To the Graduate Council:

I am submitting herewith a thesis written by Jennifer Elizabeth Noe entitled "Effects of Combinations of Cropping Sequences and Biocovers on Yield of Glyphosate-tolerant Corn, Soybean, and Cotton under No-till." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant Sciences.

Fred L. Allen, Major Professor

We have read this thesis and
recommend its acceptance:

Arnold M. Saxton

Donald D. Tyler

Dennis R. West

Acceptance for the Council:

Carolyn R. Hodges, Vice Provost
and Dean of the Graduate School

(Original signatures are on file with official student records.)

EFFECTS OF COMBINATIONS OF CROPPING SEQUENCES AND BIOCOVERS ON YIELD OF GLYPHOSATE-TOLERANT CORN, SOYBEAN, AND COTTON UNDER NO-TILL

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DEDICATION

This thesis is dedicated to my parents, Ronald and Linda Noe, who have supported and encouraged me throughout my studies, and my brother and sister-in-law, Will Noe and Katie Kanipe-Noe, and my sister Katie Noe, for always believing in me and pushing me to be better.

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ABSTRACT

No-till acreage is increasing in the United States as producers begin to recognize the environmental and economic benefits of this management system. Although the potential to receive carbon credits or payments for maintaining or initiating no-till may encourage producers to employ these practices, crop yields will be a factor in management decisions. Our objective was to examine the effects of combinations of cropping sequences and winter biocovers upon glyphosate-tolerant corn, cotton, and soybean yields under long-term no-tillage at two locations in Tennessee. Research was conducted during the first four-year phase (2002-2005) of a two-phase agronomic systems study (2002-2009) at the Research and Education Center at Milan (RECM) in Milan, Tennessee, and the Middle Tennessee Research and Education Center (MTREC) in Spring Hill, Tennessee. The experiment was a randomized complete block design with split block treatments, with the main plots consisting of 13 different cropping sequences of corn, cotton, and soybean at RECM and eight different cropping sequences of corn and soybean at MTREC. The subplots consisted of hairy vetch, wheat, poultry litter and fallow biocovers applied perpendicular to the sequences. Rotated corn and soybean yields were comparable to or higher than their respective monoculture sequences at both locations. At RECM, cotton yields took longer to respond to rotation as rotated cotton yields only outperformed continuous cotton in the final year. At both sites, corn and soybean yields were highest under fallow and poultry litter biocovers, respectively. Cotton yields were highest under poultry litter at RECM. Interaction effects of cropping sequence x biocovers were inconsistent as interaction effects were only observed on corn yields at MTREC in 2004 and 2005. Hairy vetch, wheat, and poultry increased yields

when changing from continuous corn to rotated corn. The presence of some cropping sequence x biocover interaction effects is encouraging and perhaps suggests a longer time period may be needed for the combined effects of crop sequence and biocovers upon crop yields to become apparent. Results from the next four years of the experiment will provide more information on the long-term effects of crop sequence and biocovers on corn, soybean, and cotton yields.

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INTRODUCTION

At a time when global climate change and rising gas prices are dominant topics in the United States, the amount of no-till acreage is increasing in the United States. This is perhaps no coincidence as there is great interest in no-till in part due to its potential to help alleviate the greenhouse gas effect by sequestering carbon in the soil (West and Post, 2002). Also, government programs that issue “green payments” for conservation practices such as no-till as well as the reduced input costs associated with this system cast no-till as a viable and profitable management system. While the possibility to receive payments for conservation practices is definitely one motivation for producers to switch to a no-till system, maximizing crop yields and thus profits will always be of primary importance to a producer. Maximizing crop yields has become even more important recently due to emphasis upon new biofuels initiatives that will increase demand for certain crops such as corn, as evidenced by a 24% increase in corn production from 2006 to 2007 (NASS, 2007). However, the goal of any successful management system such as no-till is for it to not only be productive in terms of crop yields but that productivity must be sustainable. Therefore, there is a need for research on crop yields in long-term no-till systems.

Cropping sequences and biocovers have been shown to reduce weed and pest populations (Fisk et al., 2001; Howard et al., 1998), reduce soil erosion, improve water aggregate stability (Villamil et al., 2006), and increase soil organic carbon levels (Varvel, 2006; Sainju et al., 2002). Cropping sequences and biocovers are often important parts of no-till systems because of these proven benefits. Crop rotations have been shown to increase yields in crops such as corn and soybean (Pedersen and Lauer, 2003; Kelley et al., 2003). Previous research has also shown that the use of biocovers can also serve to increase yields of crops such as soybean and cotton (Adeli et al., 2005; Reddy et al., 2004). However, more research is needed on the effects of combinations of cropping sequences and biocovers on crop yields in long-term no-till systems. As part of this study, the main objectives were to examine the effects of cropping sequences, biocovers, and combinations of cropping sequences and biocovers on corn, soybean, and cotton yields at two locations in Tennessee. Yield data were gathered and analyzed from the first four years (2002-2005) of a long-term no-till study (2002-2009). This study will serve to quantify the effects of cropping sequences and biocovers upon corn, soybean, and cotton yields in long-term no-till.

LITERATURE REVIEW

Crop Rotation

Crop rotation has repeatedly been shown as an effective means for increasing crop yields. Explanations for this positive influence of rotations are varied. Since soil conditions can directly impact crop yield, the influence of crop rotations on soil properties has been the subject of numerous studies. Increased soil organic matter levels in no-till production systems have been observed due to decreased erosion and to decreased microbial oxidation (Peterson et al., 1998). Likewise, crop rotation can also affect the nutrient availability in soils, especially in relation to carbon and nitrogen. The specific crops in the rotation affect carbon and nitrogen levels in large part due to the amount of biomass produced. Biomass represents an input of carbon into the soil. Therefore, those rotations that include crops that produce high amounts of residue can increase soil organic matter and promote soil productivity (USDA, 2003). For example, research has demonstrated that a sorghum/soybean rotation as well as continuously grown sorghum had higher soil carbon levels than a soybean/soybean rotation due to greater amounts of residue produced by grain sorghum (Havlin et al., 1990). Other studies have revealed that rotations that include winter cereal crops can increase soil organic matter when compared to fallow rotations (Campbell and Zentner, 1993). Corn produces more biomass than soybean and cotton. Rotations with corn often see increased carbon levels because of this large biomass production. In one study, a cotton/corn rotation increased soil organic carbon compared to continuous cotton, mainly due to the amount of corn biomass produced. In the same study, however, continuous corn also showed comparable organic carbon levels to the cotton/corn rotation, primarily due to the amount of biomass created from the constant corn production (Reddy et al., 2006). Other studies show continuous corn under no-till having higher concentrations of carbon in the top layers of the soil in comparison to a corn/soybean rotation because of the biomass produced year after year (Omonode et al., 2006).

Crop rotation can also influence the amount of soil organic nitrogen. Nitrogen is an important nutrient that, when deficient, can affect crop growth and subsequent yield. Once again, as seen with carbon, the types of crops and the amount of biomass produced by those crops in the rotation affect nitrogen levels in the soil. Ortega et al. (2002) maintained that greater amounts of crop biomass increased nitrogen levels in surface soils. Similar to carbon, soybean rotations with wheat and grain sorghum resulted in greater concentrations of nitrogen when compared to continuous soybean (Kelley et al., 2003). Including legumes in the rotation can have a significant effect on available soil nitrogen as they serve to fix nitrogen and make it more available for the next crop.

No-till, with its undisturbed residues, can increase soil moisture levels when compared to conventional till (Blevins et al., 1983). The residues decrease water evaporation from the soil surface as well as decrease water runoff. When utilizing crop rotations, biomass once again can benefit crop growth and yields by preventing water evaporation and runoff, therefore increasing the amount of plant available water. When it comes to crop rotation in a no-till system, it is not the amount of soil water that is conserved but the efficiency with which that water is used for crop growth that is important. More efficient water use can allow a crop to increase yields without increasing water use. For example, Crookston et al. (1991) demonstrated that soybean following corn increased water use efficiency of soybean. However, corn following soybean, while still increasing yields, did so by increasing water capacity and not increasing water efficiency. In another study conducted in the Great Plains, wheat water use efficiency was greater following grain sorghum than wheat (Schlegel et al., 2002). Research has shown that rotation can improve the water use efficiency of some crops, but this improvement is specific as to rotation order (Anderson, 2005).

Crop rotation can also serve to counteract the loss of weed, disease, and insect control associated with the loss of tillage. A tremendous amount of selection pressure for surviving weeds exists in a monoculture system. Weeds become adapted to the particular management system and can be detrimental to crop yields. Rotating crops can serve to alter the environment that weeds are adapted to and reduce weed populations (Higgs et al., 1990). Reductions in pest and disease damage have also been linked to rotating crops. Several studies have shown reduction in soybean cyst nematode populations when soybean is rotated with a nonhost crop such as corn (Howard et al., 1998; Chen, et al., 2001). Young et al. (2004) observed that at least two consecutive years of corn should be included in a cotton rotation to reduce reniform nematode numbers. Sclerotinia stem rot in soybeans and Fusarium head blight in wheat are both diseases shown to have reduced incidence when crop rotation is part of the management system (Kurle et al., 2001; Dill-Macky et al., 2000). Crop rotation serves to decrease disease and pest populations in the same manner as weed populations, disrupting disease and pest life cycles by introducing nonhosts into the rotation. Disease-causing fungi and pests cannot survive in these nonhosts, and population numbers decrease accordingly.

With all of the benefits associated with crop rotation and increased soil productivity in mind, it is now useful to examine the effects of crop rotation on yields.

Previous research has shown that crop rotations increase yields of corn, soybeans, and cotton when compared to continuous cropping yields (Crookston et al., 1991; Porter et al., 1997; Reddy et al., 2006). However, this rotation effect is affected by many factors, such as the frequency of certain crops within the rotation and soil type. The frequency of certain crops in the rotation can influence crop yields. Research has shown that annual corn/soybean rotations frequently show an increase in crop yields compared to their respective monoculture sequences (Porter et al., 1997; Mannering and Griffith; Meese et al., 1991). Cotton has also responded to rotation, but monoculture cotton is still a prominent production practice today (Mitchell and Entry, 1998; Wesley et al., 2001; Reddy, 2006). Rotating with a less profitable crop as well as yield uncertainty has cotton farmers unsure of the benefits of crop rotation. Some studies have suggested that crop yields could further be improved by using longer rotations, perhaps by adding a third crop to the rotation. For instance, Crookston et al. (1991) saw increases in corn and soybean yields following five consecutive years of soybean and corn, respectively, when compared to an altenating corn/soybean rotation. Crookston concluded that adding a third crop to the rotation could allow each crop to have that 1st year effect, resulting in increased yields. The previous crop seems to have an effect upon the yield of the next crop, and corn and soybean appear to yield less when following themselves. On the other hand, a study examining the viability of a corn/soybean/wheat rotation found that there was no yield advantage to a three-crop rotation, suggesting that a longer time was needed between same crop plantings in crop rotation (Lund et al., 1993).

Griffith et al. (1988) found that on high organic matter soils, rotated corn yields under no-till were less than those in conventional till. In contrast, rotated corn yields under no-till were greater than conventional till on a low organic matter soil. Soil drainage is another key factor affecting crop yields. Poorly drained soils negatively affected rotated soybean yields under no-till when compared to rotated soybean under conventional till (Dick, et al., 1991). However, the negative impacts of high organic matter and poor soil drainage on rotated yields under no-till were alleviated with time (Griffith et al., 1988; Dick et al., 1991). These results seem to suggest that long-term no-till productions systems combined with crop rotation serve to improve soil conditions so that yields are equal to or better than those under conventional till regardless of soil type.

Biocovers

Biocovers are often included in farm production systems to provide soil cover and to promote soil fertility. By covering the soil, erosion is reduced and soil productivity is increased because soil organic matter is conserved in the upper soil layers that are the most susceptible to erosion. These benefits are enhanced under no-till systems that leave previous crop residues on the soil surface. In addition to preventing carbon loss from erosion, cover crop biomass is incorporated into the soil and serves to increase soil organic carbon. A study conducted by Sainju et al. (2002) found that no-till tomatoes with a hairy vetch cover crop increased soil organic carbon levels compared to conventional till tomatoes without vetch. Similarly, bicultures of rye and legume cover crops grown with cotton and grain sorghum increased soil carbon levels compared to monoculture cover cropping of rye and grain sorghum, due in part to higher biomass produced by the biculture cover crops (Sainju et al., 2005). Corn/soybean rotations that include both vetch and rye as winter covers increase soil organic matter compared to that of just a winter fallow corn/soybean rotation (Villamil et al., 2006). These increases in soil organic matter directly influence other soil properties such as soil aggregation.

Soil aggregate stability is important in terms of water infiltration and overall soil structure. Increases in soil organic matter can lead to increased soil aggregation (Tisdall and Oades, 1980). Therefore, it is not unusual to see research demonstrating that biocovers, with their ability to increase soil organic matter, have a positive effect upon soil aggregation. In a study comparing the effects of winter wheat and dandelion upon soil aggregation, winter wheat increased soil aggregation compared to fallow plots (Karbir and Koide, 2000). Stabilization of soil aggregates by the use of biocovers can increase the water content of soils and thus positively impact crop growth and yields. Water aggregate stability is increased in corn/soybean rotations that include vetch and rye compared to fallow (Villamil et al., 2006). Increased water aggregation is not just restricted to winter cover crops, however. Composted cow manure applications also improved soil aggregation when compared to soils that received no compost in one Canadian study (Whalen et al., 2003).

Perhaps one of the most important contributions of biocovers under any cropping system is their impact on nitrogen availability in the soil. Nitrogen is an essential nutrient in terms of crop growth and yield and plays a critical role in corn, soybean, and cotton production systems. A legume biocover such as hairy vetch can serve to increase the nitrogen availability for the succeeding crop due to its nitrogen-fixing capabilities, fulfilling part of the nitrogen requirements of the crop (Schwenke et al., 2001). Poultry litter, a biocover consisting of poultry manure and bedding materials as a source of nitrogen and other nutrients, can also impact the amount of nitrogen available for plant growth. Studies comparing nitrogen accumulation using poultry litter and ammonium nitrate have demonstrated higher levels of total nitrogen as well as nitrate in the surface layers of the soil with poultry litter use (Nyakatawa et al., 2001b; Mitchell and Tu, 2006). There are concerns as to nitrate accumulation when poultry litter is used, but some studies have shown that the use of a rye cover crop can prevent the buildup and subsequent leaching of nitrate in and from soils (Nyakatawa et al., 2001a; Nyakatawa et al., 2001b). As a result, cereal cover crops have the potential to not only prevent nutrient loss due to nitrate leaching but also to prevent the environmental problems associated with nitrate contamination of groundwater. Cereal cover crops such as rye and winter wheat can reduce nitrate leaching by using the nitrogen from the preceding crop to supplement their own growth (Strock et al., 2004; Costa et al., 2000). A combination of rye and vetch winter covers in a no-till corn/soybean rotation yielded less soil nitrate than found in the same corn/soybean system without cover crops (Villamil et al., 2006). However, cereal cover crops do not efficiently return this nitrogen to the soil, and the next crop might not benefit from this retained nitrogen.

