Impacts of Single- and a Multiple-Species Cover Crop on Soybean Relative to the Wheat–Soybean Double Crop System

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Abstract

The integration of cover crops into soybean (*Glycine max*) production has many potential benefits, but little information has been collected on the impact of multiple-species cover crops on the subsequent soybean crop relative to the common wheat (*Triticum aestivum*)–soybean double crop. Experiments were established at the West Tennessee Research and Education Center in Jackson, TN in the fall of 2014, 2015, and 2016 and the Research and Education Center in Milan, TN in the fall of 2014 and 2015. Winter treatments included a winter–fallow, cover crops including cereal rye (*Secale cereal*), wheat, crimson clover (*Trifolium incarnatum*), and a five-way mixture [cereal rye, oats (*Avena sativa*), oilseed radish (*Raphanus sativus*), crimson clover, and hairy vetch (*Vicia villosa*), referred to as mix], and wheat for grain. Treatments were split to evaluate weed suppression relative to the preemergence herbicide, *S*-metolachlor + metribuzin. Largest levels of biomass (commonly 4000+ lb/acre) were associated with the wheat for grain, cereal rye, and mix treatments. Weed control was greatest in cereal rye, wheat for cover and mix treatments, but no treatment provided consistent, acceptable weed control without the use of the preemergence herbicide. Soybean yields were not impacted by cover. The delayed planting of soybeans after wheat for grain negatively impacted yields in four of five site-years by an average of 20 bushels/acre. Results suggest impacts of single- or multiple-species cover crops on soybean yields may be negligible. Market prices, incentives, and long-term benefits may be more important than short-term costs/benefits when selecting a production system.

Core Ideas

- Cereal rye and wheat cover crops produced similar levels of biomass as a multi-species mix.
- A preemergence herbicide was required to achieve acceptable, consistent levels of weed control.
- Cover crop treatment did not significantly impact soybean yields.
- A wheat–soybean double crop system reduced soybean yields in four of five site-years.

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Soil erosion remains a threat to row-crop production within the upper Mid-South. While 36% of the rich, fertile deposits that compose the Southern Mississippi Valley Loess are typically cropped, the major soil resource concern for this major land use area is water erosion (USDA-NRCS, 2006). Poor soil structure coupled with periods of minimal crop residue has supported and continues to support substantial soil loss (Rhoton et. al., 1996). While undesirable chemical properties associated with eroded soils can be managed through application of soil amendments, the most substantial, negative yield-impacting property of eroded soils is the decrease in plant-available water above the root-restricting fragipan (Rhoton and Tyler, 1990). Given only 10, 11, and 5% of the state of Tennessee's corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), and soybean acreage is irrigated, respectively (Bowling et al., 2017), producers are limited in action to combat water deficit stress. Fortunately, no-till has been widely

Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
2.54	inch	centimeter, cm (10^{-2} m)
0.304	foot, ft	meter, m
9.29×10^{-2}	square foot, sq ft	square meter, sq m
67.19	60-pound bushel per acre, bu/acre	kilogram per hectare, kg/ha
1.12	pound per acre, lb/acre	kilogram per hectare, kg/ha
5/9 (°F – 32)	Fahrenheit, °F	Celsius, °C

adopted in the region and has greatly reduced erosion potential, but many no-till soils are still characterized by poor water infiltration and relatively low water-holding capacity.

Large increases in the adoption of no-till were supported by the introduction of glyphosate-resistant crops, which allowed applications of herbicides to replace all tillage events targeting weed control (Givens et al., 2009). Unfortunately, Palmer amaranth (*Amaranthus palmeri* S. Wats.) resistance to the herbicide glyphosate has spread throughout the Mid-South and Southeastern United States (Nichols et al., 2009) and currently jeopardizes the no-till system. While the recent introduction of dicamba- and 2,4-D-tolerant crops will help manage glyphosate-resistant weeds in no-till systems, recent research indicates Palmer amaranth may quickly become resistant to these chemistries. In a recent recurrent sublethal-dose selection experiment, Tehranchian et al. (2017) noted substantial increases in the rate of dicamba required to cause 50% mortality and found reduced susceptibility of the third generation to 2,4-D. A statement by Price et al. (2011) remains valid today: "Traditional and alternative weed control strategies, such as the utilization of crop and herbicide rotation and integration of high-residue cereal cover crops, are necessary to sustain conservation tillage practices."

