FLUID FERTILIZERS FOR SUSTAINABLE RESIDUE REMOVAL IN HIGH-YIELDING CORN PRODUCTION SYSTEMS

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EXECUTIVE SUMMARY

This study demonstrates how a greater understanding of interactions between agricultural inputs and residue management practices can be used to positively influence corn yields in an efficient and sustainable manner. Five "Technology" treatments (plant population, liquid nitrogen (N) fertilizer, non-N fertility, plant hybrid trait, and fungicide) were applied at two levels (High Technology and Traditional) to test for effects of each Technology factor alone and in combination. Additionally, three residue management treatments (crop rotation, partial stover removal, and tillage) were applied at two levels (9th-year continuous corn vs. long-term corn-soybean rotation, stover retained vs. 50% stover removed, and conventional tillage vs. strip tillage) to assess their individual and combined effects on Technology treatments and corn yields. The 2012 cropping season in the U.S. Midwest will be remembered among the worst droughts on record. Nevertheless, we determined highly significant treatment effects for crop rotation, stover removal, tillage, and Technology.

This study indicates that:

- On average, the combined application of commercially available and proven technologies (High Technology treatment) increased corn yield by 19% over typical management (Traditional treatment), even in a growing season of low yield potential.
- The continuous corn yield penalty was exceptionally high in 2012; on average, continuous corn produced 55 bu a^{-1} less than corn-soybean rotation (37% reduction).
- Stover removal in continuous corn systems increased corn yield by 18 bu a^{-1} under High Technology management with conventional tillage, but had limited effect in other treatments.
- Strip tillage performed about as well as conventional tillage in corn-soybean rotations (less than 5 bu a^{-1} difference) but in continuous corn systems, strip-tilled yields were reduced by about 10 bu a^{-1}.
- Based on data from continuously monitored soil moisture sensors placed in select treatments, soil moisture was affected by residue accumulation in unexpected ways. Plant-available soil moisture was less in the high-residue continuous corn system than in the low-residue corn-soybean rotation at all 5 depths tested. We speculate that moisture from sporadic and minor precipitation events of 2012 was retained by surface residues in CC systems where it was vulnerable to rapid evaporation whereas moisture infiltrated the soil surface in lower-residue systems, such as CS rotations.
- In a season characterized by severe drought, each of the Technology treatments demonstrated significant and often unique effects on yield relative to a season of average precipitation:
  - The corn rootworm resistance trait had the greatest effect on corn yields among all Technology treatments tested. Averaged across all Management systems, adding the CRW

trait to the TRAD package increased grain yield by 31%. Similarly, omitting the CRW trait from the HT package reduced grain yield by 15%.

- The next-greatest Technology effect was that of strobilurin fungicide application. This effect, counter to expectations and previous observations, was to reduce grain yield by 5% when applied to the TRAD package and increase yield by 8% when omitted from the HT package.
- As expected, increasing plant population by 40% exacerbated effects of drought stress, particularly in continuous corn systems.
- Application of N, P, S, and Zn fertilizers demonstrated significant effects unique to severe drought conditions. Application of P, S, and Zn and sidedress N was detrimental to corn yields in high plant population systems, perhaps the result of reduced root biomass which was a strong disadvantage in drought conditions. Under lower plant populations, P, S, and Zn fertilizers had generally positive results, increasing yields by an average of 6 bu a^{-1}.
- Corn root biomass was most strongly and consistently affected by plant population; as plant population increased, per-plant corn root biomass decreased. In conventionally tilled systems, partial stover removal reduced root biomass by 15% relative to stover retention; root biomass was not affected by tillage in strip tilled systems.

INTRODUCTION

The Crop Physiology Laboratory at the University of Illinois, Urbana-Champaign has conducted experiments over the last 20 years to identify the principle factors that result in increased corn yields. The seven factors 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 treatment” experimental design was created to test five of the identified factors (nitrogen, other crop nutrients, 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 treatment experimental design in an effort to identify residue management practices that maintain or increase production in high-yielding corn production systems. Compared to 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. It is also widely accepted that corn following soybean generally produces greater yields than following corn in dryland agricultural systems in the U.S. Midwest. Research by the Crop Physiology Lab indicates that the primary agents of yield reduction in continuous corn systems are N availability, residue accumulation, and weather (Gentry et al. 2013). Despite issues associated with corn monoculture, this system is likely to become more prevalent in corn production systems in the foreseeable future as a result of increased demand for corn.

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). Other research has demonstrated that corn roots are more effective for carbon sequestration and contribute more effectually to soil structure formation than aboveground corn biomass (Gale et al. 2000; Gale and Cambardella 2000; Johnson et al., 2007). In addition to testing the sustainability of removing corn stover in continuous corn systems, we also assessed the effect of removing stover on the continuous 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, maintains soil structure and retains soil organic matter, and allows banding of fertilizers for more efficient plant uptake. Because strip tillage can incorporate seedbed preparation and fertilizer application into a one-pass field operation, it substantially reduces soil compaction associated with multiple field operations for seedbed preparation, residue incorporation, and fertilizer applications; this also represents cost savings as a result of eliminating fuel use, labor, and equipment wear associated with additional field passes. **These three agricultural management practices – crop rotation, residue management, and reduced tillage – were tested for their individual and cumulative effects on agricultural sustainability parameters and corn yields in combination with the omission treatment design previously employed to investigate high yield management factors for corn production.**

MATERIALS AND METHODS

The study was created as a split-split plot experimental design. Whole plots combined crop rotation and stover management in a treatment referred to as *System*. There were 3 whole-plot (System) treatment factors: continuous corn with stover retained (CC), continuous corn with stover removed (CCRM), and corn-soybean rotation with stover retained (CS). The split-plot treatment was Tillage (Conventional Tillage or Strip Tillage). Whole plots and split plots together formed quarter plots within each whole plot (Fig. 1). The experimental design of the study is unbalanced because stover removal was not conducted in the corn-soybean (CS) system because most research agrees that stover removal in CS rotations is not an acceptable practice due to increased potential for soil erosion and soil organic matter depletion. Figure 1 demonstrates one replication of the study, illustrating the quarter plot design. Within each quarter plot, twelve split plots comprise the omission treatment 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 strip block with no nitrogen fertilizer application was included in the design to assess nitrogen use efficiency.

