

Improving Input Use Efficiency in High-Yielding Corn Systems

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Introduction

The Crop Physiology Laboratory at UIUC has conducted experiments over the last 20 years to identify the principle factors that result in increased corn yields. The seven factors that were found to have the greatest impact on corn grain yields are weather, nitrogen, hybrid, previous crop, plant population, tillage, and growth regulators. Based on this information, an omission plot experimental design was created to test five of the identified factors (nitrogen, other fertility, genetic traits, population, and growth regulators) for their individual and cumulative effects on yield.

In 2011, we added three more factors (crop rotation, residue management, and reduced tillage) to the omission plot experimental design in an effort to identify conservation practices that maintain or improve yields in high-yielding corn production systems. Compared to a corn monoculture, corn-soybean rotations reduce N fertilizer application, reduce pest pressure, and are generally thought to promote a more diverse soil biological community to reduce disease susceptibility and serve as a reservoir for gene conservation. Research and anecdotal evidence have also shown that corn following soybean generally produce greater yields than following corn. Research by the Crop Physiology Lab indicates that the primary agent of yield reduction in corn following corn is corn residue, although the mechanism is not fully understood. Although frequently considered a poor practice for soil quality considerations, partial stover removal can be performed without degrading soil quality or reducing soil organic matter when used in the appropriate environment and with proper management (Fronning et al. 2008). Johnson et al. (2007) have also shown that compared to aboveground corn stover, corn roots are a more long-term, stable source of carbon and, thus, better for soil carbon sequestration than stover. We will quantify and compare root production in the high-yield vs. traditional environments to determine the additional biomass added as root biomass in the high-yield environment and equate that value with an allowable stover harvest value. We propose that stover removal in the high-yield corn environment can not only be performed in a sustainable manner, but that the compounded benefit of using stover for biofuel production or as an animal feed source makes good use of a secondary agricultural output in a value-added manner. In addition to testing the sustainability of removing corn stover in corn-corn systems, we will also assess if removing stover will reduce or eliminate the corn-corn yield penalty. Strip tillage is a relatively new reduced tillage system that protects soil from erosion, retains plant-available water later in the growing season, and allows banding of fertilizers for more efficient plant uptake and reduced erosional losses associated with broadcast fertilization.

Materials and Methods

The study was created as a split-split plot experimental design. Whole plots were Rotation (Continuous Corn or Corn-Soy) and split plots were Residue Management (Stover Retained or Stover Removed) and Tillage (Conventional Tillage or Strip Tillage). Figure 1 demonstrates one replication of the study,

illustrating the quarter plot design. Within each quarter plot, twelve split-split plots comprise the omissions study, as illustrated in Figure 1. All treatments were replicated 4 times. Treatments tested in the omission plot design are described in Table 1. A check plot with no nitrogen fertilizer application was included in the design to assess nitrogen use efficiency.

Two site-years are required for this study due to the Rotation treatment. Each year, one site is used to establish the previous crops for the following year. The 2011 study was located at a site previously planted to either 8th-year continuous corn or soybean in a 2-year corn-soybean rotation. Soils were classified as predominantly Flanagan silt loam with tile drainage and without irrigation. Extensive soil samples were collected in fall 2010 to establish evenness in fertility levels and to make fertilizer recommendations; data are provided in Table 2. A potassium application was made in spring 2011.

Stover removal, tillage, and fertilizer applications were made in spring 2011. Stover was removed during the first week of April in continuous corn split plots. Fifty percent of stover was removed by flail chopping all stover, raking into swaths, collecting and weighing it, and replacing 50% with a manure spreader and redistributing stover across the plots by hand. Strip tillage and conventional tillage (disking followed by light cultivation) occurred during the week of May 16th. MESZ fertilizer was band-applied with the strip tiller or band-applied with a tool bar in conventionally tilled treatments. N was broadcast-applied by hand as SuperU (Treatments 1, 2, 3, 5, 6, and 10) or urea (4, 7, 8, 9, 11, and 12). The study was planted on June 4th with Syngenta hybrid N68B (114 days) 3000GT (with corn rootworm resistance and Cruiser Extreme 250) or GT (refuge hybrid with Cruiser Extreme 250 and without rootworm resistance). A side-dress N application of 60 lb N as urea was applied at V5 on treatments 1, 2, 3, 5, 6, and 10. Strobilurin fungicide was applied to select treatments at VT. Select root samples and aboveground plants samples were collected one week after VT. Corn grain was harvested in October along with aboveground plant biomass samples. Root samples were collected during the first week of December.