Biocovers also have advantages in terms of improved weed and insect control. Several studies have documented reduced weed emergence when using cover crops such as rye, hairy vetch, and clover in corn and soybean production systems (Fisk et al., 2001; Reddy et al., 2003; Reddy et al., 2004). Brassica cover crops such as canola can reduce weed emergence in comparison to fallow treatments (Haramoto, 2005). Biocovers compete with weeds for resources such as light, water, and nutrients and prevent their establishment. Insect populations can also be reduced with the use of biocovers, primarily because biocovers provide habitats for beneficial insects (Creamer 1999;

Tillman et al., 2004). These beneficial insects seek out insect pests and regulate pest population levels.

Since biocovers can affect soil carbon and nitrogen levels, soil structure, and pest population levels, they can also affect crop yields that are directly impacted by changes in these factors. Research shows varied results when examining the effects of biocovers upon crop yields, with the differences varying according to the cover crop chosen. Corn yields have been reduced after a rye cover crop but increased after hairy vetch (Vaughan and Evanylo, 1998; Johnson et al., 1998). Lower cotton yields have been observed when another cereal cover crop, winter wheat, was used but increased with hairy vetch as a cover crop (Larson et al., 2001). These results indicate the importance of utilizing biocovers that provide much-needed nitrogen to corn and cotton.

Since nitrogen is critical to soybean production, one would expect to see the same decreased yields also seen in corn and cotton when a rye or winter wheat cover crop is used. In contrast, soybean yields after rye were observed to increase when compared to soybean in a fallow rotation. De Bruin et al. (2005) found that soybean yields in a rye rotation were equal to those in fallow but not as profitable. Soybean yields are generally not affected by cereal crops unless water is a limiting factor. Poultry litter applications have also been shown to benefit crop yields by supplying nitrogen as well. Cotton yields have increased when a winter rye cover crop with poultry litter as a nitrogen source was used compared to cotton/fallow yields (Reddy et al., 2004). Soybean yields have also been observed to benefit from poultry litter application (Adeli et al., 2005). Numerous studies seem to focus on the nutrients that biocovers can supply to succeeding crops, indicating that those biocovers that supply the most nutrients such as nitrogen will result in increased yields.

EFFECTS OF COMBINATIONS OF CROPPING SEQUENCES AND BIOCOVERS UPON YIELD OF GLYPHOSATE-TOLERANT CORN, SOYBEAN, AND COTTON UNDER NO-TILL

Abstract

Crop sequencing and biocovers are often integral parts of no-till systems because of benefits such as improved pest control and increased soil organic matter. The effects of cropping sequences and biocovers on corn, soybean, and cotton yields were studied at two locations in Tennessee. The experimental design was a randomized complete block with split block treatments. The main plots were 13 different cropping sequences of corn, cotton, and soybean at the Research and Education Center at Milan (RECM) and eight different cropping sequences of corn and soybean at the Middle Tennessee Research and Education Center (MTREC). The subplots consisted of hairy vetch, wheat, poultry litter, and fallow biocovers applied perpendicularly to the cropping sequences. Corn had a slight response to rotation at both locations, but the response of soybean was much stronger as rotated soybean yields were generally higher than continuous soybean yields. Cotton did not respond well to rotation as continuous cotton yields averaged higher than rotated cotton yields in the first three years. Four-year averages of corn yields were high under fallow biocover, producing 9.79 and 6.21 Mg ha^{-1} at RECM and MTREC. Four-year averages of soybean (RECM, 3.57 Mg ha^{-1}; MTREC, 2.85 Mg ha^{-1}) and cotton yields (RECM, 1.01 Mg ha^{-1}) were highest under poultry litter. Cropping sequence x biocover interaction effects were only observed on corn yields at MTREC. Hairy vetch and wheat biocovers combined with rotation were the most consistent in increasing corn yields. Results from the next experimental phase may better reflect the effects of cropping sequences and biocovers upon corn, soybean, and cotton yields.

CHAPTER 1

Introduction and Literature Review

Conservation tillage, or those tillage methods in which 30% or more of the soil surface is covered by plant residue, is increasingly being adopted by producers (SSSA, 2007). No-till, a conservation tillage system in which a crop is planted directly into the previous crop's residue without prior tillage, is used in this study because of the growing number of no-till acreage throughout the United States. This is a trend that is also reflected in the increasing amount of no-till acreage found in Tennessee. From 2000 to 2004, total no-till acreage rose from 55.6% to 58.4% of the total acreage planted in Tennessee (NASS, 2004). In 2004 alone, the proportion of soybean [*Glycine max* (L.) Merr.], corn [*Zea mays* L.], and cotton [*Gossypium hirsutum* L.] acreage planted in Tennessee was 67.8, 64.3, and 47.4%, respectively (NASS, 2004). Efforts to persuade more producers to switch to this type of production system should consist of not just conveying the obvious information in terms of reduced input costs but also conveying the other potential economic and environmental benefits associated with the use of no-till.

Due to concerns about the effects of a global climate change, increasing emphasis is being placed upon finding methods with which to reduce the emission of greenhouse gases such as carbon dioxide into the atmosphere. The disruption of the soil with tillage promotes the release of carbon dioxide into the atmosphere. Thus, no-till has been proposed as a way to sequester carbon into the soil and prevent its release (Lal, 1997; West and Post, 2002). The Kyoto Protocol has established a process for a global carbon credits system, but there are doubts as to its effectiveness (Kirschbaum et al., 2001; Marland et al., 2001). However, the potential to receive carbon credit payments is one incentive for producers to switch to no-till as producers can earn up to two dollars for every acre under no-till (National Farmers Union, 2007).

In addition to receiving carbon credits, switching to no-till might also allow the producer to be eligible to receive government payments for production practices that benefit the environment. No-till has been proven to improve soil conditions and soil fertility, in part because residues, left on the soil surface, have an impact on soil quality and thus plant growth. Reduced soil erosion, increased aggregate stability, and higher soil organic matter (SOM) have all been associated with no-till when compared to conventional till systems (Schuller et al., 2007; Kladivko, 1986; Rhoton, 2000; Thomas et al., 2007). The residues left from the previous crop serve to protect the soil from rain damage, to retain soil moisture, and to prevent carbon from escaping from the soil.

As a result, improved soil conditions make a more suitable environment for crop growth. Research has shown mixed results when comparing no-till crop yields to conventional crop yields, with the results varying according to the crop. Specifically, soybean yields from no-till have been found to be equal to or better than those under conventional tillage (Tyler et al., 1983; Hussain et al., 1999). Vyn et al. (2000) observed that soybean yields under no-till were initially lower than those under conventional till; however, over a 25-year period, yield reductions were not significant. Findings similar to this 25-year study could be important when examining the long-term viability of a no-till system.

For corn and cotton, yield results are more wide-ranging. Hussain et al. (1999) found that when grown in rotation with soybean, no-till corn yields were equal to conventional yields over an eight year period. Yield and economic returns were higher for no-till corn than conventional returns in semiarid environments in Texas and Mexico (Smart, 1999). Other studies have produced similar increased yield results. On the other hand, reductions in corn yield have been seen in irrigated continuous corn under no-till with low nitrogen fertilization (Sims et al., 1998). No-till cotton yields reflect the same inconsistency in returns as no-till corn. Cotton has produced similar or greater yields to those achieved under conventional tillage, but lower yields due to delayed development have also been observed (Schwab et al., 2002; Triplett, 1996; Pettigrew and Jones, 2001).

Aside from varying crop yields, no-till does have other drawbacks when compared to conventional till as well. The use of no-till eliminates the benefits that come with tillage, primarily in the forms of reduced weed, disease, and pest control. As a result, herbicides are more heavily relied upon, and any increased returns from eliminating tillage costs may be counteracted by higher herbicide costs (Smith et al., 1992). Crop rotation and biocovers become important elements in a no-till system to compensate for these problems. Crop rotation can disturb the growing environment of weeds so that weeds are no longer able to thrive in the same manner as under continuous cropping. Biocovers serve to further protect the soil from erosion, increase soil organic matter and soil stability, provide some weed control, improve crop nutrition, and increase crop yields (Snapp, 2005).

Crop rotation has been shown to be an effective way to increase crop yields. In one three year-study, Pedersen and Lauer (2002) found that a corn-soybean rotation resulted in 12% higher corn yields than continuous corn. Griffith et al. (1988) observed 20% greater rotated corn yields under no-till compared to no-till continuous corn yields. Other crops have also benefited when in rotation as compared to monocropping. Conventionally tilled soybeans in rotation with grain sorghum yielded higher than continuous soybean in research conducted by Wesley et al. (2001) in Mississippi. Wilhelm and Wortmann (2004) found that soybean in an alternating soybean-corn rotation yielded higher than continuous soybean in a 16-year study. Conventionally tilled rotated cotton yields were also higher than yields of continuous cotton in the same study.

Previous research has also shown that the use of biocovers can enhance crop yields as well. The ability of biocovers to supply nutrients to succeeding crops is a factor in increased crop yields. No-till corn yields were higher after legume cover crops such as hairy vetch when compared to fallow corn yields in two studies by Blevins et al. (1990) and Decker et al. (1994). Corn yields most likely benefited from the extra nitrogen provided by the legume biocovers. Soybean yields with a rye cover crop were equal to those with no cover crop (Reddy et al., 2003), and poultry litter applications have been shown to benefit soybean yields as well (Adeli et al., 2005). For no-tillage cotton with no nitrogen fertilization, yields were increased with a hairy vetch crop but decreased with a winter wheat cover crop (Larson et al., 2001). Conversely, Parvin et al. (2004) saw increased cotton yields with a wheat cover crop compared to no cover crop in a study performed under no-till conditions.

Given that crop rotations and winter covers can alleviate some of the problems associated with no-till as well as improve crop yields, research into their combined effects on crop yields in a no-till system is necessary to make good management recommendations that will improve corn, soybean, and cotton yields and benefit the producers in terms of improved soil quality and higher profits. While there are studies that primarily focus on just no-till systems, the ones that look at the effects of cropping sequences and biocovers on yields only incorporate a small number of sequences and biocovers and are relatively short-term experiments. Therefore, the primary objectives of this study are to determine: i) the effects of various cropping sequences, ii) the effects of biocovers, and iii) the effects of combinations of cropping sequences and biocovers upon corn, soybean, and cotton yields under a long-term no-till management system.

CHAPTER 2

Materials and Methods

Site Description and Experimental Design

Field research was conducted during the first four-year phase (2002-2005) of a two-phase systems study (2002-2009) at both the Research and Education Center at Milan (RECM) in Milan, Tennessee, and the Middle Tennessee Research and Education Center (MTREC) near Spring Hill, Tennessee. Each location was under a long-term no-till production system where the crops were planted directly into the previous crop residue. The Milan study was conducted on a Grenada silt loam (fine-silty, mixed, thermic Oxyaquic Fraglossudalf), and the Middle Tennessee study was conducted on a Maury silt loam soil (fine, mixed, semiactive, mesic Typic Paleudalf).

The experimental design was a randomized complete block in a split block arrangement with four replications. The main plots consisted of 13 different cropping sequences at RECM and eight different cropping sequences at MTREC (Tables 1a and 1b). The sequences consisted of glyphosate-tolerant corn, soybean, and cotton at RECM and glyphosate-tolerant corn and soybean at MTREC. At RECM, plots were fallow in 2001 prior to planting. At MTREC, those plots initially planted to corn were planted to soybean in 2001, and those plots initially planted to soybean were planted to corn in 2001. The subplots at both locations consisted of four different biocovers being applied perpendicular to the cropping sequences. The four biocovers were fallow, hairy vetch,

Table 1a. Corn (C), soybean (S), and cotton (T) rotation sequences at the Research and Education Center at Milan (RECM) from 2002 to 2005.

	Year			
Crop sequence	2002	2003	2004	2005
1	T	S	T	C
2	T	T	T	T
3	T	S	C	T
4	T	C	T	S
5	T	C	T	C
6	C	C	C	C
7	C	T	S	C
8	C	C	S	T
9	C	S	C	S
10	S	S	S	S
11	S	S	C	T
12	S	T	C	S
13	S	T	S	T

Table 1b. Corn (C) and soybean (S) rotation sequences at the Middle Tennessee Research and Education Center (MTREC) from 2002 to 2005.

	Year			
Crop sequence	2002	2003	2004	2005
1	C	S	C	S
2	C	C	S	C
3	C	C	C	C
4	C	S	S	C
5	S	S	S	S
6	S	C	S	C
7	S	C	C	S
8	S	S	C	S

poultry litter, and winter wheat. A total of 208 plots were studied at RECM, and a total of 128 plots were studied at RECM.

Field Operations

In 2002, four different corn hybrids and four different soybean varieties were planted at both MTREC and RECM. The four corn hybrids used were Terral 'TV 2140RR', Biogene 'BG 098RR', Dekalb 'DKC 6410RR', and Dekalb 'DKC 60-09RR'. The four soybean varieties used were USG '7440nRR', Delta King 'DK 4461RR', Asgrow 'AG 3702RR, and Asgrow 'AG 3701RR'. At RECM, the five different cotton varieties planted were Sure-Grow '215BG/RR', Paymaster '1218 BG/RR', Delta & Pine '436RR', Stoneville '4793RR', and Stoneville '4892BG/RR'. Due to discontinuation of the lines, only one corn hybrid (Dekalb 'DKC 6410RR'), one soybean variety (USG '7440nRR'), and one cotton variety (Paymaster '1218BG/RR') was planted in 2003-2005. For all four years, the continuous corn, soybean, and cotton sequences were planted with Dekalb 'DKC 6410RR', USG '7440nRR', and Paymaster '1218 BG/RR', respectively.