Due to the Rotation treatment, two site-years are required for this study. Each year, one site is used to establish the “previous crops” (corn or soybean) for the following year. The 2012 study was located at a site previously planted to either 8th-year continuous corn or soybean (in a long-term 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 P fertilizer applications were made in fall 2011 and winter 2012. Stover was removed during the first week of January in CCRM treatments. Fifty percent of stover was removed by flail chopping all stover, raking into swaths, collecting and weighing it, and replacing 50%, redistributing it evenly across plots with a manure spreader. Stover was not chopped in the CC treatments to better represent growers' field conditions and eliminate unnecessary equipment traffic and related compaction. This created a discrepancy between the CC and CCRM treatments since the chopped stover replaced in the stover removed (CCRM) treatments was subject to being blown about by wind and was also likely to decompose faster than in the CC plots where stover was not chopped. Strip tillage and conventional tillage (disking followed by light cultivation) occurred during the 2nd week of January. MESZ fertilizer was band-applied with the strip tiller or band-applied with a tool bar in conventionally tilled treatments at the same time that tillage occurred. N was broadcast-applied by hand as SuperU (Treatments 1, 2, 4, 5, 6, and 9) or sprayed in-row as urea ammonium nitrate (Treatments 3, 7, 8, 10, 11, and 12) (Table 1) during the 2nd week of April; the study was planted on April 24th and 25th with Syngenta hybrid N63R (109 days) 3000GT (with corn rootworm resistance and Cruiser Extreme 250) or GT (refuge hybrid with Cruiser Extreme 250 without rootworm resistance). A side-dress N application of 60 lb N as urea with Agrotain was applied at V4 (May 23rd) to Treatments 1, 2, 4, 5, 6, and 9 (Table 1). Strobilurin fungicide was applied to select treatments at VT. Corn grain was harvested in October along with aboveground plant biomass samples.

Root samples were collected during the first week of December. Roots were collected by running a large, custom-designed U-shaped attachment spaced 24 inches apart approximately 16 inches deep over the center two rows in each plot to loosen soil around the root balls. Four roots were collected from each row. Roots were stored in a covered area outdoors at freezing or colder temperatures in onion sacks for up to 4 weeks until they could be washed, weighed, and ground.

Soil moisture was monitored continuously all season using John Deere soil moisture sensors operating on the principle of heat capacitance. Four sets of soil moisture sensors were placed in the TRAD technology treatments of a single replication (Rep 4) in the CC/Stover Retained/Conventional Tillage, CC/Stover Retained/Strip Tillage, CS/Conventional Tillage, and CS/Strip Tillage treatments in order to test the effect of Tillage (Conventional vs. Strip Till) and Rotation (Continuous Corn vs. Corn-Soybean) on soil moisture. Each set of soil moisture sensors contained 4 individual sensors measuring soil moisture at 4, 8, 12, 20, and 40 inches below the soil surface. Sensors were carefully placed within the crop row and between corn plants to better indicate soil moisture conditions experienced by corn roots.

RESULTS AND DISCUSSION

Grain Yields

General Yield Effects

The 2012 drought was monumental both in terms of intensity and aerial expanse. July 2012 was the hottest month on record, nationwide, in the 117-year history of modern weather statistics (NOAA/NCDC). One hundred percent of the topsoil in IL was classified as “short” or “very short” of moisture by July 29th. By the end of July, 86% of the U.S. Midwest was classified under some drought category, ranking 2012 behind only the agricultural droughts of the 1930s and 1988 (Wiltgen 2012). The nation’s primary corn and soybean-growing region was particularly hard hit, including the area of this study. For this study location, official records indicate that no rain fell in the month of July (Table 3); however, records by the researchers indicate that 0.46 inches of rain fell on July 14th which was corroborated by soil moisture data collected on-site (Fig. 2).

There were highly significant treatment effects for System ($P<0.0001$), Technology ($P<0.0001$), and Tillage ($P=0.0013$) (Table 4). No treatment interactions were significant. Yield, averaged over all treatments, was 122 bu a^{-1}. The National Agricultural Statistics Service November 2012 forecast for state-wide corn grain yield was 101 bu a^{-1}; this was close to the average yield of 108 bu a^{-1} measured for the Traditional Technology package (TRAD, management practices resembling common grower practices) in this study. By contrast, the average yield of the High Technology package (HT) was 129 bu a^{-1}. Table 5 provides select summary statistics for System, Tillage, and Technology treatments. The continuous corn yield penalty was exceptionally high in 2012; continuous corn systems produced 55 bu a^{-1} less than CS rotations (37% reduction, Appendix 1). The HT package produced, on average, 19% greater yield than the TRAD package. Stover removal increased corn yields by 19% in conventionally tilled HT systems but did not affect yield in other treatments to an appreciable degree, perhaps due to the drought. Strip tillage resulted in an average 10% yield reduction relative to conventional tillage.

System (Rotation/Stover) Effects

Rotation: Ninth-year continuous corn treatments (averaged over System, Tillage, and Technology) produced an average yield of 94 bu/a and CS treatments averaged 149 bu a^{-1}, representing a 55 bu a^{-1} yield penalty for continuous corn. These results are reflective of farmer reports of yield losses from continuous corn. 2012 marks the 3rd consecutive year that farmers report markedly lower yield for continuous corn relative to CS in this region. The continuous corn yield penalty was 66 bu a^{-1} in the HT package and 49 bu a^{-1} for the TRAD package, reflecting the additional yield loss due to higher plant populations (40% greater plant population in HT vs. TRAD) in a drought stress year. This data also supports the conclusions of Gentry et al. (2013) that the continuous corn yield penalty is exacerbated during droughts because of the proportionally greater yield reduction for CC systems relative to CS under adverse growing environments.