Results and Discussion

Yield

The 2011 growing season was not favorable for corn production in east-central Illinois due to wet conditions in April and May and very dry conditions the remainder of the growing season (Table 3). Yield, averaged over all treatments, was 160 bu/a (Table 4). The 2011 average corn yield in east-central IL was 149 bu/a (NASS); this was also the average yield of all Traditional treatments (TRAD) in this study. By contrast, the average yield of the High Technology treatments (HT, Treatment 1), averaged over other treatments, was 171 bu/a. Within the Rotation, Tillage, and Residue Management quarter-plots, the HT treatment provided significantly greater yields than the TRAD treatment (Treatment 1 vs. 7, $P < 0.05$) for the following systems: Continuous Corn (CC)/Conventional Tillage (CT)/Stover Removed, Corn-Soy (CS)/CT, and CS/Strip Tillage (ST) (Tables 7, 9, and 10). The HT system did not provide significantly greater yields than the TRAD system ($P < 0.05$) for the remaining quarter plots: CC/Stover Retained/CT, CC/Stover Retained/ST, and CC/Stover Removed/ST (Tables 5, 6, and 8). In general, the greatest treatment effects resulted from N applications, other fertilizers (P, S, and Zn), and plant

population; fungicide and corn hybrid had smaller effects on yield, over all. It should be noted that the corn variety selected for the study was determined to perform sub-optimally at high plant populations in an independent study which may explain the muted hybrid effect. We have selected a more responsive corn variety for next year.

Continuous corn (CC) treatments (averaged over tillage and residue management treatments) produced an average yield of 154 bu/a and CS treatments averaged 167 bu/a, representing a 13 bu/a yield penalty for CC. Growers in the region also reported lower 2011 yields for continuous corn and 2nd-year corn relative to yields in a corn-soy rotation, usually in the range of 10-25 bu/a. When 50% of stover was removed, corn yields increased to 157 bu/a (from 151 bu/a with stover retained). The CC yield penalty averaged over residue management and tillage was 21 bu/a for HT treatments (Treatment 1; CC average yield = 161 bu/a; CS average yield = 182 bu/a) and 10 bu/a for TRAD treatments (Treatment 7; CC average yield = 144 bu/a; CS average yield 154 bu/a). The late planting date for this study makes it unlikely that the CC yield penalty was due to cold soils; reduced N mineralization and a higher potential for N immobilization are more likely explanations, although autotoxicity cannot be ruled out. Based on check plot yields (zero nitrogen fertilizer application, data not shown), there were large differences due to both tillage (12-27% reduced yield for ST vs. CT) and rotation (32% lower yield for CC vs. CS) indicating greater N immobilization potential for systems with increased corn stover residue. This data supports previous research by the crop physiology lab indicating that the continuous corn yield penalty is closely related to corn residue. A yield penalty related to corn stover may also help explain the observation of greater yields for strip tillage in CS relative to CC systems (Table 4).

Plant population was a significant effect in most CC systems but had less effect on yield in CS systems in 2011. This data suggests that CS rotations are better able to support high plant populations during adverse growing seasons, like 2011. There was a rotation-tillage interaction resulting from low yields obtained when strip tillage was applied in CC systems, although removing 50% of stover improved the yield response of ST treatments. The 28 bu/a yield difference between the HT and HT-POP treatments (Treatments 1 and 2, CC/Stover Retained/CT, Tables 4 and 5) coupled with the non-significant differences due to N and other fertilizers (Table 5) suggests that water stress, not fertilizer deficiencies, was the primary yield reduction agent in this system. Precipitation in July and August were only 33% and 45% of the long-term average, so water stress during tasseling, pollination, and grain-fill was likely to have reduced grain yields, especially in high population treatments.