Recently, the Natural Resource Conservation Service (NRCS) began promoting the use of multiple-species cover crops in Tennessee through their Conservation Stewardship Program (CSP) as a method of soil quality enhancement (USDA-NRCS, 2014). From previously conducted research evaluating singe-species cover crops, it is clear the integration of cover crops could further reduce erosion, increase infiltration, increase soil water-holding capacity, prevent nutrient loss, and serve as an alternative weed control strategy (Basche et al., 2016; Clark et al., 1994; Dabney, 1998; Liebl et al., 1992; Ruffo et al., 2004). Still, few studies have examined impacts of a cover crop mixture with more than three species on the following cash crop; evaluations of numerous single- and multiple-species cover crop blends in a corn production system have found no significant impacts of species selections and/or blends on corn yields and limited impacts on cover crop benefits (Appelgate et al., 2017; Wortman et al., 2012). Additional research must be conducted to evaluate the impacts of multiple species cover crops on the soybean production system.

Furthermore, enrolling farms within the NRCS CSP would prevent the production of winter wheat, which is commonly double-cropped with soybeans. From 2014–2018, Tennessee harvested a yearly average of 380,000 acres of wheat and 1.7 million acres of soybeans (USDA-NASS, 2018). The decision to plant wheat followed by short-season soybeans versus planting full-season soybeans largely depends on commodity prices, cash flow needs, and labor/equipment availability. Fortunately, many of the aforementioned soil erosion, infiltration, water-holding capacity and weed control benefits provided by cover crops are also provided by the production of winter wheat (Clark, 2007). Producers considering the integration of a multiple-species cover crop into their production system need more information on the subsequent impacts of the cover crop blend on soybean production system and insight into the productivity of the system versus the wheat–soybean double crop system. Therefore, the objectives of this research were to (1) evaluate biomass production and early-season weed suppression provided by common single-species cover crops and a multiple-species cover crop blend and (2) determine the yield impacts of single-species cover crops and a multiple-species cover crop mixture on soybeans relative to the wheat–soybean double-crop system.

Trial Descriptions and Cultural Practices

Research trials were established at the West Tennessee Research and Education Center (WTREC) in Jackson, TN during the fall of 2014, 2015, and 2016 and the Milan Research and Education Center (MREC) in Milan, TN during the fall of 2014 and 2015. Soil at the MREC location was classified as a Loring silt loam (fine-silty, mixed, active, thermic Oxyaquic Fragiudalfs) and a Memphis silt loam (fine-silty, mixed, active, thermic Typic Hapludalfs) at the WTREC location. Immediately prior to the establishment of these trials, sites had not been planted to cover crops. Trials were repeated within the same plot locations each subsequent year. Both locations were in long-term no-till and were maintained as no-till throughout these experiments.

Trial design within both locations was a split-plot, randomized complete block with four replications. The main-plot factor was winter cover crop treatment, and the split-plot factor was preemergence herbicide application. Treatments included winter fallow; cover crops including cereal rye,

Table 1. Main-plot and sub-plot treatments applied.