Residue Management and Soil Moisture: In conventionally tilled CC systems, stover removal increased corn yield for the HT system by 18 bu a^{-1}; otherwise, stover removal did not significantly (P<0.10) affect yield in conventionally tilled systems. Given that the primary yield constraint in 2012 was soil moisture, it seems likely that the benefits associated with removing stover in CC systems were modified by the effects of drought and the surprising effect that stover removal had on plant water availability. Although it is generally accepted that crop residues left on the soil surface make more soil moisture available for plant uptake by reducing evaporation from the soil, we suggest that during an extended drought, as in 2012, residues spread thickly and evenly across the soil surface may actually reduce plant available soil moisture by making rainfall from relatively minor (<0.75 inches) precipitation events more susceptible to evaporation. Moisture from such rainfall events collects in residue and is held at the residue/soil interface. During periods of low atmospheric humidity and moderate winds, common in July and August in the Midwest, the residue-retained moisture is vulnerable to rapid evaporation. In a severe drought situation, when soil moisture reserves have already been depleted, reduced residue systems (such as CS rotations) may make precipitation more plant-available than high-residue continuous corn systems because precipitation penetrates the soil surface and moves deeper into the soil profile. This hypothesis is supported by soil moisture data collected from CC and CS systems for both tillage factors in 2012 (Fig 2). As seen, the few precipitation events occurring between July 1st and Aug. 15th had a greater effect on soil moisture in CS rotations than in CC/Stover Retained systems, most obviously at the 4- and 8-inch depths. Based on this hypothesis, the continuous corn system with 50% stover removal (CCRM) would have demonstrated greater plant available soil moisture than the CC system with no stover removed. We hope to measure the effect of residue removal on soil moisture in 2013. It should be emphasized that these data are the result of an unusually severe drought and are not necessarily indicative of more normal weather conditions.

Tillage Effects

Early in the growing season, during mild drought conditions, researchers observed that corn in strip tillage plots appeared visually more vigorous and, in some cases, taller than in conventionally tilled treatments. However, as the drought worsened, all treatments demonstrated drought stress conditions of leaf rolling and reduced growth to a near-equal extent. As seen in Fig. 2, soil moisture during July and August was not appreciably different between tillage treatments at depths of 4, 8, and 12 inches below the soil surface.

Strip tillage resulted in yields amounting to about 90% of conventionally tilled yields. It should be noted that 2012 was the first year of strip tillage at the study site and yields are often reported to improve with more time in strip tillage. As in 2011, strip tillage performed significantly better in CS rotations than in continuous corn in 2012 (Table 5). The observation of greater vigor and height early in the season in strip tilled treatments relative to conventional tillage could indicate that the plant, receiving adequate soil moisture in the ST system early in development (and early in the drought), allocated greater photosynthate to the aboveground plant and less to the roots, leaving a smaller root system with reduced root volume and depth for obtaining moisture as the drought conditions worsened.

Technology Effects

All of the Technology traits tested in 2012 affected corn yield, but Hybrid Trait stood out among the others. Replacing the Syngenta non-Bt refuge hybrid with the same hybrid containing the corn rootworm (CRW) resistance trait (+HYBRID) increased yields by 31% relative to the TRAD package (averaged across the 6 Management Systems tested in this study; Appendix B). Similarly, when the corn rootworm resistant trait was replaced with the refuge hybrid in the HT package (-HYBRID), yields declined by 15% relative to the HT package (Appendix B). While we cannot account for the mechanism responsible for the dramatic yield increase provided by the CRW trait, our data suggest that the CRW trait confers greater stress resistance to a variety of environmental stressors, including drought. The Hybrid effect was more dramatic in continuous corn systems than CS rotations, although it was a significant factor in both Rotation systems. In continuous corn systems, the effect of reducing plant population (-POP) mimics the effect of adding CRW to the TRAD package (+HYBRID), supporting our suggestion that the CRW trait makes plants more competitive for limited resources, namely water, perhaps by making the root system larger, more effective at water uptake, or more efficient in terms of water use.

Although less dramatic than the Hybrid effect, and counter to what we expected, there was a consistent effect of strobilurin fungicide in 2012. In general, yield increased when fungicide was omitted from the HT package and decreased when fungicide was applied to the TRAD package (Table 6). A significant yield increase was obtained when fungicide was omitted from the HT package in all 6 Management Systems, averaging an 8% yield increase. Yield reduction resulting from adding fungicide application to the TRAD package was less consistent, occurring in just 2 of the 6 Management Systems. The strobilurin effect observed in 2012 was opposite that of the strobilurin effect measured in 2010, another, albeit less severe, drought season. In 2010, yields increased by 9% when strobilurin was applied to the TRAD package and decreased by 11% when it was omitted from the HT package (Ruffo et al., in preparation). Despite contradictory results between years, we are confident that the strobilurin effect observed in both drought years is related to its effect as a growth regulator rather than its fungicidal properties. Strobilurin has been shown to extend the growing season of the crop by delaying plant senescence and prolonging the photosynthetic capacity of the plant (Bartlett 2002), a side-effect of strobilurin referred to as the “stay green” effect. Our data suggests that, by increasing the window for photosynthesis to occur, strobilurin chemicals counteract the effect of abbreviated grain-fill period and reduced photosynthetic leaf area associated with drought stress. In this way, if weather becomes more amenable during grain fill, it is possible to overcome previous negative drought effects by increasing kernel weight (as seen in 2010). However, during a prolonged and intensive drought that extends through the grain-fill period, the prolonged window for photosynthesis can actually work to the detriment of yield, reducing grain weight and increasing kernel abortion.

The third most influential Technology treatment tested in 2012 was plant Population. Increasing plant population is a necessary management practice for increasing corn yields to the 300+ bu a^{-1} goal. However, greater plant populations also introduce more inter-plant competition for light, moisture, and nutrients, greater pest management issues, and, in general, greater yield variability. Since precipitation in June, July, and August were only 41% of the long-term average, drought stress was a major yieldlimiting condition in 2012, particularly in the high population systems. The -POP treatment resulted in a yield increase of 31 bu a^{-1} relative to the HT package when stover was retained and 5 bu a^{-1} when stover was removed. The relative difference in yield increase between stover retained and stover removed systems may suggest that stover removal allows continuous corn systems to better support a high plant population under drought stress conditions; however, it may also result from greater moisture availability under severe drought conditions, as discussed previously. The –POP treatment in the CS system only resulted in a 2 bu a^{-1} yield increase for CT and 8 bu a^{-1} yield increase for ST relative to the HT package, suggesting that CS rotations are better able to support high plant populations during adverse growing seasons, like 2012 (Table 6) and 2011. As expected, increasing plant population without changing other management practices (+POP) resulted in significant yield reductions for all of the 6 Management Systems tested in this study with yield reductions ranging from 7 to 35 bu a^{-1}.