Applying additional N, P, S, and Zn fertilizers had an overall positive effect. Band-application of MESZ in both the strip-till and conventional tillage systems in the spring prior to planting appears to have provided very good placement and availability of nutrients. Increasing the N rate by 60 lb N/a applied side-dress increased yields by about 10% in the CC CT treatments (both stover removed and stover retained). Similarly, applying P, S, and Zn fertilizer as MESZ increased yields by 9-10% in the CC CT treatments (stover removed and stover retained). The effect of omitting application of N, P, S, and Zn from the HT system (Treatments 4 and 5) reduced yields when stover was removed from the CC CT system (Tables 4 and 7) but was not a strong effect when stover was retained (Table 5), reflecting the level of nutrients supplied by stover during the growing season and indicating that additional fertilizer should be supplied when stover is removed in conventionally tilled systems, especially when plant

populations are high. The strip tillage treatments displayed intermediate yield responses to N, P, S, and Zn application; when stover was retained in the CC system, increasing the N rate by 60 lb N/a increased yields by 18% (24 bu/a, Table 4) and applying P, S, and Zn increased yields by almost 20% (26 bu/a). The yield response to additional fertilizer application in the stover-retained treatments suggests that nutrient immobilization may be occurring as a result of high stover biomass present in these systems. When stover was removed in the CC ST system, yields increased by, on average, 10 bu/a relative to the stover-retained treatments, but the added benefit of N, P, S, and Zn fertilizers was non-significant (only 6-7% greater than the TRAD system, Tables 4 and 8).

Rotation was particularly important in strip tillage systems as evidenced by a 15 and 36 bu/a yield increase for strip tillage between CC and CS systems for the TRAD and HT systems. The effect of rotation was illustrated by the differences between strip tillage and conventional tillage between rotations; ST yielded, on average, 27 bu/a less than CT in the CC system, however, ST yielded 5 bu/a greater than CT in the CS system (HT comparisons, Treatment 1). It is unclear why ST performed poorly in CC systems in 2011, but it may have been related to delayed early-season weed control resulting from excessively wet field conditions. This data indicates that ST can produce corn yields similar to CT in CS rotations.

This study will be conducted again in the 2012 growing season. Extensive soil sampling and belowground root biomass will be used to estimate sustainable stover removal levels. Nitrogen use efficiency calculations will provide estimations of agronomic and environmental effects of additional N side-dress applications. Fungicide application and hybrid with corn rootworm traits were less effective than fertility (N, P, S, and Zn applications) for increasing yields in 2011. Strip tillage performed as well as conventional tillage in corn-soybean rotations, but did not produce yields equivalent to conventional tillage in continuous corn production systems. This data supports previous work indicating that continuous corn systems result in lower yield than corn-soybean rotations and that the yield penalty associated with continuous corn is the result of stover accumulation. During poor growing seasons, like 2011, corn-soybean rotations are more likely to support high plant populations than continuous corn. Partial stover removal did not overcome the continuous corn yield penalty or substantially increase yield in conventionally tilled continuous corn systems in 2011, but may be more effective under favorable growing conditions. This data indicates that stover removal may require additional fertilizer application, especially when plant populations are high.

