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AGRONOMY AND SOILS

Long-Term Cotton Yield Impacts from Cropping Rotations and Biocovers under No-Tillage

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ABSTRACT

Sustaining crop yields assumedly entails crop rotations and biocovers. To test this, cropping sequences and biocover effects on cotton (*Gossypium hirsutum* L.) yields were assessed under long-term no-tillage. Main plots were eight cropping sequences of cotton, corn (*Zea mays* L.), and soybean (*Glycine max* L.) on a Loring silt loam at the Research and Education Center at Milan, TN. Sequences were repeated in 4-yr cycles (i.e., Phases I, II, and III) from 2002 to 2013. Split-plots were biocovers, which consisted of hairy vetch (*Vicia villosa* L.), Austrian winter pea (*Pisum sativum* L. *sativum* var. *arvense*), wheat (*Triticum aestivum* L.), poultry litter, and fallow control. Continuous cotton had greater yield than cotton grown in rotations [3.1 and 2.8 Mg ha^{-1}, respectively; *p* = 0.02 (averaged across biocovers and phases)]. Biocover did not increase yield in continuous cotton ($p > 0.05$). However, various cropping sequences did result in higher yield than continuous cotton within 4-yr cycles. Specifically, corn-corn-soybean-cotton rotations were highest yielding during Phase II (4.0 Mg ha^{-1}), which was equivalent to cotton-corn-cotton-soybean (3.5 and 3.8 Mg ha^{-1}, respectively); and cotton-corn-cotton-corn during Phases II and III (3.6 and 3.8 Mg ha^{-1}, respectively). All aforementioned rotations increased yield above continuous cotton during Phases I and III ($p < 0.05$). Results indicate increasing cropping diversity with one and two years of soybean or corn, respectively, in a 4-yr cycle maintains cotton seed yield long-term.

Crop rotations have been reported as effective strategies for increasing crop yields compared to continuous cotton (*Gossypium hirsutum* L.) (Reddy et al., 2006). Although some studies have suggested that crop yields could further be improved by using longer rotations, such as adding a third crop to the rotation. Despite reported cotton yield increases from cropping rotations, monoculture cotton is still a prominent production practice (Mitchell and Entry, 1998; Reddy et al., 2006; Wesley et al., 2001). Reported yield increases might be due to greater residue diversity and soil health (Havlin et al., 1990). Cotton/corn (*Zea mays* L.) rotations can increase soil organic carbon (SOC) compared to continuous cotton (Mitchell and Entry, 1998), mainly due to amounts of corn biomass produced. Given that crop rotations and winter cover can alleviate some of the problems associated with no-till, as well as improve yields, research into their combined effects on crop yields in a no-till system is necessary to make best management recommendations.

As concerns about climatic change increase, so does emphasis on finding methods for reducing greenhouse gas emission in agriculture. No-tillage has been proposed as a way to store photosynthetic C and offset elevated atmospheric CO_2, thereby acting as a C sink (Ashworth et al., 2014; Lal, 2009; West and Post, 2002). Among all annual conservation tillage practices, no-tillage creates the least amount of soil disturbance, as planters use a disk or coulter to cut a narrow furrow during sowing rather than mixing upper horizons (Angers and Giroux, 1996). No-tilled cotton can produce similar yields to those achieved under conventional tillage (Pettigrew and Jones, 2001; Schwab et al., 2002; Triplett, 1996). As of 2007, the acreage of no-till planted cotton in Tennessee was 80% (NASS, 2008).

No-till can eliminate some benefits associated with tillage, primarily in terms of reduced pest control (Parvin et al., 2004; Reddy et al., 2004; Smith et al., 1992). Crop rotation and biocovers can become important elements in a no-till system to compensate for this. Crop rotation can disrupt weed cycles compared to continuous cropping. Biocovers also protects soils from erosion, increases SOC and aggregate stability, provides weed control by niche differentiation, and improves crop nutrition, thereby

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increasing yields (Snapp et al., 1998). However, the extent of this is unknown for cotton in soils previously under long-term no-tillage. Therefore, more region-specific data are needed on cotton yield response to biocover and crop rotation.