Application of N, P, S, and Zn fertilizers demonstrated significant effects unique to severe drought conditions. In most years, adding fertility factors to the TRAD package increases corn yield (relative to the TRAD treatment); likewise, omitting fertility factors from the HT package reduces corn yield (relative to the HT treatment). In 2012, however, omitting fertility factors from the HT package often resulted in yield increases rather than yield reductions. In the high-population, high-input HT package, omission of the N sidedress application (-N) increased corn yields in 3 of the 6 Management Systems by 23-25 bu a^{-1}. Addition of sidedress N application to the TRAD package only resulted in one significant yield effect, an 8 bu a^{-1} yield reduction (Table 6). Although the sidedress N application was apparently detrimental to crop yield in 2012, it was not because the drought caused the crop to be non-N responsive. Nitrogen fertilizer applications resulted in yield increases ranging from 20 to 67 bu a^{-1} above N check plot yields (Table 6). Nitrogen fertilizer application benefited continuous corn systems much more than CS rotation. It is interesting to note that N check plot yields in CS treatments are 2.5 to 3 times greater than those of continuous corn, illustrating the much greater N availability of CS rotations (Gentry et al. 2013). The addition of P, S, and Zn fertilizer (+FERT) had the expected result of increasing yields (relative to the TRAD treatment) in 4 of 6 Management Systems. In one Management System, adding P, S, and Zn to the TRAD package reduced yield. Yields increased in 3 Management Systems when P, S, and Zn were omitted from the HT package, similar to the effect observed when sidedress N was omitted from the HT package.

Yield Summary

Hybrid trait, specifically CRW-resistance traits, played a critical role in protecting corn yields from yield loss during the drought of 2012. This data directly supports previous work from this research group indicating that the yield penalty associated with continuous corn is much greater under drought conditions (Gentry et al. 2013). Reduced plant populations and omission of fungicide also improved crop yields during the severe drought of 2012. P, S, and Zn fertilizers had generally positive results when applied to the TRAD package, increasing yields by an average of 6 bu a^{-1}, but N, P, S, and Zn applications actually reduced grain yields when applied to the high-population, high-input HT package. During poor growing seasons, like 2012, corn-soybean rotations are more likely to support high plant populations than continuous corn. Stover removal was effective for high-population, conventionally tilled continuous corn systems, but did not provide a yield advantage to other systems under the poor growth conditions of 2012. Reduced surface residues in corn-soybean rotations appear to have made soil moisture penetrate the residue/soil interface and move deeper in the soil profile, as evidenced by soil moisture readings at 5 depths in 4 Management Systems in this study. During a severe drought, such as 2012, accumulation of residue on the soil surface appears to have made rainfall less root-available by sequestering the moisture in the residue where it was more vulnerable to rapid evaporation.

Roots

Root biomasses, sampled immediately after harvest, demonstrated significant differences ($P<0.10$, Table 4) for System, Tillage, and Technology. There was also a significant interaction effect for System x Tillage. In general, removing stover in the CC system reduced per-plant root biomass by an average of 15% in conventionally tilled systems but did not affect root biomass in strip tilled systems (Table 7). Among the HT factors and for conventionally tilled systems, corn root biomass was greater in CC systems than in CS rotations. With conventional tillage, there was a consistent effect of stover removal in CC systems: stover removal reduced corn root biomass. This effect was less consistent in strip tilled systems. When stover was retained in CC systems, conventionally tilled systems generally had greater root biomasses than strip tilled systems, at least to the soil depths measured. When stover was partially removed in CC systems, there was little effect of tillage on root biomass among the High Technology factors (high inputs with high plant populations), but reduced levels of inputs and plant populations (TRAD factors) demonstrated reduced root biomass in strip tillage systems relative to conventional tillage, at least to the soil depths measured. Based on root data from this study measured in 2011, we found that root biomass of corn declines under increased plant populations. These findings were confirmed by 2013 results; as seen in Table 7, all of the HT factors (45k plants acre^{-1}) except for –POP demonstrate reduced root biomasses relative to the TRAD factors (32k plant acre^{-1}). This data indicates that smaller root systems inherent in high-population systems must be supported with complete crop nutrition and advanced crop genetics in order to maintain healthy roots and optimum crop productivity.