Biocovers were planted in or around October of the previous year and burned down prior to planting. Corn, soybean, and cotton plots were planted at RECM using a 4-row John Deere 7600 Maxemerge planter and at MTREC using a 6-row John Deere plateless planter (Deere & Company, Moline, IL). At both locations, corn, soybean, and cotton plots were planted at recommended University of Tennessee seeding rates of 64,247 seeds ha^{-1}, 258,334 – 344,445 seeds ha^{-1}, and 64,495 seeds ha^{-1}, respectively. Corn and soybean plots were harvested at RECM with an AC Gleaner combine (AGCO, Duluth, GA) in 2002 and with a two-row ALMACO (ALMACO, Nevada, IA) combine in 2003, 2004, and 2005 and at MTREC using a K-2 AC Gleaner combine with a three-row header and 3.05 m grain platform.

At RECM, corn plots were planted with 76.20 cm row spacing in 6.10 m x 13.70 m plots, creating 8-row plots. Corn plots were planted on 12 April 2002, 28 April 2003, 29 April 2004, and 9 May 2005. Corn plots were harvested on 29 August 2002, 19 September 2003, 24 September 2004, and 14 September 2005. Two rows were harvested in each year. At MTREC, corn plots were planted with 76.20 cm row spacing in 6.10 m x 12.19 m plots, creating 8-row plots. Corn plots were planted on 16 April 2002, 28 April 2003, 23 April 2004, and 5 May 2005. In 2005, corn plots were replanted on 18 May because of poor emergence due to a combination of dry weather and animal damage. Corn plots were harvested on 9 September 2002, 15 September 2003, 27 September 2004, and 23 September 2005. Two rows were harvested in 2002, 2003, and 2004 and ten rows were harvested in 2005. The measurements taken at both locations at the time of harvesting were plot weights in pounds and percentage moisture content. Corn plot weights were adjusted to Mg ha^{-1} and standard moisture content of 155 g kg^{-1} for further data analysis.

Soybean plots at RECM were planted with 76.20 cm row spacing in 6.10 m x 13.72 m plots, creating 8-row plots. Planting dates at RECM were 21 May 2002, 30 May 2003, 25 May 2004, and 10 May 2005. Soybean plots were harvested on 23 September and 16 October 2002, 2 October 2003, 24 September 2004, and 30 September 2005. Two rows were harvested in 2002 and 2003 and three rows were harvested in 2004 and 2005. Soybean plots at MTREC were also planted with 76.20 cm row spacing in 6.10 m x 12.19 m plots, creating 8-row plots. At MTREC, soybean plots were planted on 29 April 2002, 13 May 2003, 17 May 2004, and 16 May 2005. Soybean plots were harvested on 16 October 2002, 30 September 2003, 3 October 2004, and 9 September 2005. Four rows were harvested each year. The measurements taken at both locations at the time of harvesting were plot weights in pounds and percentage moisture content. Soybean plot weights were adjusted to Mg ha^{-1} and standard moisture content of 130 g kg^{-1} for further data analysis.

Cotton plots were planted only at RECM. Cotton plots were planted with 101.60 cm row spacing in 6.10 m x 12.19 m plots, creating 6-row plots. Cotton plots were planted on 7 May 2002, 12 May 2003, 5 May 2004, and 11 May 2005. Cotton plots were harvested on 10 September 2002, 16 October 2003, 8 November 2004, and 25 October 2005. Two rows were harvested each year. Measurements taken at RECM at the time of harvesting included plot weights in pounds, lint weights in pounds, and lint percentages. Plot weights were adjusted to Mg ha^{-1} using their respective lint percentages to obtain an adjusted plot weight for further data analysis.

Pesticides and Fertilizers

Before planting, burn down herbicides were used for removal of existing vegetation and biocovers at both locations. Either paraquat (1,1-Dimethyl-4,4-bipyridinium), glyphosate (*N*-(phosphonomethyl)-glycine), or glufosinate ammonium (ammonium(±)-2amino-4-(hydroxymethylphosphinyl) butanoate) were applied for burn down in April of each year before corn, soybean and cotton seeding. One or two applications of glyphosate were applied to the soybean and corn plots at both locations in or around May or June of each year. For the cotton plots located only at RECM, pesticide use was extensive and application dates ranged from June through September of each year. Glyphosate 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 four years. Def (S,S,S-Tributyl phosphorotrithioate), Bidrin (Dimethyl phosphate of 3-Hydroxy-N,N-dimethyl-cis-crotonamide) and Pix (1,1-dimethylpiperidinium chloride) were also used for additional pest control and plant growth regulation. A more complete list of pesticides and application rates at both locations can be found in Tables A1, A2, and A3 in the Appendix.

Fertilizer applications were made according to University of Tennessee recommendations. At RECM, broadcast applications of ammonium nitrate at rates ranging from 45 to 90 kg ha^{-1} of nitrogen were applied specific to cover crops on various dates in March, April, and May of each year. Adjusted nitrogen application rates for each biocover are shown in Table A4 of the Appendix. Additional sidedressing applications of ammonium nitrate at rates of 112 to 157 kg ha^{-1} of nitrogen were made to the corn plots in May or June of each year. In June of 2004, cotton plots were sidedressed with 34 kg $ha^{-1}$of nitrogen. Poultry litter was applied at rates ranging from 2241 to 4482 kg ha^{-1} in March or April prior to planting to achieve 67 kg ha^{-1} of nitrogen based on 50% bioavailability. At MTREC, ammonium nitrate was applied specific to cover crops all four years at rates of 50 to 67 kg ha^{-1} of nitrogen. Adjusted nitrogen application rates for each biocover at MTREC are located in Table A4 in the Appendix. Corn plots were sidedressed with ammonium nitrate in May or June of 2002, 2003, and 2005 at rates of 123 to 135 kg ha^{-1} of nitrogen. Corn was topdressed with ammonium nitrate in 2004 at a rate of 112 kg $acre^{-1}$ of nitrogen. Potash was applied to all plots in April of each year at rates ranging from 112 to 168 kg ha^{-1}. As at RECM, poultry litter was applied at rates ranging from 2241 to 4482 kg ha^{-1} in March or April prior to planting to achieve 67 kg ha^{-1} of nitrogen based on 50% bioavailability.

Statistical Analysis

Analysis of variance (ANOVA) of the data was performed using the MIXED procedure of SAS (SAS, 2003). All years and crops were analyzed separately at both locations. Crop sequence and biocovers were treated as fixed effects and replication as a random effect. Log transformations of the data were performed when necessary to satisfy normality and homogeneity of variances. Data were then back-transformed, and back transformed means and standard errors were reported. Means were separated using Fisher's protected LSD ($P \leq 0.05$), and a SAS macro PDMIX800 (Saxton, 1998) was used to convert the mean separation output to letter groupings.

CHAPTER 3

Results and Discussion

Crop Sequence Main Effects

Research and Education Center at Milan (RECM)

At RECM, continuous corn, soybean, and cotton yields were comparable to or higher than rotated corn, soybean, and cotton yields as expected in the first year of the experiment. Both corn and soybean showed some positive response to rotation, with the response of soybean yields being stronger than the response of corn yields. Cotton yields responded to rotation only in the fourth year. The alternating corn-soybean sequence, when comparisons could be made, had significantly higher yields than both continuous corn and soybean. It appeared that corn and soybean responded much quicker to rotation than cotton, but some higher rotated cotton yields in the fourth year may indicate that cotton will respond favorably to rotation as the experiment progresses another four years.

Corn For the most part, continuous corn yields, when averaged over all biocovers, were higher in 2004 and 2005 than in 2002 and 2003. In the fourth year, continuous corn yields slightly decreased (Fig. 1). However, both soybean and cotton yields also decreased in this year, suggesting that this was a lower-yielding year. Statewide crop yields also reflected this decrease from 2004 to 2005, as corn yields decreased from 8.81 to 8.72 Mg ha^{-1}, soybean yields decreased from 2.75 to 2.55 Mg ha^{-1}, and cotton yields decreased from 1.01 to 0.95 Mg ha^{-1} (NASS, 2007). Continuous corn yields were the same as or significantly lower than corn yields in rotation in the last three years (Fig. 2). These results were not surprising as previous studies have shown that continuous corn

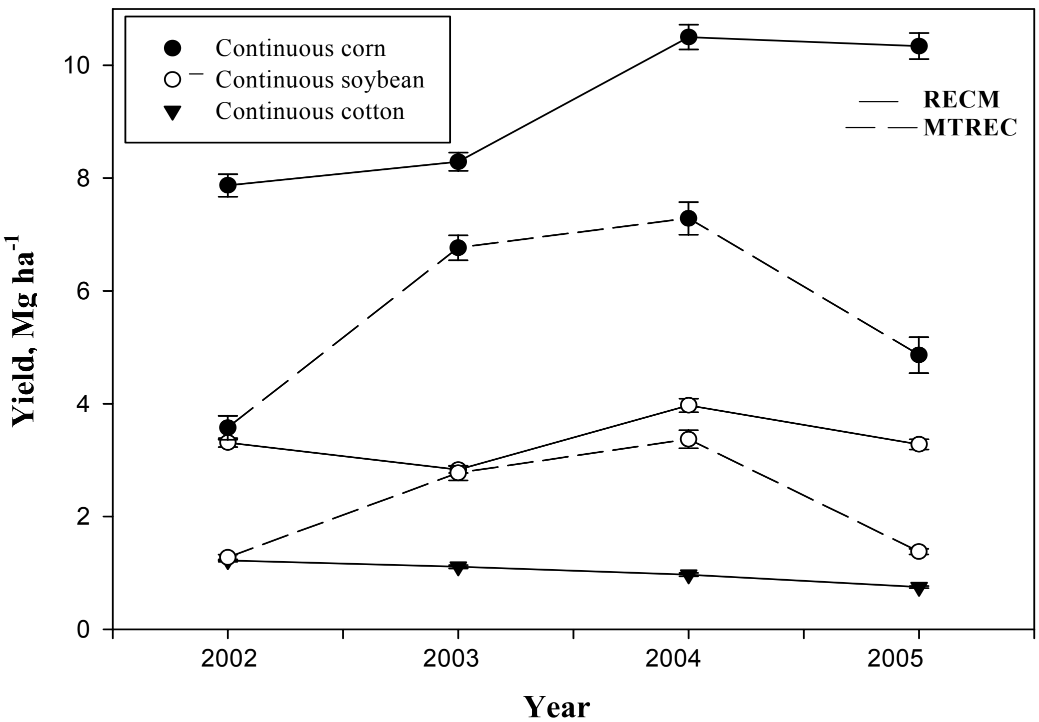

Fig. 1. Continuous crop yields averaged over all biocovers at both the Research and Education Centers at Milan (RECM) and Spring Hill (MTREC) for 2002 to 2005.

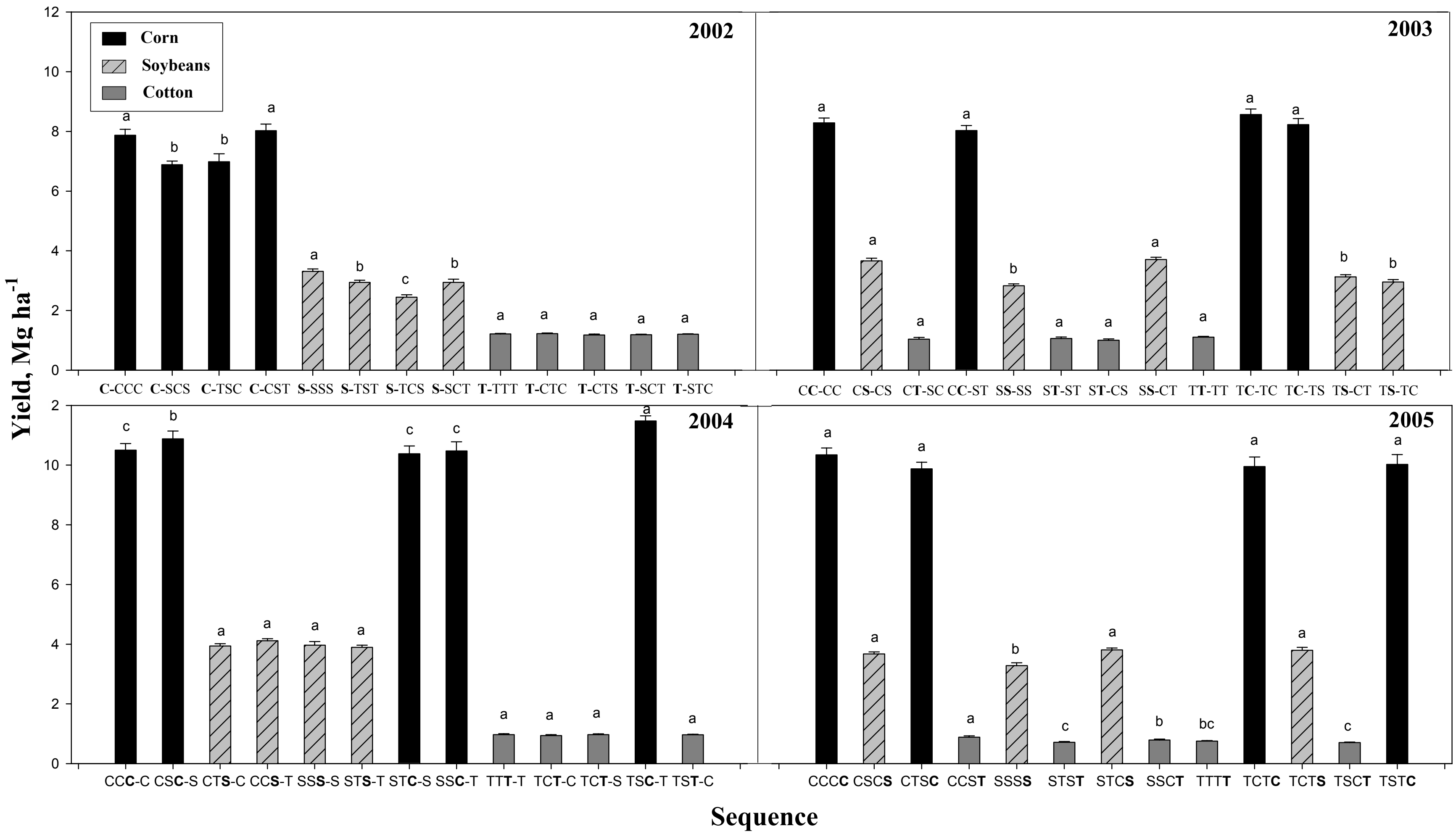

Fig. 2. Corn (C), soybean (S), and cotton (T) yields by sequence averaged over biocovers at the Research and Education Center at Milan (RECM) for 2002 to 2005. Mean separation (Fisher's LSD, $P \leq 0.05$) only valid for the same crop within each year.

yields are often lower than rotated yields in no-till systems (Lund et al., 1993; Vyn et al., 2000). Significant corn crop sequence effects ($P \leq 0.01$) were observed in 2002 and 2004. While a significant corn crop sequence effect was unexpected in the first year of the experiment, one explanation could be that four different corn varieties were used in this year, perhaps contributing to the significant sequence effect. In 2004, the alternating corn-soybean rotation yielded significantly higher than continuous corn, producing 10.88 Mg ha^{-1} to continuous yields of 10.50 Mg ha^{-1} (Fig. 2). These results support research by Lauer et al. (1997) that found a corn-soybean rotation yielded 13% greater than continuous corn. Rotations in which corn immediately followed one year of soybean (CS-C and TS-C) yielded significantly higher than corn following two years of soybean (SS-C) and corn immediately following cotton (ST-C) in 2004 as well (Fig. 2). In both years where a comparison could be made, no differences were found in corn yields of the alternating cotton-corn rotation versus continuous corn. Bruns et al. (2007) found that corn yields increased when in rotation with cotton as compared to yields of continuous corn. Even though our results show corn yields in the cotton-corn rotation to be comparable to and not higher than the alternating rotation, it may be too early in the cropping sequence to see the negative effects of monoculture corn as compared to putting cotton and soybean in the rotation with corn.

