N from late April through May in New York, USA when cool temperatures prevail, which may inhibit rapid mineralization of organic N. Nevertheless, organic wheat with recommended inputs compared with conventional wheat with high inputs, a typical management system for many growers in the Eastern USA, yielded similarly in 2016. Wheat was thus an excellent second year transition crop in this study. We recommend the organic soybean-wheat/red clover rotation during the transition for locations with similar environmental conditions of this study because this rotation compared most favorably with its conventional counterpart during the transition.

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