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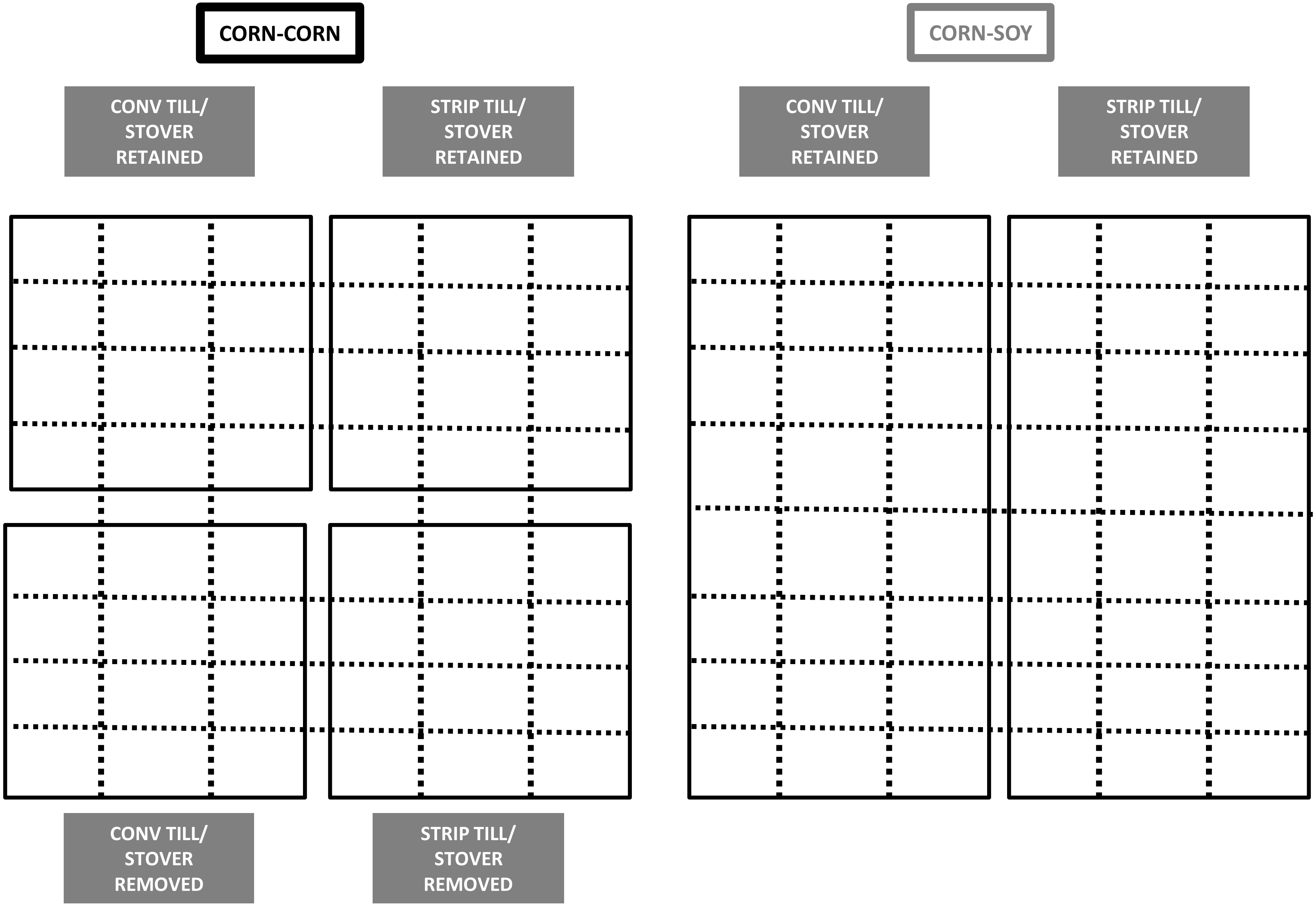

Figure 1. Experimental design of one replication of the study. The 12 treatments are repeated in each quarter-plot of each rotation (corn-corn or corn-soy) plot. The four quarter-plots (conventional tillage+stover, conventional tillage-stover, strip tillage+stover, strip tillage-stover) assess residue 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 Sustainability Omissions Plot Design. The six subplot treatments are plant population, hybrid traits, N rate, other nutrients, and crop protection inputs (fungicide).

TRT #	TECHNOLOGY	POP	HYBRID[1]	N[2]	FERT.	FUNGICIDE
1	HIGH TECHNOLOGY	45K	MULTI-TRAIT	BASE+SLOW REL	MESZ	STROBILURIN
2	-FERTILITY	45K	MULTI-TRAIT	BASE +SLOW REL	NONE	STROBILURIN
3	-NITROGEN	45K	MULTI-TRAIT	BASE	MESZ	STROBILURIN
4	-HYBRID TRAIT	45K	REFUGE	BASE+SLOW REL	MESZ	STROBILURIN
5	-POPULATION	32K	MULTI-TRAIT	BASE+SLOW REL	MESZ	STROBILURIN
6	-FUNGICIDE	45K	MULTI-TRAIT	BASE +SLOW REL	MESZ	NONE
7	TRADITIONAL	32K	REFUGE	BASE	NONE	NONE
8	+FERTILITY	32K	REFUGE	BASE	MESZ	NONE
9	+NITROGEN	32K	REFUGE	BASE+SLOW REL	NONE	NONE
10	+HYBRID TRAIT	32K	MULTI-TRAIT	BASE	NONE	NONE
11	+POPULATION	45K	REFUGE	BASE	NONE	NONE
12	+FUNGICIDE	32K	REFUGE	BASE	NONE	STROBILURIN

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[1] Multi-traits comprised glyphosate tolerance and corn rootworm resistance; refuge hybrid only contained glyphosate tolerance

[2] Nitrogen fertilizer base rate was 180 lb N a^{-1} as either UAN or SuperU

Table 2. Site summary data for the 2012 field site (Fisher 600). Soil test nutrient levels measured in Fall 2011 are listed for continuous corn (C-C) and corn-soybean (C-S) rotation split blocks.

Rotation	NO_3^- (ppm, 0-42”)	P (ppm, 0-6”)	K (ppm, 0-6”)	S (ppm, 0-6”)	S (ppm, 6-24”)	Zn (ppm, 0-6”)
C-C	16	35	125	15	26	2
C-S	20	35	112	13	25	2

Table 3. 2012 in-season monthly average air temperature, total precipitation, and growing degree days (GDD, base 50), reported for Champaign IL, monthly average values (1981-2010) provided in parentheses. Data obtained from Nexrad (monthly temp, precip, and GDD), NOAA National Climatic Data Center (average temp and precip), and climate.com (30-yr GDD avg, via Nexrad).

	April	May	June	July	August	September	October
Temp (°F)	55 (41)	69 (63)	72 (72)	81 (75)	73 (73)	65 (66)	52 (54)
Precipitation (in.)	2.59 (3.68)	2.30 (4.89)	2.12 (4.34)	0.00 (4.70)	3.25 (3.93)	5.94 (3.13)	4.27 (3.26)
GDD	167 (199)	590 (398)	655 (650)	939 (768)	700 (718)	449 (489)	149 (237)

Table 4. P-values describing sources of variation for corn yield and per-plant root biomass, 2012. Main plot treatment was System (Continuous Corn-Stover Retained, Continuous Corn-50% Stover Removed, and Corn-Soy-Stover Retained). Split-plot treatment was Tillage (conventional tillage vs. strip tillage). Omission split-split plot treatments (Technology) were Fertility, Hybrid, Nitrogen, Population, and Fungicide.

Sources of Variation	**Grain Yield**	**Root Biomass**
SYSTEM	<0.0001	0.0001
TILLAGE	0.0013	0.0025
TECHNOLOGY	<0.0001	<0.0001
SYSTEM*TILLAGE	0.5054	0.0128
SYSTEM*TECHNOLOGY	0.4664	0.2508
TILLAGE*TECHNOLOGY	0.9508	0.2477
SYSTEM*TILLAGE*TECHNOLOGY	0.9992	0.2482

Table 5. Summary of 2012 corn yields for High Technology and Traditional Technology treatments for System (continuous corn/stover retained [CC], continuous corn/stover removed [CCRM] and corn-soybean/stover retained [CS]), and Tillage (conventional tillage and strip tillage).