References

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CORN-CORN

CORN-SOY

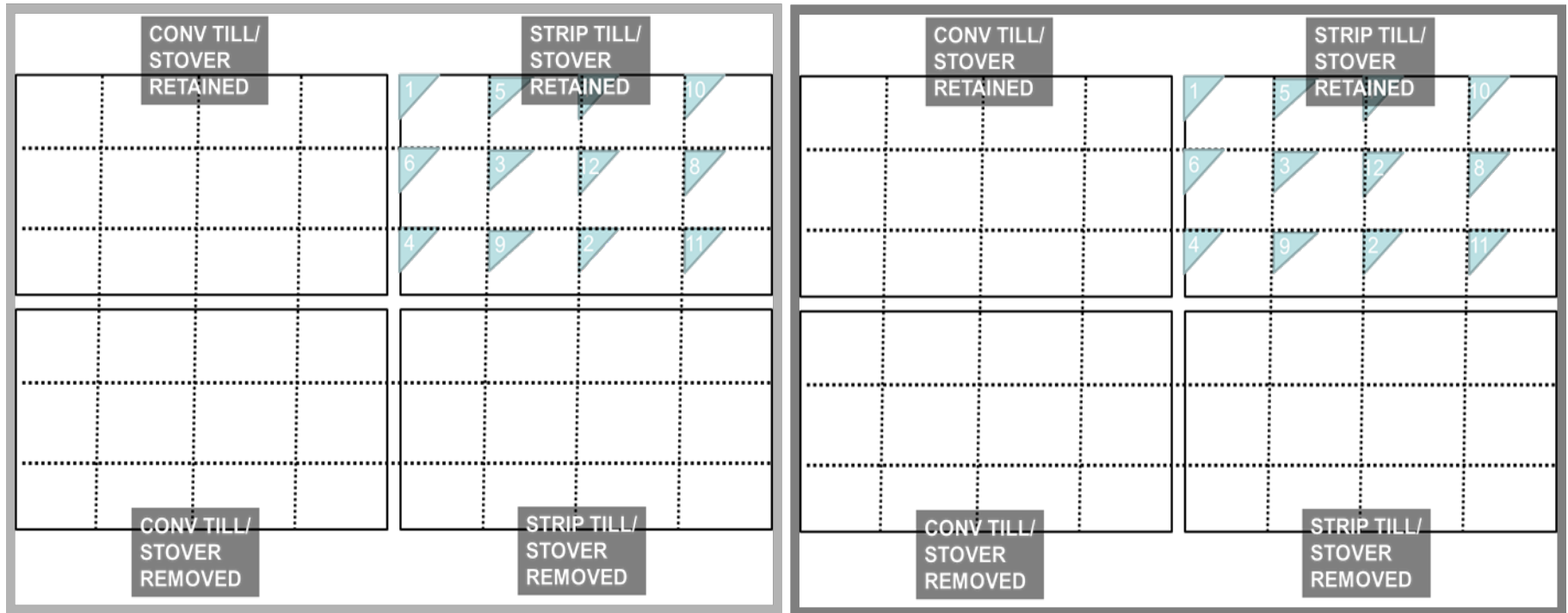


Figure 1. Experimental design of one replication of the 2011/2012 proposed project. The 12 treatments are repeated in each quadrat of each rotation (corn-corn or corn-soy) plot. The four split-plots per rotation (conventional tillage+stover, conventional tillage-stover, strip tillage+stover, strip tillage-stover) assess residue management concerns in high-yielding corn systems. The 12 split-split plot treatments are described in Table 2. A zero-N check plot (not shown) was included to assess nitrogen use efficiency.

Table 1. Subplot treatments evaluated in the 2011/2012 Sustainability Omissions Plot Design. The six subplot treatments are plant population, hybrid traits, N rate, other nutrients, and crop protection inputs (fungicide).

Trt. No.	Trt.	Pop	Hybrid	N	Fert.	Fungicide
1	HIGH TECHNOLOGY	45K	MULTI-TRAIT	BASE+SLOW REL	MESZ	STROBILURIN
2	-POPULATION	32K	MULTI-TRAIT	BASE+SLOW REL	MESZ	STROBILURIN
3	-HYBRID TRAIT	45K	REFUGE	BASE+SLOW REL	MESZ	STROBILURIN
4	-NITROGEN	45K	MULTI-TRAIT	BASE	MESZ	STROBILURIN
5	-FERTILITY	45K	MULTI-TRAIT	BASE +SLOW REL	NONE	STROBILURIN
6	-FUNGICIDE	45K	MULTI-TRAIT	BASE +SLOW REL	MESZ	NONE
7	TRADITIONAL	32K	REFUGE	BASE	NONE	NONE
8	+POPULATION	45K	REFUGE	BASE	NONE	NONE
9	+HYBRID TRAIT	32K	MULTI-TRAIT	BASE	NONE	NONE
10	+NITROGEN	32K	REFUGE	BASE+SLOW REL	NONE	NONE
11	+FERTILITY	32K	REFUGE	BASE	MESZ	NONE
12	+FUNGICIDE	32K	REFUGE	BASE	NONE	STROBILURIN

Rotation	NO ₃ ⁻ (ppm, 0-34")	P (ppm, 0-6")	K (ppm, 0-6")	S (ppm, 0-6")	S (ppm, 6-24")	Zn (ppm, 0-6")
C-C	8.75	28.31	164	9.13	18.3	1.59
C-S	13.75	20.00	133	9.25	16.8	1.27

	April	May	June	July	August	September	October
Temp (°F)	54	63 (63)	74 (72)	80 (75)	74 (73)	64 (66)	55 (54)
Precipitation (in.)	8.45 (3.68)	4.80 (4.89)	4.20 (4.34)	1.57 (4.70)	1.76 (3.93)	2.79 (3.13)	2.64 (3.26)

Table 2. Site summary data. Soil test nutrient levels (Fall 2010) averaged over continuous corn (C-C) and corn-soybean (C-S) rotation split blocks.

Table 3. Monthly average air temperature and total precipitation for the 2011 growing season, reported for Champaign IL, monthly average values (1981-2010) provided in parentheses.