Soybean Continuous soybean yields, when averaged over all biocovers, fluctuated from year to year. Yields were higher in 2003 and 2004 compared to 2002 and 2005 (Fig. 1). In 2003-2005, continuous soybean yields were found to be the same as or significantly lower than rotated yields (Fig. 2). These results support previous findings that soybean yields in rotation are higher than those yields of continuous soybean (Vyn et al., 2000;

Kelley et al., 2003). Significant soybean crop sequence effects ($P \leq 0.01$) were found in 2002, 2003, and 2005. Like corn, four different soybean varieties were used in 2002 and were possibly a factor in the significant sequence effect in this year. For both years in which comparisons could be made, the alternating corn-soybean sequence had significantly higher yields than continuous soybean ($P \leq 0.01$), producing 3.66 and 3.67 Mg ha-1 compared to 2.83 and 3.28 Mg ha-1 in 2003 and 2005, respectively (Fig. 2). Lauer et al. (1997) observed that soybean yields in a corn-soybean rotation were 10% greater than continuous soybean yields. The presence of cotton in the sequence may influence soybean yields. In 2003, soybean after corn yields (3.66 Mg ha^{-1}) and soybean after soybean yields (3.71 Mg ha^{-1}) were significantly higher than soybean after cotton yields (3.13 and 2.95 Mg ha^{-1}) and continuous soybean (2.83 Mg ha^{-1}) yields (Fig. 2). No differences in yield were found between the soybean following cotton rotation and continuous soybean. While no significant differences were found between rotated and continuous soybean yields in 2004, soybean after two years of corn (CC-S, 4.11 Mg ha^{-1}) averaged higher when compared to soybean after one year of corn and cotton (CT-S, 3.94 Mg ha^{-1}), soybean after one year of soybean and cotton (ST-S, 3.89 Mg ha^{-1}), and continuous soybean (SSS, 3.97 Mg ha^{-1}) (Fig. 2). No differences were found in soybean yields of the alternating soybean-cotton rotation and continuous soybean (Fig. 2).

Cotton Continuous cotton yields, averaged over all biocovers, steadily decreased over the four years of the experiment, with yields ranging from 1.22 Mg ha^{-1} to .75 Mg ha^{-1} (Fig. 1). This is especially surprising since both corn and soybean yields were higher in 2003 and 2004, and statewide average yields of cotton increased from 2002 to 2004 with a decrease only observed in 2005 (NASS, 2007). Reasons for the decrease of cotton yields in this experiment were unknown, but yields of the district in which our experiment was located produced lower cotton yields than statewide averages in two out of the four years (NASS, 2007). It was expected that with steadily decreasing continuous cotton yields that the crop sequence effect would be significant and rotations would outperform continuous cotton. However, continuous cotton averages were generally the same as or higher than rotated cotton averages for the first three years of the experiment (Fig. 2). Significant crop sequence differences were found in cotton yields in 2005 ($P \leq 0.01$). It appeared that in this year, the more cotton put into the rotation, then the lower the yields. When cotton was preceded by a combination of just soybean and corn (SSC-T, 0.79 Mg ha^{-1}; CCS-T, 0.89 Mg ha^{-1}), yields were the same as or significantly higher than continuous cotton yields (0.75 Mg ha^{-1}) (Fig. 2). However, no significant differences were found in yields of those rotations that included one year of cotton with some combination of corn and soybean (STS-T, 0.71 Mg ha^{-1}; TSC-T, 0.70 Mg ha^{-1}) and continuous cotton yields. When just looking at rotated cotton yields, rotated cotton after three years of some combination of just corn and soybean (SSC-T, 0.79 Mg ha^{-1}; CCS-T, 0.89 Mg ha^{-1}) yielded higher than rotations with one year of cotton mixed in with some combination of soybean and corn (STS-T, 0.71 Mg ha^{-1}; TSC-T, 0.70 Mg ha^{-1}) (Fig. 2). Overall, two out of the four cotton rotations in 2005 had higher yields than continuous cotton, compared to no rotations yielding greater than continuous cotton in the previous two years. It had been previously shown that after switching to no-till from conventional till, rotated cotton yields outperformed continuous cotton yields (Burmester et al., 2002). It was especially surprising that the cotton-corn rotation produced comparable yields to continuous cotton as several studies (Reddy et al., 2006; Burmester et al., 2002) have shown that cotton yields increase when in rotation with corn. While our results do not support these findings, it was encouraging to see that some rotated cotton yields were averaging higher than continuous yields in the fourth year of the experiment, suggesting that rotations might begin to consistently yield greater than continuous cotton in the next phase of the experiment (2006-2009).

Middle Tennessee Research and Education Center (MTREC)

At MTREC, rotated corn and soybean yields were generally comparable to or higher than continuous corn and soybean yields in all four years. Corn in the rotation appeared to affect soybean yields. Soybean yields increased as the frequency of corn increased in the rotation. Reflecting the results found at RECM, both corn and soybean responded to rotation, but the response of soybean was stronger than the response of corn.

Corn Continuous corn yields averaged over all biocovers reflected the same trend observed in corn yields at RECM. Yields tended to increase for the first three years and then were lower in the fourth year (Fig. 1). Since soybean yields also showed the same decline in the final year, the decrease in crop yields in the fourth year could possibly be attributed to a lower-yielding year. Continuous corn yields were comparable to or lower than rotated corn yields in all four years (Fig. 3). There was a significant corn crop sequence effect in both 2002 ($P \leq 0.01$) and 2003 ($P \leq 0.05$). Once again, as at RECM, four different corn varieties were used in the first year and undoubtedly contributed to the significant sequence effect observed. In 2003, continuous corn (6.77 Mg ha^{-1}) had comparable yields to corn after soybean in rotation (6.69 and 7.00 Mg ha^{-1}) and

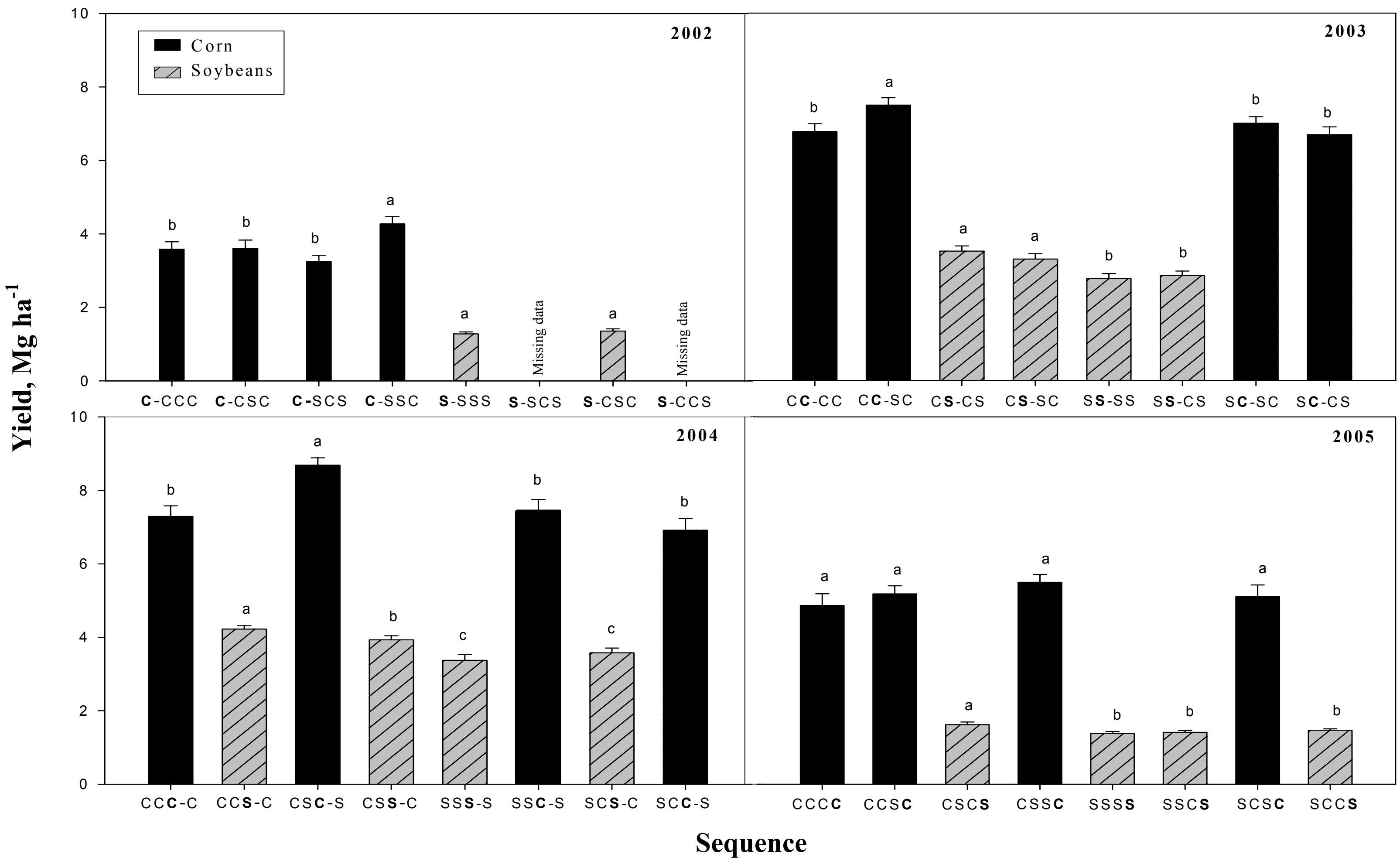

Fig. 3. Corn (C) and soybean (S) yields by sequence averaged over all biocovers at the Middle Tennessee Research and Education Center (MTREC) from 2002 to 2005. Mean separation (Fisher's LSD, P ≤ 0.05) only valid for the same crop within each year.

significantly lower yields than corn after corn in rotation (7.50 Mg ha^{-1}) (Fig. 3). These results were unexpected as previous studies such as one conducted by Pedersen and Lauer (2003) have indicated that corn after soybean yields higher than continuous corn. It was expected that continuous corn (CC) and corn after corn in rotation (C-C) would produce comparable yields in the second year of the experiment, and corn after soybean (S-C) would outperform both. However, when just looking at rotated corn yields, corn after corn yielded 7.50 Mg ha^{-1} which was significantly higher than corn after soybean yields of 6.99 and 6.69 Mg ha^{-1} ($P \leq 0.01$) (Fig. 3). Since it was so early in the sequence, the expected yield benefits of corn after soybean as opposed to corn after corn may not be apparent yet.

Soybean Yields of continuous soybean averaged over all four biocovers also increased for the first three years and were lower in the fourth year (Fig. 1). In general, it appeared that 2005 was just a year that exhibited low yields as corn yields showed the same decrease. In all four years, continuous soybean yields were the same as or significantly lower than rotated soybean yields (Fig. 3). Significant soybean crop sequence effects ($P \leq 0.01$) were observed in 2003, 2004, and 2005. Soybean yields tended to significantly increase with the frequency of corn in rotation in all three years. In 2003, rotations with soybean following one year of corn produced 3.52 and 3.31 Mg ha^{-1}, yields that were significantly higher than soybean after soybean yields of 2.85 Mg ha^{-1} and continuous soybean yields of 2.78 Mg ha^{-1} (Fig. 3). Rotated soybean yields in sequences where soybean followed some combination of corn and soybean (CS-S, 3.93 Mg ha^{-1}; SC-S; 3.58 Mg ha^{-1}) yielded the same as or significantly higher yields than continuous soybean (3.37 Mg ha^{-1}), but soybean yields after two years of corn (CC-S, 4.22 Mg ha^{-1}) yielded significantly higher than those rotations with just one year of corn in 2004 (Fig. 3). These results continued into the final year. When evaluating the trends, those rotations with two years of corn preceding soybean (CSC-S, 1.62 Mg ha^{-1}; SCC-S, 1.47 Mg ha^{-1}) had higher yields than both the rotation with one year of corn preceding soybean (SSC-S, 1.41 Mg ha^{-1}) and continuous soybean (1.38 Mg ha^{-1}) (Fig. 3). However, only one of those sequences with two years of corn, the alternating corn-soybean rotation, yielded significantly higher than the rotation with one year of corn and continuous soybean. These results were not surprising as earlier studies have observed that first year soybean after several years of corn had higher yields than continuous soybean (Meese et al., 1991; Temperly and Borges, 2006). While the four-year duration of the first phase of this experiment limits the frequency of corn in the rotation, it is not unreasonable to think that this trend of more corn increasing soybean yields will continue into the next four years of the second phase.

Biocover Main Effects

Research and Education Center at Milan (RECM)

At RECM, biocovers averaged over all sequences generally did not have a significant effect upon corn, soybean, and cotton yields. Excluding the first year in which different crop varieties were used, significant biocover effects were found in just one year for corn and cotton and not at all in soybean. In terms of trends, fallow and hairy vetch biocover produced consistently high corn yields. This was not the case for soybean and cotton as yields of both crops trended higher under poultry litter.