Because biocovers can affect SOC, nitrogen (N), soil structure, and pest population levels, it also can impact crop yields that are directly impacted by changes in these factors. Research shows mixed results when examining effects of biocovers on cotton yields, with differences varying according to cover crops. Lower cotton yields have been observed with winter wheat, but increased with hairy vetch (*Vicia villosa* L.) as a cover crop (Larson et al., 2001). Cotton yields have reportedly increased with winter rye (*Secale cereale* L.) and poultry litter compared to cotton/fallow yields (Reddy et al., 2004). Similarly, bi-cultures of rye and legume cover crops reportedly increased SOC levels compared to monoculture cropping, due in part, to higher biomass produced by the bi-culture systems (Sainju et al., 2005). Consequently, research is needed on the combined effects of cropping sequences and biocovers on cotton yields in long-term no-till systems. Therefore, the primary objective of this study was to determine effects of various cropping sequences, biocovers and its interaction with cropping sequences, and biocover on cotton yields under a long-term no-till management system in the southeast.

MATERIALS AND METHODS

Site Description and Experimental Design. The study was conducted under long-term no-tillage where crops were planted directly into the previous crop residue to evaluate cropping system impacts. The experiment was located at the Research and Education Center at Milan, TN (RECM; 35.54^o N, 88.44^o W) in the Eastern Gulf Coastal Plain that covers most of western Tennessee, western Alabama, a major portion of Mississippi, eastern Louisiana, and a small section of western Kentucky (NRCS MLRA 134 classified as Southern Mississippi Valley Loess, East Gulf Coastal Plain in LRR "P"). Soils at RECM are classified as a Loring series (Fine-silty, mixed, thermic Oxyaquic Fragiudalf) and the site has a mean annual precipitation of 135 cm and a mean annual temperature of 16.6^{o}C. The April to September and 30-yr average rainfall and temperature data for each of the study years are presented in Table 1. Phase II (2006-2009) tended to have more deviations from normal compared to Phases I and III. This site was under no-till for 16 yr prior to initiating the experiment. During the 3 yr previous to this study, the site was planted to wheat double cropped with cotton in 1998 to 1999, wheat double cropped with soybean in 1999 to 2000, and wheat double cropped with corn in 2000 to 2001. Winter cover crop treatments were established in the winter of 2001.

Table 1. Total monthly precipitation (rain) and mean monthly air temperature (MT) at the Research and Education Center at Milan, TN, from April to September during 2002 to 2013. Weather data were taken at the research center and obtained from the U.S National Oceanic and Atmospheric Administration

Year	April		May		June		July		August		September	
	Rain	MT	Rain	MT	Rain	MT	Rain	MT	Rain	MT	Rain	MT
	cm	*°C*	*cm*	*°C*	*cm*	*°C*	*cm*	*°C*	*cm*	*°C*	*cm*	*°C*
2002	4.5	17.0	13.4	18.9	5.8	25.2	3.5	27.3	16.8	26.0	28.7	22.7
2003	8.6	16.1	27.8	20.4	8.0	22.1	5.9	26.0	11.4	25.9	8.6	20.1
2004	20.7	21.4	11.7	27.7	12.8	29.6	5.3	30.8	12.3	29.9	0.8	28.7
2005	19.2	15.0	1.5	18.5	12.9	24.0	13.5	25.9	20.5	26.6	9.6	22.6
2006	8.3	18.1	12.8	19.8	15.1	23.9	9.0	26.6	8.4	26.9	11.4	19.8
2007	8.4	13.1	5.8	21.7	11.2	24.8	5.5	25.5	3.2	29.6	18.4	22.7
2008	24.1	14.1	23.9	19.3	3.9	25.5	7.9	26.6	1.9	25.1	1.1	22.7
2009	8.2	14.9	23.0	20.1	5.6	26.0	20.1	24.6	5.7	24.5	12.0	22.4
2010	15.2	17.1	53.5	21.8	8.2	27.5	15.1	27.6	5.0	27.8	0.9	23.1
2011	24.9	10.9	28.5	13.8	17.3	20.4	3.6	22.0	2.9	19.5	25.9	14.1
2012	3.1	16.5	4.1	22.6	4.7	24.3	12.2	28.4	11.7	25.9	12.9	21.9
2013	27.6	14.2	24.8	19.5	13.8	24.9	17.7	24.5	7.4	24.8	15.0	22.4
30 yr avg[z].	14.9	11.6	14.2	19.9	10.9	24.4	10.0	26.2	8.4	25.7	9.0	21.5