Table 4. Corn yield averages, bu/a. Data provided for 2 crop rotations (corn-corn, corn-soybean), 2 residue management regimes (stover retained, 50% stover removed), 2 tillage systems (conventional, full-width tillage, strip-tillage), and 12 management factors. Percent differences (% diff) display the difference between the + treatments (+FERT, +FUNGICIDE, +HYBRID, +N, AND +POP) relative to the traditional-input treatment (TRAD) and the – treatments (-FERT, -FUNGICIDE, -HYBRID, -N, AND -POP)

ROTATION	RES MNGMNT	TILLAGE	TRT	YIELD (bu/a)	% DIFF
CORN-CORN	RETAINED	CONV	+FERT	162	8.83
			+FUNGICIDE	122	-17.90
			+HYBRID	134	-9.71
			+N	164	10.43
			+POP	123	-17.34
			-FERT	169	2.33
			-FUNGICIDE	155	-6.26
			-HYBRID	164	-1.11
			-N	158	-4.40
			-POP	194	16.98
			HIGH TECH	166	
			TRAD	149	
			LSD (P<0.05)	23	
	CORN-CORN STOVER RETAINED CONVENTIONAL TILL AVG			155	
		STRIP	+FERT	159	19.46
			+FUNGICIDE	141	6.33
			+HYBRID	153	15.06
			+N	157	18.39
			+POP	123	-7.19
			-FERT	139	-0.76
			-FUNGICIDE	147	4.93
			-HYBRID	149	6.10
			-N	137	-2.33
			-POP	176	25.34
			HIGH TECH	140	
			TRAD	133	
			LSD (P<0.05)	20	
	CORN-CORN STOVER RETAINED STRIP TILL AVG			146	
CORN-CORN STOVER RETAINED AVG				151	

relative to the high-input, high-technology treatment (HIGH TECH).

ROTATION	RES MNGMNT	TILLAGE	TRT	YIELD (bu/a)	% DIFF
CORN-CORN	REMOVED	CONV	+FERT	168	10.24
			+FUNGICIDE	145	-4.60
			+HYBRID	163	7.14
			+N	167	9.72
			+POP	118	-22.41
			-FERT	147	-20.72
			-FUNGICIDE	170	-8.14
			-HYBRID	168	-8.83
			-N	165	-10.90
			-POP	188	1.77
			HIGH TECH	185	
			TRAD	152	
			LSD (P<0.05)	26	
	CORN-CORN STOVER REMOVED CONVENTIONAL TILL AVG			161	
		STRIP	+FERT	152	6.18
			+FUNGICIDE	150	4.59
			+HYBRID	153	6.75
			+N	154	7.05
			+POP	123	-14.50
			-FERT	158	2.27
			-FUNGICIDE	161	4.03
			-HYBRID	159	2.54
			-N	146	-5.83
			-POP	171	10.55
			HIGH TECH	155	
			TRAD	143	
			LSD (P<0.05)	18	
	CORN-CORN STOVER REMOVED STRIP TILL AVG			152	
CORN-CORN STOVER REMOVED AVG				157	
CORN-CORN AVG YIELD					154

Table 4. Continued

ROTATION	RES MNGMNT	TILLAGE	TRT	YIELD (bu/a)	% DIFF
CORN-SOY	-	CONV	+FERT	163	4.70
	-		+FUNGICIDE	154	-1.33
	-		+HYBRID	156	0.15
	-		+N	175	12.50
	-		+POP	147	-5.75
	-		-FERT	175	-2.13
	-		-FUNGICIDE	184	2.95
	-		-HYBRID	175	-2.33
	-		-N	158	-11.80
	-		-POP	183	2.31
	-		HIGH TECH	179	
	-		TRAD	156	
			LSD (P<0.05)	20	
	CORN-SOY CONVENTIONAL TILL AVG			167	
	-	STRIP	+FERT	162	6.07
	-		+FUNGICIDE	158	3.02
	-		+HYBRID	159	3.97
	-		+N	158	3.40
	-		+POP	146	-4.57
	-		-FERT	179	-2.62
	-		-FUNGICIDE	176	-4.44
	-		-HYBRID	174	-5.46
	-		-N	168	-8.63
	-		-POP	182	-0.81
	-		HIGH TECH	184	
	-		TRAD	153	
			LSD (P<0.05)	23	
	CORN-SOY STRIP TILL AVG			167	
CORN-SOY AVG YIELD					167
AVG YIELD, ALL TREATMENTS					160

Table 4. Continued

Table 5. Orthogonal contrast results of yield data for Continuous Corn (CC) Conventional Tillage with Stover Retained, yield data.