Corn Corn yields resulting from all four biocovers averaged over all sequences tended to increase for the first three years and then decrease slightly in the fourth year, a decrease due to an overall lower-yielding year (Fig. 4a). There was a significant biocover main effect on corn yield ($P \leq 0.05$) in 2002 and 2003. In 2002, fallow and poultry litter resulted in the highest corn yields and were comparable to each other, but only fallow resulted in significantly higher yields than hairy vetch and wheat (Fig. 4a). In 2003, corn yields under fallow (8.57 Mg ha^{-1}) and hairy vetch (8.73 Mg ha^{-1}) produced the highest yields and were comparable to each other, and both averaged higher than poultry litter (7.72 Mg ha^{-1}) and wheat (8.12 Mg ha^{-1}) yields (Fig. 4a). No significant differences were found between corn yields of all four biocovers averaged over all sequences in 2004 and 2005. Mean corn yield ranged from 11.21 to 9.94 Mg ha^{-1} in 2004 and from 10.75 to 9.80 Mg ha^{-1} in 2005. For corn, our results may indicate that the use of biocovers alone may not be sufficient to significantly increase yields. One overall trend was that when averaged across all four years, fallow (9.79 Mg ha^{-1}) and hairy vetch (9.81 Mg ha^{-1}) had significantly higher ($P \leq .01$) corn yields than poultry litter (9.25 Mg ha^{-1}) and wheat (8.94 Mg ha^{-1}) (Fig. 4a). It was surprising that fallow produced higher corn yields than poultry litter as it was hypothesized that corn would perhaps benefit from the accumulated nutrients provided by this biocover and yields would be greater than those under fallow. For example, one study performed by Endale et al. (2004) found that no-till and poultry litter increased corn yields by 27%. Our results did not show this increase with poultry litter. However, the rate of application of poultry litter to corn in the Endale experiment was more than double the rate of application in our experiment, suggesting that a higher rate of application for poultry litter is needed to result in higher corn yields. It was not

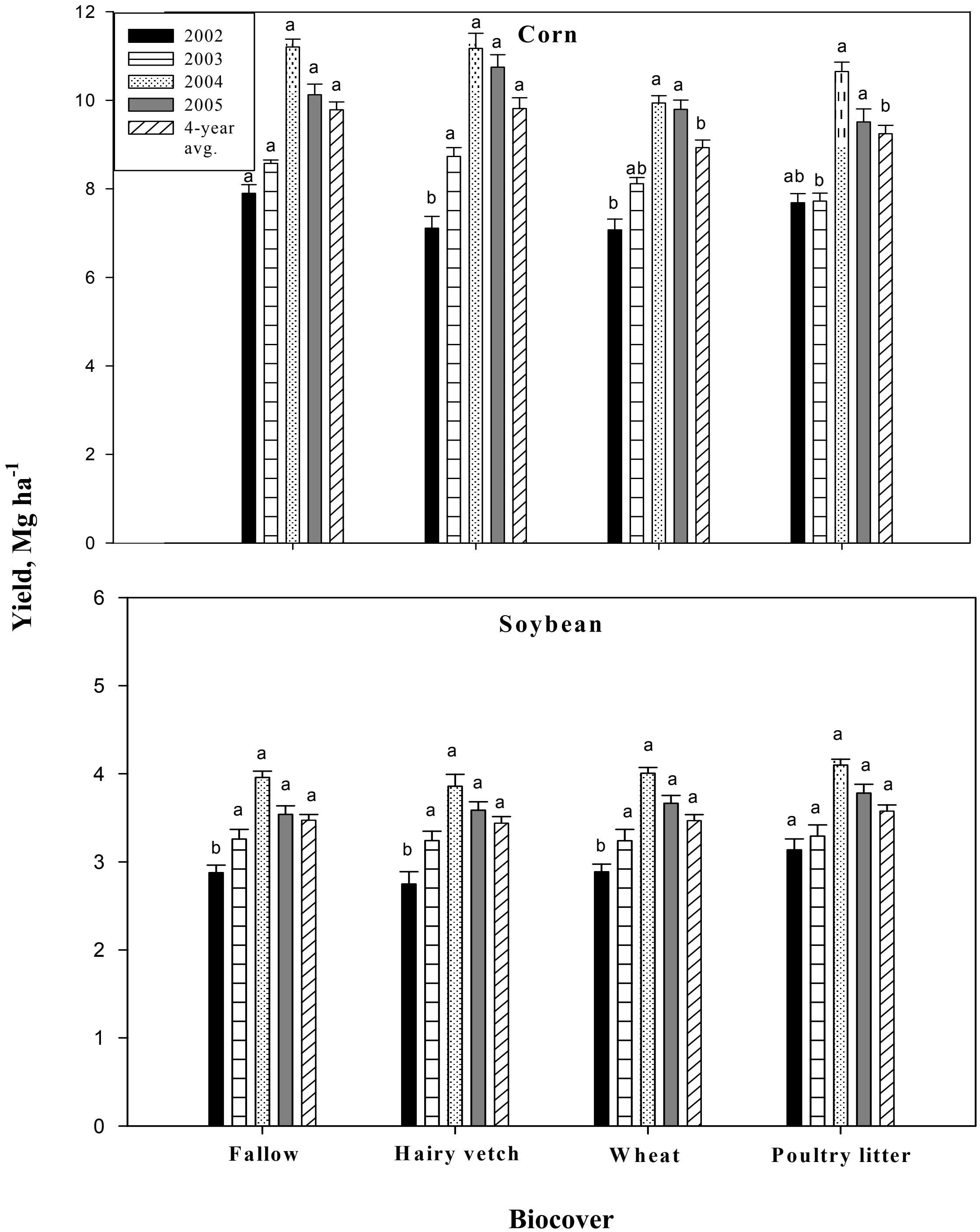

Fig. 4a. Corn and soybean yields by biocover averaged over all sequences at the Research and Education Center at Milan (RECM) from 2002 to 2005. Mean separation (Fisher's LSD, P ≤ 0.05) only valid for biocover within the same crop and year.

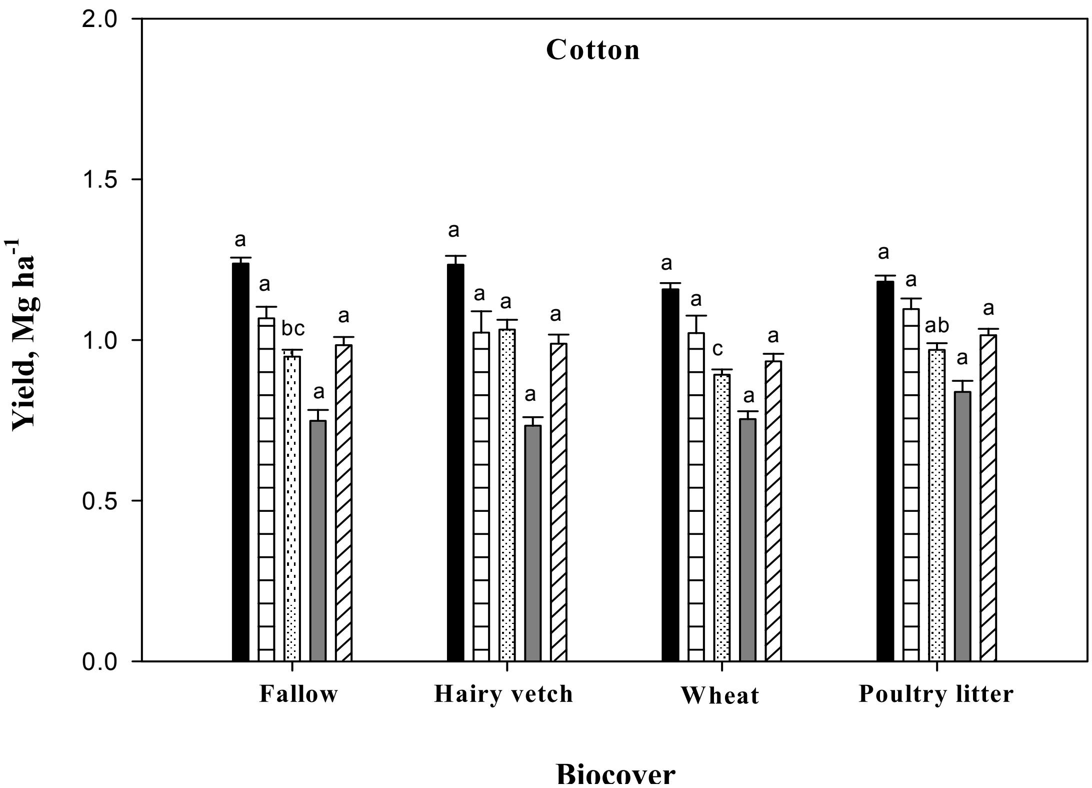

Fig. 4b. Cotton yields by biocover averaged over all sequences at the Research and Education Center at Milan (RECM) from 2002 to 2005. Mean separation (Fisher's LSD, $P \leq 0.05$) only valid for biocover within the same crop and year.

unexpected to see low corn yields after wheat biocover as one explanation would involve reduced nitrogen levels resulting from wheat being a high C:N crop. Lower soil nitrogen levels after winter wheat have been reported (Kravchenko and Thelen, 2007; Dabney et al., 2001), and this may have negatively impacted corn yield.

Soybean Soybean yields under all four biocovers reflected the same trend observed in corn yields, with yields increasing for the first three years and then lower in the last year (Fig. 4a). A significant biocover main effect on soybean yields was found only in 2002 ($P \leq 0.05$). Soybean yields under poultry litter were 3.14 Mg ha^{-1}, which was significantly higher than corresponding soybean yields under fallow (2.88 Mg ha^{-1}), hairy vetch (2.75 Mg ha^{-1}), and wheat (2.89 Mg ha^{-1}) (Fig. 4a). However, these results could have been a reflection of the different soybean varieties used in this year. In further support that these results were not expected, biocover main effects on soybean yield were not significant ($P > 0.05$) in the remaining three years of the experiment. Yields ranged from 3.29 to 3.24 Mg ha^{-1} in 2003, from 4.10 to 3.86 Mg ha^{-1} in 2004, and 3.78 to 3.54 Mg ha^{-1} in 2005 (Fig. 4a). When averaged across all four years, poultry litter (3.57 Mg ha^{-1}) resulted in higher soybean yields than wheat (3.47 Mg ha^{-1}), fallow (3.47 Mg ha^{-1}), and hairy vetch (3.44 Mg ha^{-1}) (Fig. 4a), but these differences were not significant. Once again, our results at RECM seem to suggest that biocovers alone may not significantly increase soybean yields. However, with the trend that poultry litter and wheat resulted in comparable to or slightly higher soybean yields than fallow across the four years, it may be that more time is needed before significant differences will be seen with hairy vetch, wheat, and poultry litter biocovers compared to fallow biocover.

Cotton Unlike corn and soybean yields, steadily decreasing cotton yields were observed under all four biocovers as the experiment progressed, with the exception of a slight increase in cotton yields under hairy vetch between the years 2003 and 2004 (Fig. 4b). A significant biocover main effect ($P \leq 0.01$) on cotton yield was found only in 2004. Cotton yields under hairy vetch (1.03 Mg ha^{-1}) and poultry litter (0.97 Mg ha^{-1}) were significantly higher than the wheat (0.89 Mg ha^{-1}), but only hairy vetch yielded significantly higher than fallow in 2004 (Fig. 4b). For 2002, 2003, and 2005, the biocover main effect was not significant in cotton ($P > 0.05$) at RECM. One general trend was that when averaged across all four years, cotton yield under poultry litter at 1.01 Mg ha^{-1} averaged highest and cotton yield under wheat at 0.93 Mg ha^{-1}averaged the lowest (Fig. 4b), but there were no significant differences among the four-year averages of all four biocovers. Daniel et al. (1999) reported that a hairy vetch/rye cover crop treatment increased cotton yields more so than a wheat cover crop, perhaps due to an increased availability of nitrogen. Therefore, one possible explanation for increased cotton yield with hairy vetch and poultry litter is that hairy vetch, as a legume, and poultry litter, as manure with slowly available nitrogen, might have increased the amount of nitrogen available for cotton growth as opposed to a wheat biocover. Furthermore, wheat has a high C:N ratio which can immobilize nitrogen and make it less available for the following cotton crop (Dabney et al., 2001).

Middle Tennessee Research and Education Center (MTREC)

At MTREC, corn yield response to biocovers averaged over all sequences reflected those results found at RECM. Apart from the first year when different varieties were planted, a significant biocover main effect was found in only one other year. Generally, fallow and hairy vetch produced the highest corn yields; whereas, wheat produced the lowest. Soybean yield at MTREC responded more favorably to biocovers than corn, with yields under poultry litter being significantly higher than all other biocovers in the two years in which biocover effects were significant.

Corn Corn yields resulting from all four biocovers averaged over all sequences tended to mirror the results found at RECM. Yields increased for the first three years and then decreased in the fourth year (Fig. 5). Significant corn biocover effects ($P \leq 0.05$) were seen in 2002 and 2004. In 2002, corn under fallow at 4.46 Mg ha^{-1} resulted in significantly higher yields than under hairy vetch (3.56 Mg ha^{-1}), wheat (3.43 Mg ha^{-1}), and poultry litter (3.24 Mg ha^{-1}) (Fig. 5). There was a significant crop sequence x biocover interaction effect in 2004 and so the interaction will be examined more closely than the significant biocover main effect. Overall trends in corn yields under all biocovers at MTREC seemed to indicate that mean corn yields under fallow were consistently high in all four years, producing the highest yields in two out of the four years and the second highest yields in the other two years. Corn yields under wheat were consistently in the bottom two in terms of mean yield for all four years. Corn yield resulting from fallow treatment, when averaged across all four years, was 6.21 Mg ha^{-1}. That was the same as corn yields under hairy vetch (6.21 Mg ha^{-1}) and higher than corn yields under poultry litter (5.85 Mg ha^{-1}) and wheat (5.83 Mg ha^{-1}) (Fig. 5). Again, this result was not encouraging as it appeared that biocovers alone were ineffective at increasing corn yields at MTREC as well as RECM as fallow consistently trended the same as or higher than the other biocovers.