	Corn Yields (bu acre^{-1})			
	CC	CCRM	CS	Average
Conv. Tillage – High Tech.	95	113	168	136
Conv. Tillage – Traditional	85	83	138	115
Strip Till – High Tech.	87	90	156	122
Strip Till - Traditional	73	81	129	103

Table 6. 2012 corn grain yields (bu acre^{-1}) among Systems (Rotation/Stover Management), Tillage, and Technologies (omissions treatments)

	Corn Yield (bu acre^{-1}) for System & Tillage Treatments						
Technology	CC/RETAINED/CT[1,2]	CC/REMOVED/CT[1,2]	CS/CT[3,4]	CC/RETAINED/ST[1,2]	CC/REMOVED/ST[1,2]	CS/ST[1,2]	*Average (for Technology)*[3]
HIGH TECH	**95**	**113**	**168**	**87**	**90**	**156**	***129***
-FERT	109	107	161	89	99	169	*135*
-N	118	109	165	112	114	160	*138*
-HYBRID	80	88	149	67	65	138	*109*
-POP	126	118	166	124	111	164	*142*
-FUNGICIDE	122	124	158	106	116	168	*140*
0N Check Plot	51		134	47		133	
TRADITIONAL	**85**[4]	**83**	**138**	**73**	**81**	**129**	***108***
+FERT	91	95	147	89	67	137	*114*
+N	87	85	139	77	73	135	*109*
+HYBRID	132	130	149	119	123	149	*142*
+POP	61	62	126	62	46	122	*91*
+FUNGICIDE	72	81	128	72	77	130	*102*
0N Check Plot	43		118	40		99	
Average (for System/Tillage) [1,3]	*99*	*99*	*151*	*91*	*88*	*146*	

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[1] LSD (P<0.10) for Technology x System <u>within</u> Tillage (compare values within Conventional Tillage OR Strip Tillage treatments) is 18 bu a^{-1}

[2] LSD (P<0.10) for System x Tillage (compare values from various Technologies within a System x Tillage treatment) is 7.0 bu a^{-1}

[3] LSD (P<0.10) for Technology x System x Tillage (compare Technology values averaged across System and Tillage OR between System/Tillage treatments) is 24 bu a^{-1}

[4] One outlier removed from dataset

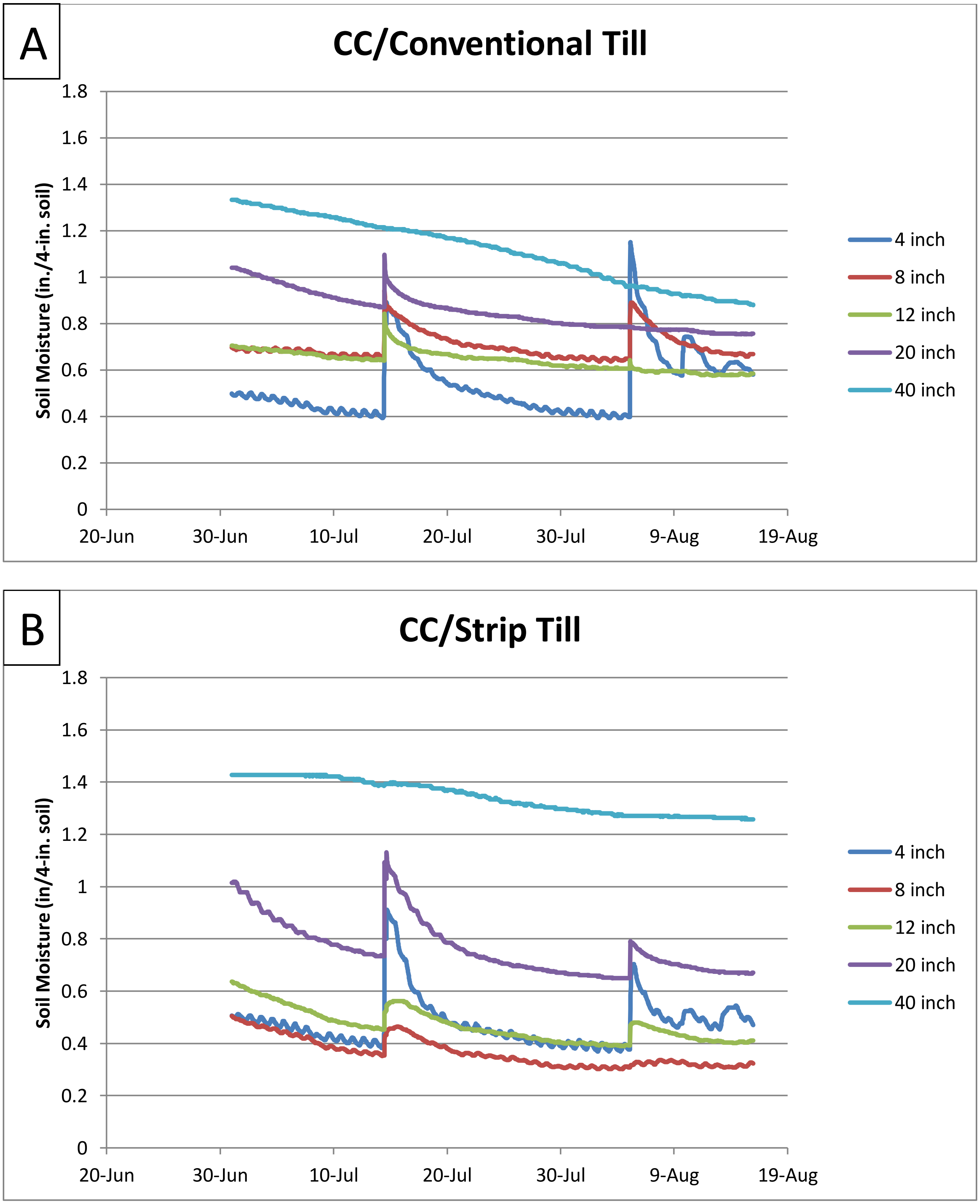

Figure 2. Soil Moisture of various Rotation/Tillage Management Systems, measured from July 1 through Aug. 15, 2012. A) Continuous corn (CC)/Conventional Tillage; B) CC/Strip Tillage; C) Corn-Soybean (CS)/Conventional Tillage; D) CS/Strip Tillage. Stover removal was not conducted in any of the systems represented here.