[z] 30 yr avg. represent averages from 1981-2010

The experiment was conducted as a split-block treatment design with four blocks. Whole-block treatments consisted of cropping sequences (see Table 2 for whole plot sequences), with split-block treatments comprised of four biocovers. Plot sizes were 6.1 x 12.2 m with eight different cropping sequences of cotton, corn, and soybean repeated in 4-yr cycles (assigned as Phases I, II, and III; Table 2) from 2002 to 2013. Biocovers of wheat, vetch, poultry litter, and a fallow (winter weeds) control were repeated annually under no-tillage production. This created 32 sequence x biocover combinations. In 2012, extreme drought (11.9-cm precipitation April-June; Table 1) and high temperatures (Table 1) occurred, and consequently crop establishment failures ensued; therefore, these data were not included in Phase III (2010-2013) of this study.

Table 2. Cropping sequences 2002 (Yr-0) to 2013 (Yr-12) at the Milan Research and Education Center, Milan, TN

Crop Sequence	Year			
	2002[z] 2006 2010	2003 2007 2011	2004 2008 2012	2005 2009 2013
1	cotton	cotton	cotton	cotton
2	soybean	cotton	soybean	cotton
3	corn	corn	soybean	cotton
4	corn	cotton	soybean	corn
5	cotton	soybean	cotton	corn
6	cotton	soybean	corn	cotton
7	cotton	corn	cotton	soybean
8	cotton	corn	cotton	corn

[z] 2002-2005 = Phase I; 2006-2009 = Phase II; 2010-2013 = Phase III

Crop Establishment and Treatment Maintenance. Glyphosate-resistant (GR) cotton cultivars Paymaster PM 1218 BG/RR (2002-2005) and Delta Pine DP 117 RRBG (2006-2009) were used in Phases I and II, respectively. GR corn hybrids were DeKalb DKC 6410 RR (2002-2005), DeKalb DKC63-81 RR2/YGCB (2006-2008), and DeKalb 63-42 (2009). The GR soybean cultivar USG 7440nRR was used for Phases I and II (2002-2009). Phase III cultivars were Phytogen 375 cotton; Augusta 6867 corn; and Halo 4:65 soybean. All cotton, corn, and soybean plots were planted at recommended University of Tennessee seeding rates of 64,495; 64,247; and 258,334 to 344,445 seeds ha^{-1}, respectively.

Cotton was planted with a John Deere 1710 Maxemerge planter (Deere and Company, Moline, IL) in 101.6-cm–wide rows in plots that were 6.1 x 12.2 m, thus creating 6-row plots. Cotton was planted between 7 and 12 May, and harvest occurred between 10 September and 25 October. Two-row centers were harvested each year with a IH 1822 cotton picker (Case, Amsterdam, Netherlands). Yield measurement taken during harvests was seed cotton weight on a per plot basis.

Corn was planted in 76.2-cm–wide rows in plots that were 6.1 x 13.7 m with a John Deere 1700 Maxemerge planter, thus creating 8-row plots. During the 12 study years, corn was planted between 12 April and 9 May. Eight-row plots of soybean were planted with a John Deere 1700 Maxemerge planter in 76.2-cm–wide rows in plots that were 6.1 x 13.7 m. Planting dates were between 29 April and 30 May.

Poultry litter was analyzed each year for N content prior to application (A&L Analytical Laboratories, Inc., Memphis, TN). Poultry litter biocover plots received the equivalent of 66.7 kg N ha^{-1} (approximately 4.4 tonne ha^{-1}; assuming 50% bioavailable) annually from 1 March and 15 April. Similarly, wheat and fallow biocover treatments received 66.7 kg N ha^{-1}, whereas vetch and Austrian winter pea (*Pisum sativum* L. *sativum* var. *arvense*) received 50.4 kg N ha^{-1} in the form of urea (CH_4N_2O) prior to planting (due to calculated N contribution from vetch). Corn plots received 128.5 kg N ha^{-1} and cotton plots received 33.4 kg N ha^{-1} as sidedress applications in May to June each year. Muriate of potash (K_2O) was applied to all plots in April of each year at a rate of 112 kg ha^{-1}.