Soybean Similar to corn yields, soybean yields averaged over all sequences increased in

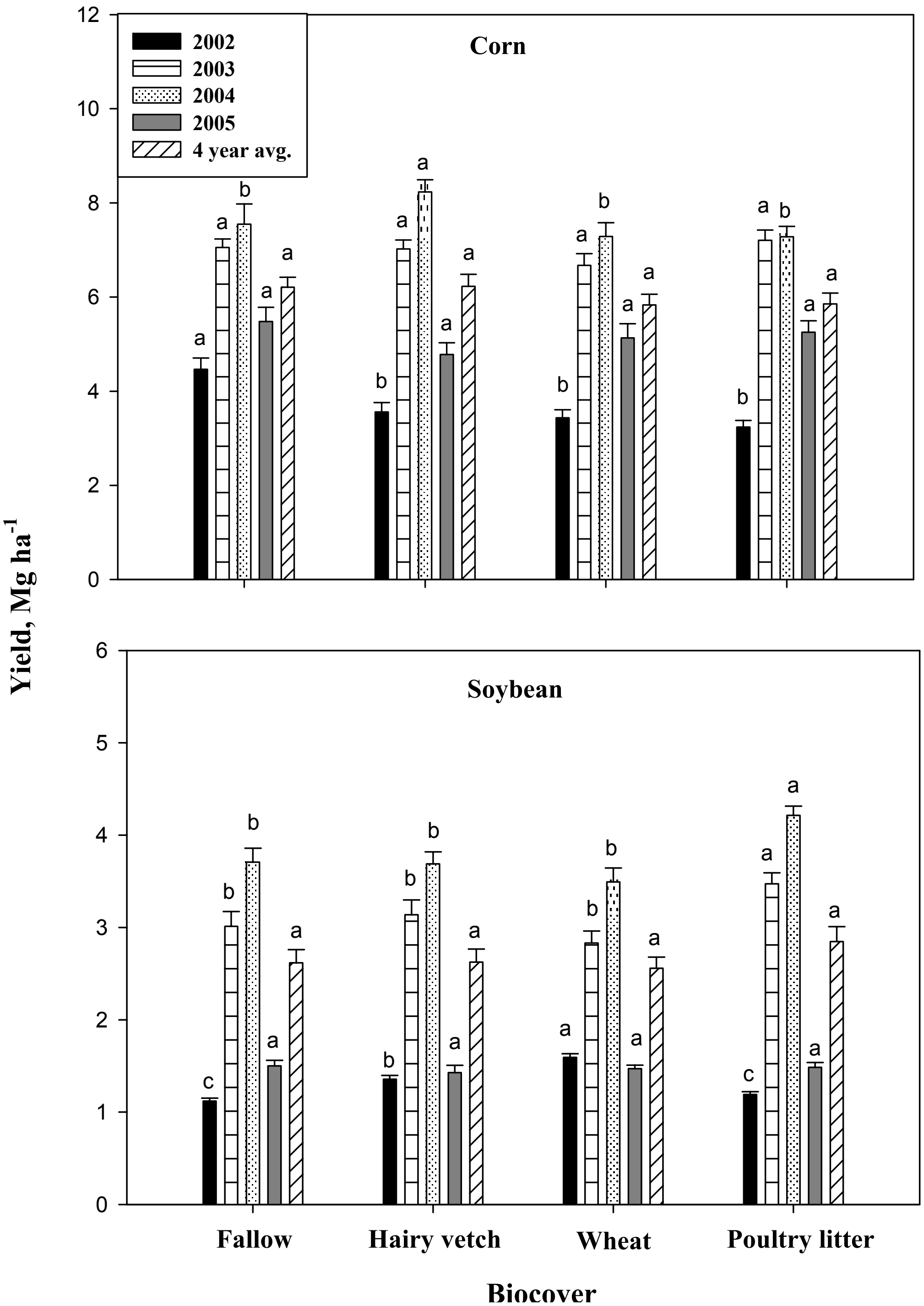

Fig. 5. Corn and soybean yields by biocover averaged over all sequences at the Middle Tennessee Research and Education Center (MTREC) from 2002 to 2005. Mean separation (Fisher's LSD, P ≤ 0.05) only valid for biocovers within the same crop and year.

the first three years and then sharply decreased in the fourth year for each biocover (Fig. 5). However, as stated earlier, the statewide average soybean yields were lower in 2005 when compared to 2004. Soybean yields appeared to respond to the use of biocovers at MTREC. Significant soybean biocover effects ($P \leq 0.01$) were detected in 2002, 2003, and 2004. In both 2003 and 2004, results were very similar. Soybean yields under poultry litter were significantly higher than all other biocovers, with yields of 3.47 Mg ha^{-1} in 2003 and 4.21 Mg ha^{-1} in 2004 (Fig. 5). The biocover effect was not significant in 2005 ($P > 0.05$). When looking at the four-year averages to provide more insight into the differences between the biocovers, soybean yields were highest under poultry litter, producing 2.85 Mg ha^{-1} compared to the four-year averages of hairy vetch (2.63 Mg ha^{-1}), fallow (2.61 Mg ha^{-1}), and wheat (2.56 Mg ha^{-1}) (Fig. 5). These differences in soybean yield were not significant. Previous research has shown that biocovers such as winter wheat and poultry litter can benefit soybean (Gallagher et al., 2003; Adeli et al., 2005). While not significant, with poultry litter and hairy vetch averaging higher soybean yields than fallow when averaged over the first four years, it is not unreasonable to perhaps expect more significant differences among the biocovers to occur in the next four years of the experiment.

Crop Sequence x Biocover Interaction Effects

Research and Education Center at Milan (RECM)

No crop sequence x biocover interaction effects ($P > 0.05$) were observed at RECM for corn, soybean, or cotton yields in any of the four years. As expected, when looking at just the continuous sequences, the effects of the biocovers reflected those results found when looking at the main effect of the biocovers. Continuous corn yields were highest under hairy vetch in 2003, 2004, and 2005 and lowest under wheat in 2002 and 2005 and poultry litter in 2003 and 2004. Continuous soybean yields tended to be higher under poultry litter in 2002, 2004, and 2005 and lowest under fallow in 2002, 2004, and 2005. For continuous cotton, yields varied according to biocover from year to year.

Corn As indicated by the nonsignificant crop sequence x biocover interactions ($P > 0.05$) for corn in every year at RECM, the biocover effects were generally consistent over all 13 sequences (Fig. 6a). A complete list of the corn yield values for each crop sequence and biocover combination at RECM can be found in Table A4 of the Appendix. Generally, mean corn yields decreased from fallow to poultry litter or wheat across all sequences in every year. Inconsistent results were seen with hairy vetch as corn yields increased when moving from fallow to hairy vetch across all sequences in two years but decreased in the remaining two years. This inconsistency was not enough to cause a significant crop sequence x biocover interaction. However, the major effects of biocovers were again observed by looking within just the continuous corn sequence in all four years. Continuous corn yields were highest under hairy vetch in 2003 (8.67 Mg ha^{-1}), 2004 (11.27 Mg ha^{-1}), and 2005 (10.73 Mg ha^{-1}) (Fig. 6a). Continuous corn yields were lowest under wheat in 2002 (7.56 Mg ha^{-1}) and 2005 (10.17 Mg ha^{-1}) and poultry litter in 2003 (7.86 Mg ha^{-1}) and 2004 (9.89 Mg ha^{-1}) (Fig. 6a). These results were not unexpected as both fallow (9.45 Mg ha^{-1}) and hairy vetch (9.44 Mg ha^{-1}) resulted in the highest 4-year average corn yields over all sequences. Conversely, poultry litter (8.90 Mg ha^{-1}) and wheat (8.73 Mg ha^{-1}) had the lowest (Fig. 6a).

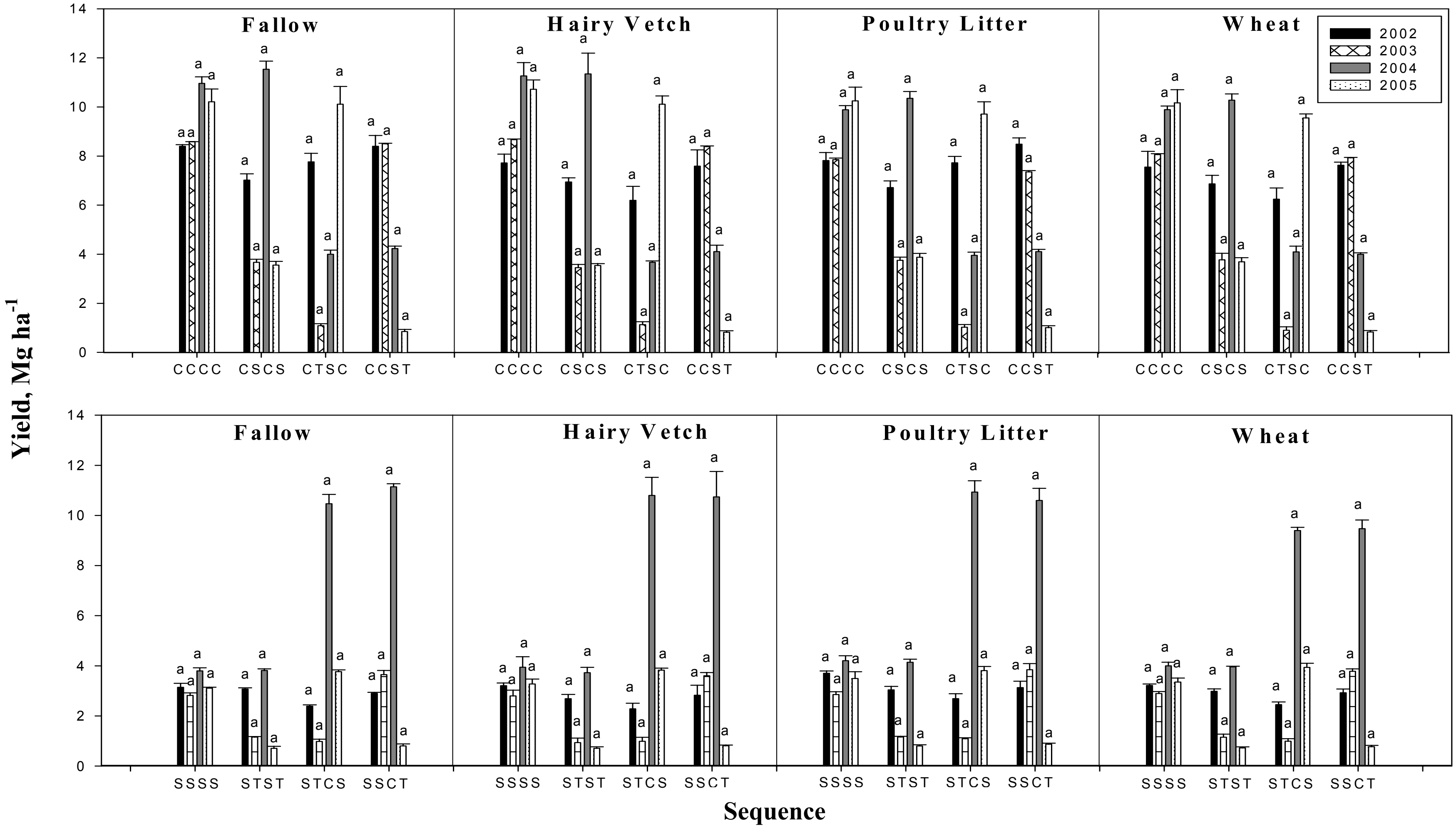

Fig. 6a. Interaction effects of crop sequence x biocover for those sequences beginning with corn (C) and soybean (S) at the Research and Education Center at Milan (RECM) from 2002 to 2005. Mean separation (Fisher's LSD, $P \leq 0.05$) only valid for those crops within the same year.

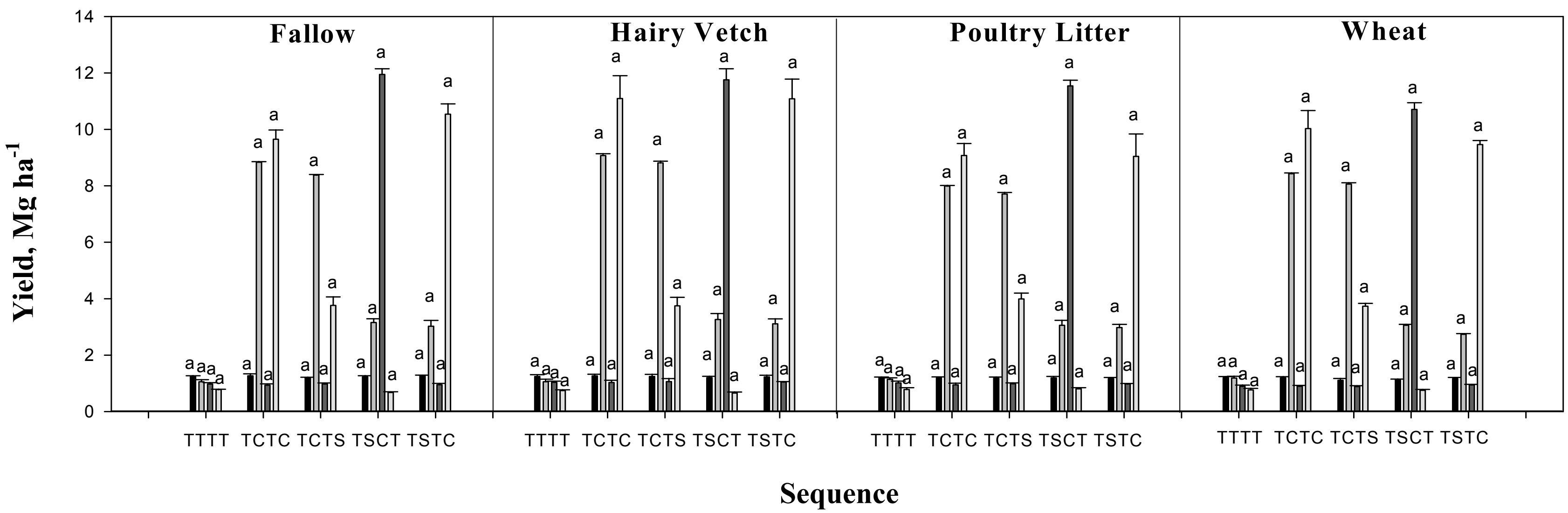

Fig. 6b. Interaction effects of crop sequence x biocover for those sequences beginning with cotton (T) at the Research and Education Center at Milan (RECM) from 2002 to 2005. Mean separation (Fisher's LSD, $P \leq 0.05$) only valid for those crops within the same year.