System	Contrast Element 1	Contrast Element 2	P-value
CC Stover Retained Conventional Tillage	High Tech	High Tech - Pop	0.0202
	High Tech	High Tech – Hybrid	0.8742
	High Tech	High Tech – N	0.5316
	High Tech	High Tech – Fertility	0.7393
	High Tech	High Tech – Fungicide	0.3745
	High Tech	Traditional	0.1518
	Traditional	Traditional + Pop	0.0321
	Traditional	Traditional + Hybrid	0.2189
	Traditional	Traditional + N	0.1873
	Traditional	Traditional + Fertility	0.2626
	Traditional	Traditional + Fungicide	0.0273

Table 6. Orthogonal contrast results of yield data for Continuous Corn (CC) Strip Tillage with Stover Retained.

System	Contrast Element 1	Contrast Element 2	P-value
CC Stover Retained Strip Tillage	High Tech	High Tech - Pop	0.0012
	High Tech	High Tech – Hybrid	0.3990
	High Tech	High Tech – N	0.7461
	High Tech	High Tech – Fertility	0.9157
	High Tech	High Tech – Fungicide	0.4950
	High Tech	Traditional	0.4492
	Traditional	Traditional + Pop	0.3841
	Traditional	Traditional + Hybrid	0.0544
	Traditional	Traditional + N	0.0205
	Traditional	Traditional + Fertility	0.0146
	Traditional	Traditional + Fungicide	0.4078

Table 7. Orthogonal contrast results of yield data for Continuous Corn (CC) Strip Tillage with Stover Removed.

System	Contrast Element 1	Contrast Element 2	P-value
CC Stover Removed Conventional Tillage	High Tech	High Tech - Pop	0.7992
	High Tech	High Tech – Hybrid	0.2090
	High Tech	High Tech – N	0.1233
	High Tech	High Tech – Fertility	0.0050
	High Tech	High Tech – Fungicide	0.2459
	High Tech	Traditional	0.0159
	Traditional	Traditional + Pop	0.0113
	Traditional	Traditional + Hybrid	0.3992
	Traditional	Traditional + N	0.2533
	Traditional	Traditional + Fertility	0.2289
	Traditional	Traditional + Fungicide	0.5859

Table 8. Orthogonal contrast results of yield data for Continuous Corn (CC) Strip Tillage with Stover Removed.

System	Contrast Element 1	Contrast Element 2	P-value
CC Stover Removed Strip Tillage	High Tech	High Tech - Pop	0.0762
	High Tech	High Tech – Hybrid	0.6620
	High Tech	High Tech – N	0.3193
	High Tech	High Tech – Fertility	0.6960
	High Tech	High Tech – Fungicide	0.4894
	High Tech	Traditional	0.2162
	Traditional	Traditional + Pop	0.0258
	Traditional	Traditional + Hybrid	0.2848
	Traditional	Traditional + N	0.2647
	Traditional	Traditional + Fertility	0.3271
	Traditional	Traditional + Fungicide	0.4653

Table 9. Orthogonal contrast results of yield data for Corn-Soy (CS) Rotation with Conventional Tillage

System	Contrast Element 1	Contrast Element 2	P-value
CS Conventional Tillage	High Tech	High Tech - Pop	0.6833
	High Tech	High Tech – Hybrid	0.6812
	High Tech	High Tech – N	0.0399
	High Tech	High Tech – Fertility	0.7066
	High Tech	High Tech – Fungicide	0.6031
	High Tech	Traditional	0.0230
	Traditional	Traditional + Pop	0.3793
	Traditional	Traditional + Hybrid	0.9813
	Traditional	Traditional + N	0.0580
	Traditional	Traditional + Fertility	0.4720
	Traditional	Traditional + Fungicide	0.8383

Table 10. Orthogonal contrast results of yield data for Corn-Soy (CS) Rotation with Strip Tillage

System	Contrast Element 1	Contrast Element 2	P-value
CS Strip Tillage	High Tech	High Tech - Pop	0.8970
	High Tech	High Tech – Hybrid	0.3862
	High Tech	High Tech – N	0.1725
	High Tech	High Tech – Fertility	0.6769
	High Tech	High Tech – Fungicide	0.4813
	High Tech	Traditional	0.0094
	Traditional	Traditional + Pop	0.5451
	Traditional	Traditional + Hybrid	0.5991
	Traditional	Traditional + N	0.6527
	Traditional	Traditional + Fertility	0.4224
	Traditional	Traditional + Fungicide	0.6892