Austrian winter pea, wheat, and hairy vetch biocovers were planted with a John Deere 1560 drill. Row spacing was 19 cm in 13.8 x 104.6-m strips planted perpendicular to crop rows. Initially, canola (*Brassica napus* L.) was included in this study, but due to failures in establishment during the first Phase (2002-2005), this species was replaced with Austrian winter pea starting in Phase II. Austrian winter pea, hairy vetch (cultivar Auburn Early), and wheat cover crops were seeded at a rate of 56, 34, and 100 kg pure live seed ha^{-1}, respectively. Biocover was planted approximately mid-October through mid-November during the previous cropping year, and then terminated with herbicides prior to planting the following year.

Before planting, burndown herbicides were used to kill existing vegetation and biocover. Either paraquat (1,1-Dimethyl-4,4-bipyridinium), glyphosate (*N*-(phosphonomethyl)-glycine), or glufosinate ammonium [ammonium(±)-2-amino-4-(hydroxymethylphosphinyl)butanoate] were applied in April of each year 2 to 3 wk prior to corn, soybean, and cotton planting. One or two applications of glyphosate were applied post-emergence to cotton, soybean, and corn plots in May or June of each year. Insecticide and crop growth regulation chemicals were applied to cotton as needed from June through September each year. Glyphosate, glufosinate, and clethodim (RS)-2-9[(E)-1-[(E)-3-chloroallyloxyimino] propyl]-5-[2-(ethylthio) propyli]-3-hydroxycyclohex-2-en-1-l-one] were the most common herbicides used all 12 study years. Defoliant (S,S,S-tributyl phosphorotrithioate), Bidrin (dimethyl phosphate of 3-hydroxy-N,N-dimethyl-cis-crotonamide), and Pix (1,1-dimethylpiperidinium chloride) also were used for additional insect control and plant growth regulation.

Soil Sampling and Analysis. At the termination of Phase III (spring 2014), soil tests were conducted on a per plot basis to a 0 to 15-cm depth to determine soil pH and concentrations of P, K, Mg, and Ca, as well as percentage C and N. Samples were ground to pass through a 1-mm sieve on a Wiley soil crusher (Thomas Scientific, Swedesboro, NJ) and Mehlich-1 extractable nutrients were measured by inductively coupled plasma using a 7300 ICP-OES DV (Perkin-Elmer, Waltham, MA). Soil pH was determined on a 1:1 soil-to-water ratio using an AS3010D Dual pH Analyzer (Labfit, Burswood, Australia). In addition, percentage N and C was determined via combustion (weight loss on ignition; Schulte and Hopkins, 1996). Thereafter, all soil chemical data were converted to kilogram of nutrient on a per hectare basis using the surface 15-cm soil surface weight as 2,268,678 kg.

Analysis of Data and Model Development. Analysis of variance (ANOVA) tests of seed cotton yield and soil characteristics (i.e., pH, P, K, Ca, Mg, N, and C) were performed using the MIXED procedure of SAS (SAS Ver. 9.3; SAS Institute. Cary, NC). Contrast statements were used to test yield penalties from continuous cropping, as well as impacts from biocover and cropping sequence interactions. For the 12-yr dataset, cropping sequence (whole-plot) and biocover (split-plot) were considered fixed effects and phase (i.e., three 4-yr cycles) was considered as a repeated measure. For the repeated measure, an autoregressive covariance was tested and found to be unimportant by a likelihood ratio test, so repeated measures was dropped. Thereafter block and year were considered random effects. When main effects or interactions were found, mean separations were performed using the SAS macro "pdmix800" (Saxton, 1998) with Fisher's least significant difference (LSD) at a Type I error rate of 5% (SAS, 2007). Contrasts were implemented by defining new factors comparing continuous cotton with all rotations with soybean and corn occurring in sequences with cotton. Other contrasts were included to assess yield impacts from corn and soybean occurring once, twice, or thrice depending on sequence.