Soybean Nonsignificant crop sequence x biocover interactions for soybean were also observed all four years at RECM (Fig. 6a). Again, this indicated that the biocover effects were the same over all the sequences. There were no significant differences in soybean yields when moving from biocover to biocover among or between sequences. Overall trends were that in every year, average soybean yields tended to increase when moving from under fallow to poultry litter or wheat and to decrease when moving from under fallow to hairy vetch. Examining the continuous soybean sequence, yields tended to be higher under poultry litter in 2002 (3.70 Mg ha^{-1}), 2004 (4.19 Mg ha^{-1}), and 2005 (3.47 Mg ha^{-1}) (Fig. 6a). Continuous soybean yields were lowest under fallow in those same three years, with 2002 yields of 3.14 Mg ha^{-1}, 2004 yields of 3.79 Mg ha^{-1}, and 2005 yields of 3.09 Mg ha^{-1}(Fig. 6). Our results do not agree with those of Reddy (2001) who observed that with herbicide use, yield of no-till soybean was higher under no cover crop when compared with no-till soybean yield under hairy vetch and wheat. However, the length of the Reddy study was two years and differences between biocovers and fallow were discovered in the last two years of our experiment, indicating that more time may be needed to fully observe the effects of biocovers upon soybean yields. While no significant differences were detected among the four biocovers for continuous soybean yields in our study, it appeared that biocovers did serve to increase continuous soybean yields compared to fallow. A complete list of soybean yield values for each crop sequence and biocover combination at RECM can be found in Table A4 of the Appendix.

Cotton For every year, crop sequence x biocover interactions were not significant for cotton yields at RECM (Fig. 6b). There were no significant differences when moving from biocover to biocover among or between sequences (Fig. 6b). The effects of biocovers were consistent across all sequences. Moving from fallow to poultry litter generally increased mean cotton yields; whereas, moving from fallow to wheat resulted in an overall decrease for all four years (Fig. 6b). Results for moving from fallow to hairy vetch were inconsistent as mean yields increased in two years and decreased in the other two years. Examining the continuous cotton sequence, no one biocover clearly yielded higher than the other three for all four years. However, in terms of trends, continuous cotton under poultry litter had consistently high yields. Again, a complete list of the cotton yield values for each crop sequence and biocover combination at RECM can be found in Table A4 of the Appendix.

Middle Tennessee Research and Education Center (MTREC)

The effects of biocovers on corn yields were not consistent across all eight sequences at MTREC, as significant crop sequence x biocover interactions were observed in the last two years of the experiment. Biocovers did not appear to have a great effect upon continuous corn yields in 2004. In 2005, more differences between the effects of biocovers were discovered when looking at continuous corn yields as fallow and poultry litter produced the highest yields. In both years, it appeared that some biocovers produced greater yields when moving from continuous corn to rotated corn when compared to fallow. Hairy vetch and wheat appeared to be the most consistent biocovers in terms of higher yields when shifting from continuous to rotated corn. An unexpected significant crop sequence x biocover interaction was observed in 2002 for soybean yields but could have been caused by the use of different varieties in that year or by a limited data set for that year.

Corn No crop sequence x biocover interaction effects were seen for corn yields in the 2002 and 2003 (Fig. 7). Unlike at RECM, the effects of biocovers were not consistent across all sequences in the final two years of the experiment. Significant interaction effects were detected in both 2004 and 2005 ($P \leq 0.01$). In 2004, one explanation for the significant interaction could be that continuous corn decreased from 7.92 to 6.33 Mg ha^{-1} when moving from fallow to wheat biocover while the SCCS rotation increased from 5.56 to 7.54 Mg ha^{-1} (Fig. 7). When examining the continuous corn sequence, no differences were found in continuous corn yields under fallow, hairy vetch, or poultry litter. Only continuous corn under fallow was significantly higher than wheat but no differences were found in continuous corn yields under hairy vetch and poultry litter. The inconsistent effect of biocovers across sequences is observed when comparing continuous and rotated corn yields under all four biocovers. While not significant, continuous corn yields (7.92 Mg ha^{-1}) under fallow averaged higher than corn yields of two out of the three rotations under fallow (5.56 and 7.36 Mg ha^{-1}) in 2004 (Fig. 7). However, this was not the case for corn yields under hairy vetch and wheat. Rotated corn yields under hairy vetch (9.05, 7.75, and 8.67 Mg ha^{-1}) and wheat (8.24, 7.54, and 7.05 Mg ha^{-1}) averaged higher than continuous corn yields under hairy vetch (7.46 Mg ha^{-1}) and wheat (6.33 Mg ha^{-1}) (Fig. 7). Rotated corn yields under poultry litter were generally lower than continuous corn yields under poultry litter. These results suggest that the use of hairy vetch and wheat biocovers in corn improved corn yields when moving from continuous corn to rotated corn in 2004. For example, when changing from continuous corn to the SCCS rotation, average yields increased from 7.46 to 7.75 Mg ha^{-1} under hairy vetch and increased from 6.33 to 7.54 Mg ha^{-1} under wheat while yields decreased

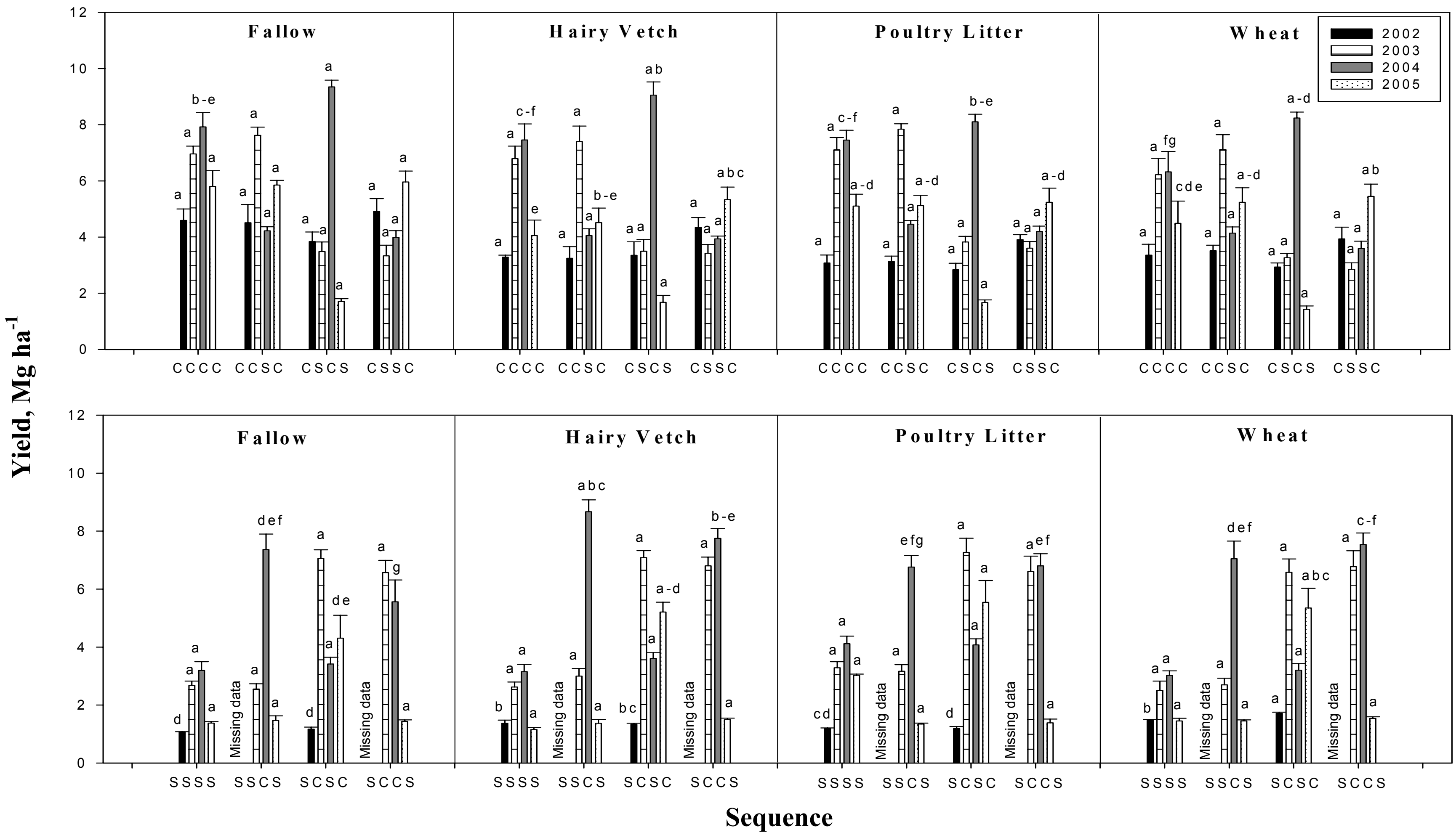

Fig. 7. Crop sequence x biocover interaction effects for corn (C) and soybean (S) yields at the Middle Tennessee Research and Education Center (MTREC) from 2002 to 2005. Mean separation (Fisher's LSD, P ≤ 0.05) only valid for the same crop within each year.

to 5.56 from 7.92 Mg ha^{-1} and decreased to 6.80 from 7.45 Mg ha^{-1} under fallow and poultry litter, respectively (Fig. 7). One rotation in particular, the alternating corn-soybean rotation, did significantly increase yields across all biocovers. When changing from continuous corn under one biocover to the corn-soybean rotation under that same biocover, yields were significantly higher in the corn-soybean rotation for fallow, hairy vetch and wheat. However, only the combination of the corn-soybean rotation under fallow with the highest overall average yield of 9.34 Mg ha^{-1} was significantly higher than all combinations of continuous corn/biocover (Fig. 7).

In 2005, the significant interaction effect could have been caused in part by continuous corn decreasing from 5.81 to 4.49 Mg ha^{-1} when moving from fallow to wheat biocover while the alternating soybean-corn rotation increased from 4.31 to 5.35 Mg ha^{-1} (Fig. 7). Yield differences among the biocovers became more pronounced when looking at continuous corn. Continuous corn under fallow produced comparable yields to that under poultry litter but significantly higher than yields under hairy vetch and wheat. A continuous corn yield of 5.11 Mg ha^{-1} under poultry litter was significantly higher than 4.06 Mg ha^{-1} under hairy vetch (Fig. 7). When switching from continuous corn under fallow to rotation under fallow, rotated corn yields were the same as or significantly lower than continuous corn yields as shown by continuous corn yields of 5.81 Mg ha^{-1} and rotated corn yields of 5.85, 5.96, and 4.31 Mg ha^{-1} (Fig. 7). This did not hold true for all other biocovers as rotated corn yields were comparable or significantly higher than continuous corn yields for hairy vetch, poultry litter, and wheat. This suggests that the use of hairy vetch, poultry litter, and wheat biocovers combined with rotation enhanced corn yields when switching from continuous corn to rotated corn in 2005. Within the rotations, the alternating soybean-corn rotation under fallow had the lowest mean yields and was the same as or significantly lower than all other rotation-biocover combination yields. This was a surprising result since the corn-soybean rotation under fallow had the highest yields in the previous year. In general, no differences were found between yields of each rotation/biocover combination. A complete list of corn yield values for each crop sequence and biocover combination at MTREC can be found in Table A5 of the Appendix.

Soybean The crop sequence x biocover interaction effect was significant ($P \leq .05$) only in 2002 when looking at soybean yields (Fig. 7). A complete list of the soybean yield values for each crop sequence and biocover combination at MTREC can be found in Table A5 of the Appendix. For both continuous soybean and rotated soybean, the highest yields were observed under wheat and the lowest yields under fallow (Fig. 7). For fallow, hairy vetch, and poultry litter, no differences were found when changing from continuous soybean to an alternating soybean-corn rotation, the only rotation on which data were gathered for 2002. However, these results were surprising as it was the first year of the experiment and no crop sequence x biocover interaction effect was expected. As stated before, different soybean varieties were used in the first year of the experiment and could be a factor in the significant interaction effect. Also, four sequences involved soybean that year, but yield data were only able to be gathered on two of those four sequences.

CHAPTER 4

Conclusions

Crop rotation and biocovers are often utilized in no-till and have been shown to increase crop yields. Our results show that crop rotation benefited corn to some extent at both locations, but soybeans appeared to have a stronger response to rotation than corn. Cotton was slower to respond to rotation. The effect of biocovers alone upon crop yields was not as pronounced as that of crop rotation as significant differences in corn, soybean, and cotton yields were not consistently found between the four biocovers. Trends such as the four-year average yield of soybean being highest under hairy vetch, poultry litter, and wheat biocovers and the four-year average yield of cotton being highest under poultry litter biocover indicate that significant differences in crop yields under different biocovers may be more evident in the next phase (2006-2009) of the experiment. Corn yields were relatively unaffected by the use of biocovers as corn yields under fallow were consistently among the highest yields at both locations. However, at MTREC, interaction effects of cropping sequence x biocover on corn yields were observed in the latter two years of the experiment. Continuous corn yields under fallow were higher than rotated corn yields under fallow. However, in the presence of hairy vetch and wheat biocovers, rotated corn yields were higher than continuous corn yields. These results suggest that the combined effect of crop rotation and biocovers can increase corn yields and a longer time period may be needed before significant differences in yields as a result of this combined effect may be apparent. Results from the next four years will provide greater detail as to the combined effects of cropping sequence x biocovers upon corn yields as well as soybean and cotton yields under a long-term no-till management system.

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CONCLUSION

As no-till acreage increases in the United States, due in part to increasingly available economic incentives and wide-ranging environmental benefits, more research will be needed into the long-term effects of such a management system on crop yields. Cropping sequences and biocovers can be utilized in no-till systems to promote soil productivity and thus benefit crop yields. Research was conducted during the first four-year phase (2002-2005) of a two-phase experiment (2006-2009) at the Research and Education Center at Milan (RECM) in Milan, Tennessee, and the Middle Tennessee Research and Education Center (MTREC) in Spring Hill, Tennessee. The experimental design was a randomized complete block design with split block treatments. The main plots were 13 different cropping sequences consisting of corn, soybean, and cotton at RECM, and eight different cropping sequences consisting of corn and soybean at MTREC. The subplots were four biocovers applied perpendicular to the cropping sequences. The four biocovers were hairy vetch, wheat, poultry litter, and fallow as a control. With four replications, there were a total of 208 observations at RECM and 128 observations at MTREC each year. The objectives of our research were to determine the effects of cropping sequences, biocovers, and combinations of cropping sequences and biocovers upon corn, soybean, and cotton yields under long-term no-till.