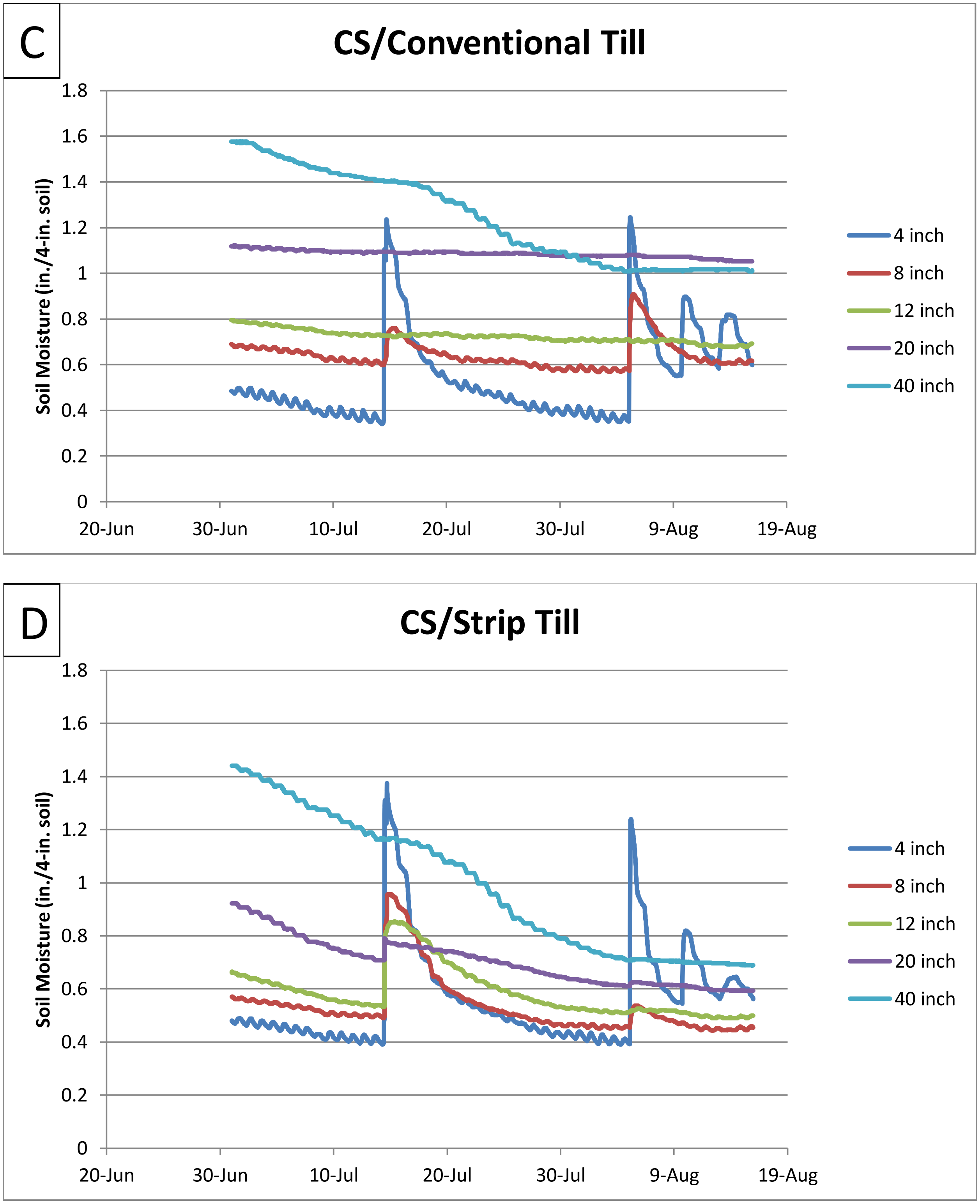

Figure 2, cont'd. Soil Moisture of various Rotation/Tillage Management Systems, measured from July 1 through Aug. 15, 2012. A) Continuous corn (CC)/Conventional Tillage; B) CC/Strip Tillage; C) Corn-Soybean (CS)/Conventional Tillage; D) CS/Strip Tillage. Stover removal was not conducted in any of the systems represented here.

Table 7. 2012 corn root biomass (g plant^{-1}) among Systems (Rotation/Stover Management), Tillage, and Technologies (omissions treatments)

	Corn Root Biomass (g plant^{-1}) for System & Tillage Treatments						
Technology	CC/RETAINED/CT	CC/REMOVED/CT	CS/CT	CC/RETAINED/ST	CC/REMOVED/ST	CS/ST	*Average (for Technology)*[3]
HIGH TECH	**13.09**	**11.26**	**9.95**	**11.93**	**11.69**	**10.13**	***11.01***
-FERT	11.69	11.94	10.99	12.78	11.59	11.21	*11.55*
-N	11.48	10.73	11.04	10.14	13.44	11.41	*11.34*
-HYBRID	14.69	10.66	13.59	11.76	13.73	10.18	*12.30*
-POP	20.11	12.42	13.87	15.08	15.36	12.92	*14.57*
-FUNGICIDE	13.74	10.33	13.20	11.93	13.33	8.08	*11.49*
0N Check Plot	12.83		10.52	10.70		8.60	
TRADITIONAL	**19.21**	**15.35**	**14.31**	**10.82**	**12.21**	**12.23**	***13.84***
+FERT	17.84	15.44	11.78	15.27	12.14	11.39	*13.38*
+N	13.76	13.44	14.41	15.59	12.14	14.81	*14.18*
+HYBRID	16.49	15.23	14.16	13.78	13.81	12.58	*14.10*
+POP	16.84	10.54	11.84	11.03	12.38	11.27	*12.13*
+FUNGICIDE	15.10	12.66	14.98	14.74	13.08	12.63	*13.85*
0N Check Plot	11.15		14.92	11.98		13.40	
Average (for System/Tillage) [1,3]	*14.64*	*12.50*	*12.83*	*12.59*	*12.91*	*11.51*	

Appendix A. 2012 corn yield averages, bu a^{-1}. Data provided for 3 systems of Rotation and Stover Management (Continuous Corn/Stover Retained; Continuous Corn/Stover Removed; Corn-Soy Stover Retained), 2 tillage systems (conventional full-width tillage, strip-tillage), and 12 Technology treatments. Percent differences (% diff) display the difference between the + treatments (+FERT, +N, +HYBRID, +POP, AND +FUNGICIDE) relative to the traditional-input treatment (TRAD) and the – treatments (-FERT, -N, -HYBRID, -POP, AND -FUNGICIDE) relative to the high-input, high-technology treatment (HIGH TECH).