RESULTS AND DISCUSSION

Biocovers affected all terminal soil characteristics [i.e., pH, P, K, Ca, Mg, N, and C ($p < 0.05$)], with each variable being greatest under poultry litter treatments and all others being lower, excluding pH under the fallow control (Table 3). In addition, the fallow control was not different from all biocover treatments in terms of soil P, N, and C. Soil chemical characteristics also were affected by cropping sequence ($p < 0.05$). Soil P and pH were greatest under soybean/cotton/corn/soybean and soybean/cotton/soybean/cotton rotations, respectively, as was soil Mg, N, and C under the cotton/corn/cotton/corn rotation compared to long-term continuous cotton systems (Table 3). Carbon was generally greatest for rotations with higher sequence diversity compared to continuous cropping ($p < 0.05$; Table 3), perhaps due to greater residue diversity being favored by bacterial assemblages (Six et al., 2006).

Continuous cotton yields were higher than average yields from all rotations [continuous vs. all rotations (CvR)] (3.1 and 2.8 Mg ha^{-1}, respectively; $p = 0.02$), when averaged across biocovers and phases (4-yr cycles; Table 4). However, various cropping sequences did result in increases in yield over continuous cotton (within phase), as continuous cotton yielded lower than cotton grown in rotation during Phase III ($p < 0.0001$). Furthermore, main effects of phase ($p < 0.0001$) and cropping sequences (within 4-yr phases) impacted ($p < 0.0001$) cotton yields (Table 4), likely owing to intra-annual weather variance (Table 1). Conversely, biocover ($p = 0.06$) and interactions of cropping sequence x biocover (within phase) and phase x biocover did not impact yield ($p > 0.05$; Table 4). Similarly, there were no interactions ($p > 0.05$) among phases for biocover x crop sequence [continuous vs. all rotations (CvR)], phase x crop sequence (CvR), and biocover x crop sequence (CvR; Table 4).

Table 3. Soil characteristics to a 0-15-cm depth per cropping rotation and biocover treatment at the Research Education Center, Milan, TN during the end of Phase III (2014)

	pH	P	K	Ca	Mg	N	C
Rotation[z]		------------------	------------------	------------------	kg ha^{-1}	------------------	------------------
Ct/S/Ct/C	6.6 bc[y]	93.2 abc	203.3 cde	3,058 b	227.9 de	3,176 bcd	26,316 cde
Ct/Ct/Ct/Ct	6.5 cd	122.0 ab	253.9 a	2,916 bc	246.8 cd	3,176 bcd	23,8821 ef
Ct/S/C/Ct	6.3 e	97.0 abc	219.1 bcd	2,771 cd	247.8 bcd	3,403 ab	27,244 bcd
Ct/C/Ct/S	6.3 e	88.8 bc	220.7 bc	2,897 bc	266.4 abc	3,403 ab	28,358 bc
Ct/C/Ct/C	6.3 de	85.4 c	226.4 b	2,867 bc	277.7 a	3,403 ab	31,988 a
C/Ct/S/C	6.5 cd	79.6 c	222.8 bc	2,978 bc	271.1 ab	3,403 ab	29,677 ab
C/C/S/Ct	6.3 de	70.7 c	206.5 bcd	2,598 de	251.0 bcd	3,176 abc	27,677 bcd
S/S/C/Ct	6.8 ab	96.7 abc	206.3 bcde	2,896 bc	187.3 f	2,949 bc	23,821 ef
S/Ct/C/S	6.9 a	99.6 abc	168.8 g	3,340 a	181.3 f	2,949 cd	25,182 de
S/Ct/S/Ct	6.7 b	127.7 a	183.3 efg	2,964 bc	182.3 f	2,722 d	21,779 f
Biocover							
Austrian winter pea	6.3 c	56.2 b	161.6 cd	2,646 c	201.5 c	3,176 b	25,636 b
Fallow	6.6 ab	54.3 b	177.8 b	2,872 b	225.4 b	2,949 b	25,409 b
Hairy Vetch	6.3 c	55.2 b	154.9 d	2,744 bc	200.3 c	3,176 b	27,224 b
Poultry litter	6.7 a	234.1 a	368.4 a	3,401 a	315.4 a	3,629 a	29,716 a
Wheat	6.5 b	58.5 b	172.1 bc	2,777 bc	219.7 b	2,949 b	25,636 b

[z] C = corn; S = soybean; Ct = cotton per phase

[y] Means followed by a letter in common are not significantly different based on $p \leq 0.05$ within analyte and either cropping rotation or biocover.