Excluding the first year of the experiment in which a cropping sequence effect was not expected, significant cropping sequence effects on corn yields were only observed in one other year at both RECM and MTREC. However, one noticeable trend was that in the last three years, most rotated corn yields averaged higher than continuous corn yields even though the significant differences were detected only in 2004 at RECM and in 2003 at MTREC. Soybeans had a stronger response to rotation, as significant differences in soybean yields were observed in 2003 and 2005 at RECM and in 2003, 2004, and 2005 at MTREC. Rotated soybean yields were greater than continuous soybean in the last three years of the experiment at both locations. These results suggest that rotation is a viable way to increase corn and soybean yields, but it may be too early in the cropping sequence to see significant differences in yield among corn cropping sequences. Cotton did not readily respond to rotation. Despite declining continuous cotton yields, a significant cropping sequence effect was only observed in 2005, and rotated cotton yields were higher than continuous cotton yields in this year. Since this significant effect occurred in the last year of the experiment, it is theorized that rotated cotton might yield higher than continuous cotton as the experiment progresses another four years.

In general, biocovers did not have an effect upon corn yields. Excluding the first year, significant biocover effects on corn yields were only observed in one other year at both RECM and MTREC. These results were further confirmed when our results showed that corn yields under fallow had the second-highest four-year average at RECM and the highest four-year average at MTREC. These results indicate that the use of biocovers alone may not be as effective at increasing corn yields as crop sequencing. No significant biocover effect on soybean yields was detected at RECM, but soybean responded better to biocovers at MTREC with significant biocover effects observed in 2003 and 2004. While significant differences in soybean yields among the biocovers were generally not observed, four-year averages of the four biocovers showed that soybean yields under poultry litter and wheat were higher than yields under fallow at RECM. At MTREC, four-year averages of soybean yields under poultry litter, wheat, and hairy vetch all were higher than soybean yields under fallow. These results suggest that biocovers were relatively effective at increasing soybean yields. However, since the increases were largely not significant, a longer time period may be needed to fully determine whether the use of biocovers can significantly impact soybean yields. Cotton yields did not respond as well to the use of biocovers as soybean yields. Only one significant biocover effect was observed for cotton in 2004. However, four-year averages of cotton yields under poultry litter and hairy vetch were slightly higher than those yields observed under fallow. Similar to the soybean yield response to biocovers, cotton yields may just need more time to significantly respond to biocover use.

Crop sequence x biocover interaction effects on corn yields were inconsistent. At RECM, no crop sequence x biocover interactions were observed for corn in all four years. However, at MTREC, interactions on corn yields were detected in 2004 and 2005. Hairy vetch and wheat biocovers increased yields when moving from continuous corn to rotated corn. This suggests that corn yields may be starting to show a response to the use of both crop sequencing and biocovers. Soybean and cotton yields, however, did not show a response to the effects of combinations of cropping sequences and biocovers. Excluding the first year, no cropping sequence x biocover interactions were observed for soybean or cotton in any of the remaining three years at both locations. The next phase of the experiment may better define the effects of cropping sequences and biocovers upon corn, soybean, and cotton yields under no-till as more research is needed into studying the effects of different combinations of sequences and biocovers upon crop yields in no-till management systems.

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APPENDIX

Table A1. Herbicide management program for corn at RECM and MTREC.

Year	Burn down		Post-emergence	
		RECM		
	Herbicide	Rate	Herbicide	Rate
		kg ha^{-1}		kg ha^{-1}
2002	Paraquat	2.24	Glyphosate	2.24
2003	Paraquat	2.24	Glyphosate	1.82
2004	Paraquat	2.24	Glyphosate	1.54
2005	Glyphosate	1.96	Glyphosate	1.54
		MTREC		
2002	Paraquat	1.68	Glyphosate (2x)	2.24
2003	Paraquat	1.68	Glyphosate (2x)	2.24
2004	Paraquat	1.38	Glyphosate (2x)	2.24
2005	Glyphosate, Paraquat	2.24	Glyphosate (2x)	2.24

Table A2. Herbicide management program for soybean at RECM and MTREC.

Year	Burn down		Post-emergence	
		RECM		
	Herbicide	Rate	Herbicide	Rate
		kg ha^{-1}		kg ha^{-1}
2002	Paraquat	2.24	Glyphosate (2x)	1.68
2003	Paraquat	2.24	Glyphosate	1.40
2004	Paraquat	2.24	Lambda-cyhalothrin	0.14
			Azoxystrobin	0.42
2005	Glufosinate	2.24	Glyphosate (2x)	1.54
			Propiconazole-azoxystrobin	1.54
		MTREC		
2002	Paraquat	0.56	Glyphosate (2x)	2.24
2003	Paraquat	1.68	Glyphosate (2x)	2.24
2004	Paraquat	-	Glyphosate (2x)	-
2005	Roundup	2.24	Glyphosate (2x)	-

Table A3. Herbicide management program for cotton at RECM.

Year	Burn down		Post-emergence	
		RECM		
	Herbicide	Rate	Herbicide/Insecticide	Rate
		kg ha^{-1}		kg ha^{-1}
2002	Paraquat	2.24	Glyphosate	1.68
			Dicrotophos	0.21
			Glyphosate (2x)	1.68
			Oxamyl	0.56
			Mepiquat chloride	0.56
			Lambda-cyhalothrin	0.18
			Ethephon-cyclanilide	2.94
			Tribufos	0.56
2003	Paraquat	2.24	Glyphosate	1.4
			Mepiquat chloride	0.56
			Lambda-cyhalothrin	0.11
			Ethephon-cyclanilide	2.24
			Tribufos	0.84
			Thidiazuron	0.11
2004	Glufosinate	2.80	Glyphosate	1.68
			Mepiquate chloride	0.56
			Clethodim	0.56
			Tribufos	1.12
2005	Paraquat	1.68	Dicrotophos (2x)	0.22
			Glyphosate	1.54
			Mepiquat chloride	1.12-1.68
			Prometryn + Trifloxysulfuron	1.40
			Glyphosate	1.54
			Ethephon	2.24
			Tribufos	0.56
			Thidiazuron	0.11

Table A4. Adjusted nitrogen application rates for fallow (F), hairy vetch (HV), wheat (W), and poultry litter (PL) biocovers at the Research and Education Centers at Milan (RECM) and Spring Hill (MTREC) from 2002 to 2005.

	Nitrogen rate							
	RECM				MTREC			
Year	F	HV	W	PL	F	HV	W	PL
	kg ha^{-1}							
2002	67-90	62	67-90	67	67	50	67	67
2003	62	45	50	67	62	56	56	67
2004	67	50	50	67	67	67	67	67
2005	67	50	50	67	67	50	50	67

Table A5. Corn (C), soybean (S), and cotton (T) yields for sequence/biocover combinations at the Research and Education Center at Milan (RECM) from 2002 to 2005. LSD values are valid within each crop and year for every biocover (e.g. 2002 C-F, C-HV, C-PL, and C-W have the same LSD value).

	2002					2003					2004					2005				
Sequence	F	HV	PL	W	Avg.	F	HV	PL	W	Avg.	F	HV	PL	W	Avg.	F	HV	PL	W	Avg.
	$Mg\ ha^{-1}$																			
CCCC	8.40	7.72	7.82	7.56	7.87	8.58	8.67	7.86	8.06	8.29	10.97	11.27	9.89	9.89	10.51	10.21	10.73	10.25	10.17	10.34
CCST	8.40	7.59	8.49	7.63	8.03	8.50	8.38	7.36	7.93	8.04	4.23	4.11	4.11	4.00	4.11	0.86	0.83	1.02	0.84	0.89
CSCS	7.02	6.94	6.72	6.87	6.89	3.67	3.46	3.75	3.77	3.66	11.54	11.35	10.35	10.28	10.88	3.57	3.56	3.88	3.70	3.68
CTSC	7.76	6.19	7.73	6.25	6.98	1.09	1.14	1.03	0.90	1.04	4.00	3.68	3.96	4.10	3.94	10.11	10.12	9.72	9.56	9.88
SSSS	3.14	3.20	3.70	3.21	3.31	2.81	2.79	2.84	2.88	2.83	3.79	3.92	4.19	3.98	3.97	3.09	3.25	3.47	3.33	3.29
SSCT	2.90	2.82	3.13	2.92	2.94	3.64	3.59	3.83	3.76	3.71	11.13	10.73	10.58	9.45	10.47	0.78	0.78	0.85	0.75	0.79
STCS	2.39	2.28	2.68	2.44	2.45	0.97	0.98	1.08	0.98	1.00	10.45	10.78	10.91	9.38	10.38	3.75	3.81	3.79	3.91	3.82
STST	3.07	2.68	3.03	2.98	2.94	1.15	0.93	1.14	1.03	1.06	3.80	3.71	4.13	3.94	3.90	0.69	0.69	0.77	0.70	0.71
TTTT	1.24	1.24	1.18	1.20	1.22	1.05	1.05	1.14	1.18	1.11	0.97	1.03	1.00	0.89	0.97	0.76	0.73	0.76	0.75	0.75
TCTC	1.27	1.26	1.19	1.19	1.23	8.83	9.07	7.99	8.42	8.58	0.92	1.02	0.93	0.88	0.94	9.64	11.08	9.06	10.02	9.95
TCTS	1.20	1.24	1.18	1.11	1.18	8.38	8.81	7.71	8.05	8.24	0.97	1.05	0.98	0.87	0.97	3.75	3.73	3.98	3.72	3.80
TSCT	1.23	1.20	1.19	1.13	1.19	3.15	3.26	3.05	3.05	3.13	11.94	11.75	11.54	10.70	11.48	0.66	0.64	0.79	0.73	0.71
TSTC	1.25	1.23	1.17	1.16	1.20	3.02	3.10	2.97	2.73	2.96	0.94	1.03	0.96	0.93	0.97	10.53	11.08	9.03	9.45	10.02
$Avg._{corn}$	7.90	7.11	7.69	7.07		8.57	8.73	7.73	8.12		11.21	11.18	10.65	9.94		10.12	10.75	9.52	9.80	
$Avg._{soybean}$	2.88	2.75	3.14	2.89		3.26	3.24	3.29	3.24		3.96	3.86	4.10	4.01		3.54	3.59	3.78	3.67	
$Avg._{cotton}$	1.24	1.24	1.18	1.16		1.07	1.03	1.10	1.02		0.95	1.03	0.97	0.89		0.75	0.73	0.84	0.75	

(Table A5 continued)

LSD .05	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s
	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s
	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s
	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s
	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s
	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s
	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s
	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s
	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s
	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s
	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s
	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s
	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s

Table A6. Corn (C) and soybean (S) yields for sequence/biocover combinations at the Middle Tennessee Research and Education Center (MTREC) from 2002 to 2005. LSD values are valid within each crop and year for every biocover (e.g. 2002 C-F, C-HV, C-PL, and C-W have the same LSD value).

	2002					2003					2004					2005				
Sequence	F	HV	PL	W	Avg.	F	HV	PL	W	Avg.	F	HV	PL	W	Avg.	F	HV	PL	W	Avg.
	Mg ha^{-1}																			
CCCC	4.59	3.29	3.08	3.35	3.58	6.96	6.79	7.10	6.22	6.77	7.92	7.46	7.45	6.33	7.29	5.81	4.06	5.11	4.49	4.87
CCSC	4.51	3.25	3.13	3.51	3.60	7.62	7.40	7.84	7.12	7.50	4.22	4.06	4.46	4.14	4.22	5.85	4.51	5.12	5.24	5.18
CSCS	3.84	3.35	2.84	2.94	3.24	3.49	3.50	3.83	3.27	3.52	9.34	9.05	8.10	8.24	8.69	1.71	1.68	1.67	1.43	1.62
CSSC	4.91	4.35	3.91	3.93	4.27	3.33	3.42	3.61	2.85	3.30	3.99	3.94	4.20	3.59	3.93	5.96	5.33	5.24	5.45	5.50
SSSS	1.07	1.38	1.19	1.47	1.28	2.68	2.62	3.29	2.51	2.78	3.20	3.15	4.12	3.03	3.37	1.38	1.16	3.03	1.46	1.76
SSCS	—	—	—	—	—	2.56	3.00	3.17	2.70	2.85	7.37	8.67	6.76	7.05	7.46	1.47	1.38	1.35	1.45	1.41
SCSC	1.17	1.34	1.19	1.71	1.35	7.06	7.09	7.27	6.58	7.00	3.42	3.61	4.08	3.21	3.58	4.31	5.21	5.55	5.35	5.10
SCCS	—	—	—	—	—	6.57	6.80	6.61	6.78	6.69	5.56	7.75	6.80	7.54	6.91	1.44	1.50	1.39	1.54	1.47
$Avg._{corn}$	4.46	3.56	3.24	3.43		7.05	7.02	7.20	6.67		7.55	8.23	7.28	7.29		5.48	4.78	5.25	5.13	
$Avg._{soybean}$	1.12	1.36	1.19	1.59		3.01	3.14	3.47	2.83		3.71	3.69	4.21	3.49		1.50	1.43	1.86	1.47	
LSD .05	ns	ns	ns	ns		ns	ns	ns	ns		1.33	1.33	1.33	1.33		0.99	0.99	0.99	0.99	
	ns	ns	ns	ns		ns	ns	ns	ns		ns	ns	ns	ns		0.99	0.99	0.99	0.99	
	ns	ns	ns	ns		ns	ns	ns	ns		1.33	1.33	1.33	1.33		ns	ns	ns	ns	
	ns	ns	ns	ns		ns	ns	ns	ns		ns	ns	ns	ns		0.99	0.99	0.99	0.99	
	0.16	0.16	0.16	0.16		ns	ns	ns	ns		ns	ns	ns	ns		ns	ns	ns	ns	
	—	—	—	—		ns	ns	ns	ns		1.33	1.33	1.33	1.33		ns	ns	ns	ns	
	0.16	0.16	0.16	0.16		ns	ns	ns	ns		ns	ns	ns	ns		0.99	0.99	0.99	0.99	
	—	—	—	—		ns	ns	ns	ns		1.33	1.33	1.33	1.33		ns	ns	ns	ns	

VITA

Jennifer Elizabeth Noe was born on July 6th, 1983, in Morristown, Tennessee. She graduated from Morristown-Hamblen High School West in 2001. She graduated cum laude with a Bachelor of Science degree in Biological Sciences with a concentration in Microbiology from the University of Tennessee in May 2005. After working for six months as a student worker under Dr. Fred Allen in the State Variety Trials laboratory, she entered the Plant Sciences program at the University of Tennessee, where she is currently a candidate for a Master of Science degree in Plant Sciences with a minor in Statistics. She graduated in December 2007.