ROTATION	RES MNGMNT	TILLAGE	TECHNOLOGY	YIELD (bu/a)	% DIFF
CORN-CORN	RETAINED	CONV	**HIGH TECH**	**95**	
			-FERT	109	15
			-N	118	24
			-HYBRID	80	**-16**
			-POP	126	33
			-FUNGICIDE	122	28
			TRAD	**85**[5]	
			+FERT	91	7
			+N	87	2
			+HYBRID	132	55
			+POP	61	**-28**
			+FUNGICIDE	72	**-15**
	C-C STOVER RETAINED CONV TILL AVERAGE YIELD			99	
		STRIP	**HIGH TECH**	**87**	
			-FERT	102	17
			-N	112	29
			-HYBRID	67	**-23**
			-POP	124	42
			-FUNGICIDE	106	22
			TRAD	**73**	
			+FERT	89	22
			+N	77	5
			+HYBRID	119	63
			+POP	62	**-15**
			+FUNGICIDE	72	**-1**
	C-C STOVER RETAINED STRIP TILL AVERAGE YIELD			91	
CORN-CORN STOVER RETAINED AVERAGE YIELD				95	

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[5] one outlier removed from dataset

Appendix A, continued

ROTATION	RES MNGMNT	TILLAGE	TECHNOLOGY	YIELD (bu/a)	% DIFF
CORN-CORN	REMOVED	CONV	**HIGH TECH**	**113**	
			-FERT	107	**-5**
			-N	109	**-3**
			-HYBRID	88	**-22**
			-POP	118	4
			-FUNGICIDE	124	10
			TRAD	**83**	
			+FERT	95	14
			+N	85	2
			+HYBRID	130	57
			+POP	62	**-25**
			+FUNGICIDE	81	**-2**
	C-C STOVER REMOVED CONV TILL AVERAGE YIELD			99	
		STRIP	**HIGH TECH**	**90**	
			-FERT	99	10
			-N	114	27
			-HYBRID	65	**-28**
			-POP	111	23
			-FUNGICIDE	116	29
			TRAD	**81**	
			+FERT	67	**-17**
			+N	73	**-10**
			+HYBRID	123	52
			+POP	46	**-43**
			+FUNGICIDE	77	**-5**
	C-C STOVER REMOVED STRIP TILL AVERAGE YIELD			88	
CORN-CORN STOVER REMOVED AVERAGE YIELD				94	
CORN-CORN AVERAGE YIELD					94

Appendix A, continued

ROTATION	RES MNGMNT	TILLAGE	TECHNOLOGY	YIELD (bu/a)	% DIFF
CORN-SOY	-	CONV	**HIGH TECH**	**168**	
	-		-FERT	161	**-4**
	-		-N	165	**-2**
	-		-HYBRID	149	**-11**
	-		-POP	166	**-1**
	-		-FUNGICIDE	158	**-6**
	-		**TRAD**	**138**	
	-		+FERT	147	6
	-		+N	139	1
	-		+HYBRID	166	20
	-		+POP	126	**-9**
	-		+FUNGICIDE	128	**-7**
	C-S CONV TILL AVERAGE			151	
	-	STRIP	**HIGH TECH**	**156**	
	-		-FERT	169	8
	-		-N	160	3
	-		-HYBRID	138	**-11**
	-		-POP	164	5
	-		-FUNGICIDE	168	8
	-		**TRAD**	**129**	
	-		+FERT	137	6
	-		+N	135	5
	-		+HYBRID	149	15
	-		+POP	122	**-5**
	-		+FUNGICIDE	130	1
	C-S STRIP TILL AVERAGE			146	
CORN-SOY AVERAGE YIELD					149
AVERAGE YIELD, ALL TREATMENTS					122

Appendix B. Most influential treatments based on yield differences compared with the High Technology (HT) or Traditional (TRAD) treatment.

MANAGEMENT SYSTEM	**Greatest Yield INCREASES among Technology Trts**	**% Change[6]**	**Greatest Yield DECREASES among Technology Trts.**	**% Change[6]**
CC/RETAINED/CT	1. +HYBRID	+55%	1. +POP	-28%
	2. –POP	+33%	2. –HYBRID	-16%
	3. –FUNG	+28%	3. +FUNG	-15%
CC/REMOVED/CT	1. +HYBRID	+57%	1. +POP	-25%
	2. +FERT	+14%	2. –HYBRID	-22%
	3. –FUNG	+10%	3. –FERT	-5%
CS/CT	1. +HYBRID	+20%	1. –HYBRID	-11%
	2. +FERT	+6%	2. +POP	-9%
	3. +N	+1%	3. +FUNG	-7%
CC/RETAINED/ST	1. +HYBRID	+63%	1. –HYBRID	-23%
	2. –POP	+42%	2. +POP	-15%
	3. –N	+29%	3. +FUNG	-1%
CC/REMOVED/ST	1. +HYBRID	+52%	1. +POP	-43%
	2. –FUNG	+29%	2. –HYBRID	-28%
	3. –N	+27%	3. +FERT	-17%
CS/ST	1. +HYBRID	+63%	1. –HYBRID	-11%
	2. –FUNG	+8%	2. +POP	-5%
	3. –FERT	+8%	3. -	-

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[6] relative to HT (for +TECHNOLOGY treatments) or TRAD (for –TECHNOLOGY treatments)