Table 4. Analysis of variance results for cotton yields at the Milan Research and Education Center, Milan, TN. Cropping sequences were repeated in 4-yr cycles with biocover repeated annually from 2002 to 2013

Fixed effect	DF	F Value	Pr > F
Biocover	4	2.27	0.06
Continuous vs. All Rotations (CvR)	1	6.38	0.02
Biocover x CvR	4	0.74	0.56
Sequence(phase x CvR)	24	10.16	<0.001
Sequence x biocover (CvR)	32	0.32	0.99
Sequence x biocover (phase x CvR)	96	0.33	1.00
Phase	2	23.74	<0.001
Phase x biocover	8	4.46	0.12
Phase x CvR	2	2.55	0.08
Phase x biocover x CvR	8	0.73	0.67

Based on contrast results, varying impacts occurred when corn or soybean was included either once or twice within cotton rotations per phase, but both crops impacted cotton yields when included in rotations ($p < 0.05$). Averaged across all phases, including soybean once within a 4-yr cropping cycle with cotton resulted in equivalent yields to that of continuous cotton (2.8 and 3.1 Mg ha^{-1}, respectively; Table 5). However, including soybeans twice within a 4-yr rotation decreased cotton seed yield by 16% compared to continuous cotton across the entire study period ($p < 0.05$); whereas, including corn once within a phase decreased cotton yields compared to continuous cotton (2.7 and 3.1 Mg ha^{-1}, respectively) and doubling corn frequency provided equivalent seed cotton yield ($p > 0.05$). Consequently, these results indicate that increasing cropping sequence diversity by one and two years of soybean or corn, respectively in a 4-yr cycle did not improve cotton seed yield; however, including soybeans twice and corn once resulted in cotton yield penalties long-term. Rotation complexity is thought to enhance C sequestration under systems converted from conventional to no-tillage, due to more diverse substrate in above and belowground residues (Franzluebbers, 2005; McDaniel et al., 2013; Stockmann et al., 2013). Therefore, high-residue crops, such as corn were expected to result in greater cotton yields; however, this hypothesis was not supported in our region and under soils tested herein ($p > 0.05$).

Table 5. Contrast statement results from soybeans and corn occurring once or twice within a 4-yr rotation (i.e., Phases I, II, and III) from 2002 to 2013 compared to continuous cotton systems at Research and Education Center, Milan, TN

Cotton in rotation vs. continuous cropping	Cotton yield[z¶] $Mg\ ha^{-1}$
1 soybean in rotation	2.8 a
2 soybean in rotation	2.6 b
Continuous cotton	3.1 a
1 corn in rotation	2.7 bc[y]
2 corn in rotation	2.9 ab
Continuous cotton	3.1 a

[z] Yield represents cotton seed yield (37-41% of lint yield).

[y] Means followed by a letter in common are not significantly different based on $p \leq 0.05$ within either soybean ($p = 0.003$) or corn ($p = 0.004$) rotations.

All biocover treatments resulted in equivalent cotton seed yield when compared across the 12-study years. Poultry litter was not different from wheat, hairy vetch, Austrian winter pea, or the fallow control ($p > 0.05$). Conversely, some previous studies have shown biocover serves to increase cotton yields (Adeli et al., 2005; Foote et al., 2014; Reddy et al., 2004). In a no-tillage cotton study by Larson et al. (2001), hairy vetch resulted in yield increases compared with no N fertilization additions, but cotton yields decreased with a winter wheat cover crop. However, Parvin et al. (2004) observed increased cotton yields with a wheat cover crop compared to no cover crop treatments in a study performed under no-till. Results indicated no yield advantage or detriment for any biocover, although indirect ecosystem benefits mighty occur, such as reduced weed competition, facilitation of pollinator habitat, and promotion of greater residue diversity for soil health (Foote et al., 2014; Tilman et al., 2002).

Across all phases, seed cotton yields were highest in Phase III (3.3 Mg ha^{-1}), with the first and second not differing (2.7 and 2.8 Mg ha^{-1}, respectively). Favorable Phase III yields were likely resultant from above-average rainfall in three out of the four years during April, May, July, and September. Seed cotton yield also varied based on crop rotation per phase ($p < 0.001$; Table 4). Specifically, the corn-corn-soybean-cotton rotation was the highest yielding sequence during Phase II (4.0 Mg ha^{-1}), which was equivalent to the cotton-corn-cotton-soybean rotation during Phases II and III (3.5 and 3.8 Mg ha^{-1}, respectively), and the cotton-corn-cotton-corn rotation during Phases II and III (3.6 and 3.8 Mg ha^{-1}, respectively; Fig. 1). All of these rotations resulted in yield increases above continuous cotton during Phases I and III ($p < 0.05$; Fig. 1), but not during Phase II. Yield reductions during Phase II (2006-2009) could have been caused by lower than average precipitation for three of the four years during April, July, and August (Table 1). Lowest seed cotton yields were also observed for the soybean-cotton-corn-soybean rotations during Phase II (1.5 Mg ha^{-1}). Similarly, cotton yields from the soybean-cotton-soybean-cotton rotation was consistently the lowest in all three phases (Fig. 1). This could have been resultant from excess N (via soybean biological N_2 fixation not being accounted for) during the following cotton crop, as excessive N can produce excessive vegetative growth, delay flowering, boll set, and maturity due to cotton being an indeterminate perennial (Gerik et al., 1998; Grimes et al., 1969). An additional rotation that was consistently low was that of corn-corn-soybean-cotton during Phases I and II (2.3 and 1.7 Mg ha^{-1}; Fig. 1). Therefore, selected rotations exceed continuous cotton yields during Phases I and III; however, cotton after soybeans might negatively impact seed cotton yield per 4-yr cropping cycle. The additional N contribution from the previous soybean crop is an issue that should be evaluated in the future.

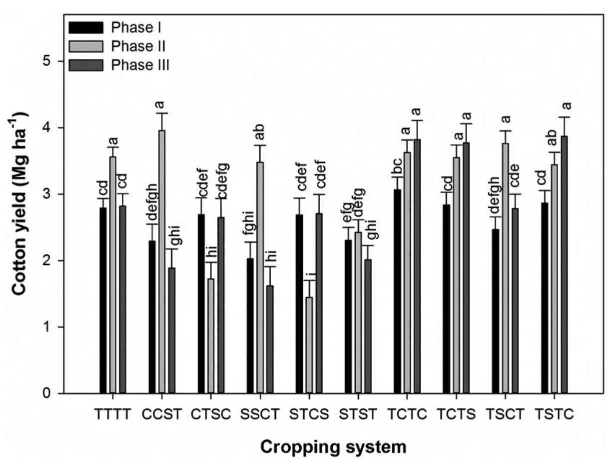

Figure 1. Seed cotton yield by cropping sequence at Milan Research and Education Center, Milan, per phase (i.e., three 4-yr cycles) from 2002 to 2013, totaling 12 study years. Vertical bars are the standard error

C = corn; S = soybean; T = Cotton. Sequences are repeated every 4 yrs.

† Phase x sequence varied ($P<0.0001$) for seed cotton yield; hence the interactions are reported.

Different letters indicate a significant difference at an alpha level of 0.05; LSD = 1.52.

CONCLUSIONS

The results of this 12-yr study revealed that across phases and biocovers there were no significant yield declines from growing continuous cotton under no-tillage. Within phases, there were various cropping sequences that did result in increases in yield over continuous cotton. Specifically, the corn-corn-soybean-cotton rotation was the highest yielding sequence during Phase II, which was equivalent to the cotton-corn-cotton-soybean rotation during Phases II and III, and the cotton-corn-cotton-corn rotation during Phases II and III. All of the aforementioned rotations resulted in yield increases above continuous cotton during Phases I and III, suggesting that rotations of corn with cotton may provide yield benefits over time.

Including soybean twice within a 4-yr rotation decreased cotton yields by 16% compared to continuous cotton across the 12-yr study period. Specifically, the soybean-cotton-soybean-cotton rotation was consistently the lowest yielding in all three phases. Other research has shown that excessive N levels can result in greater vegetative growth, delayed lint development, and lower yields. This might have been the case with rotations containing soybeans, as we did not measure or adjust N fertilizations based on contributions from N_2 fixation from previous soybean crops. The carryover N contribution from a previous soybean crop should be accounted for in determining N fertilizer rate for a subsequent cotton crop. On the other hand, high-N containing biocovers such as hairy vetch, Austrian winter pea, and poultry litter exerted no detrimental yield effects over the control in this 12-year study, albeit no yield benefits were observed either.

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