Main plot treatment	Description	Planting rate
1	Fallow	–
2	Cereal rye (*Secale cereal* L.)	75 lb/acre
3	Crimson clover (*Trifolium incarnatum* L.)	15 lb/acre
4	Multiple-species blend	15 lb/acre cereal rye 20 lb/acre common oats (*Avena sativa* L.) 2 lb/acre oilseed radish (*Raphanus sativus* L.) 4 lb/acre crimson clover 6 lb/acre hairy vetch (*Vicia villosa* Roth.)
5	Wheat (*Triticum aestivum* L.)	75 lb/acre
6	Wheat for grain	75 lb/acre
Split-plot treatment		**Herbicide**
1	No preemergence applied	None
2	Preemergence applied	metribuzin + s-metolachlor

wheat, crimson clover, and a five-way mixture (cereal rye, oats, oilseed radish, crimson clover, and hairy vetch, referred to as mix); and wheat for grain (Table 1). The main plot consisted of eight 30-inch rows 30 ft in length. Each main plot was divided between the fourth and fifth rows to evaluate weed suppression relative to a preemergence herbicide, S-metolachlor + metribuzin.

Cover treatments were selected to represent common, readily available cover crops historically grown within the region. The multiple-species mixture was constructed to (1) qualify for the NRCS Tennessee Environmental Quality Incentives Program (EQIP) (USDA-NRCS, 2014) and (2) represent a common mixture planted by participants within the program. Seeding rates were selected from ranges published in either the University of Tennessee Cover Crop Quick Facts (McClure et al., 2017) or from the USDA-NRCS EQIP Guidelines (USDA-NRCS, 2014). Wheat for grain plots were planted at the same time as other winter cover crop treatments (Table 2). The winter wheat cultivar planted was Pioneer 26R10 (Pioneer Hi-Bred International, Inc., Johnston, IA). Fertility, insects, and weeds were managed in the wheat for grain plots in accordance with University of Tennessee Extension recommendations (Raper, 2014). Wheat for grain plots were commonly sprayed with an herbicide during late fall or early spring to control broadleaf leaves as well as *Poa annua.* All cover crop treatments were terminated approximately 4 wk prior to planting the full-season soybean treatments with glyphosate + dicamba at 1.0 + 0.25 lb a.i./acre, respectively (Table 2). Immediately prior to termination, a biomass sample was collected from 2.70 ft^2 of each main plot unit. Samples were then dried at 140°F until a constant mass was reached.

Approximately 4 wk after termination, soybeans were planted at a seeding rate of 145,000 seed/acre with a 30-inch no-till planter. Each planter consisted of John Deere Max Emerge 2 units (Deere and Co., Moline, IL) with row cleaners, smooth double-disk openers, and round, steel closing wheels. Full-season soybean and double-crop soybean plots were managed according to the University of Tennessee Extension recommendations (McClure, 2017). The soybean cultivar planted each year was Pioneer 47T36. Soybean planting dates are listed in Table 2. After planting but before emergence, preemergence herbicide treatments were applied to the split plots. Treatments consisted of no preemergence herbicide or metribuzin + *S*-metolachlor at 0.3 + 1.3 lb a.i./acre, respectively. The selected preemergence herbicide is a common, readily available product frequently used within the region. Approximately 21 days after application of the preemergence herbicide, all treatments were rated for weed

Table 2. Field activity dates for the 2014–2017 seasons at the West Tennessee Research and Education center (WTREC) and Milan Research and Education Center (MREC).

|	Date, DD-Mon				
	2014–2015		2015–2016		2016–2017
Activity	WTREC	MREC	WTREC	MREC	WTREC
Cover planting	27 Oct.	23 Oct.	30 Oct.	5 Nov.	29 Oct.
Winter assessment	22 Jan.	30 Jan.	29 Mar.	29 Mar.	–
Late-season cover assessment	22 Apr.	22 Apr.	25 Apr.	18 Apr.	17 May
Cover termination	22 Apr.	22 Apr.	25 Apr.	18 Apr.	22 May
Full-season soybean planting	12 May	11 May	24 May	25 May	9 June
Preemergence application	15 May	16 May	24 May	27 May	22 June
Wheat harvest	15 June	17 June	11 June	13 June	17 June
Weed control rating	15 Jun	16 June	16 June	–	7 July
Short-season soybean planting	16 June	17 June	14 June	14 June	25 July
Soybean harvest	23 Oct.	23 Oct.	7 Oct.	27 Oct.	10 Nov
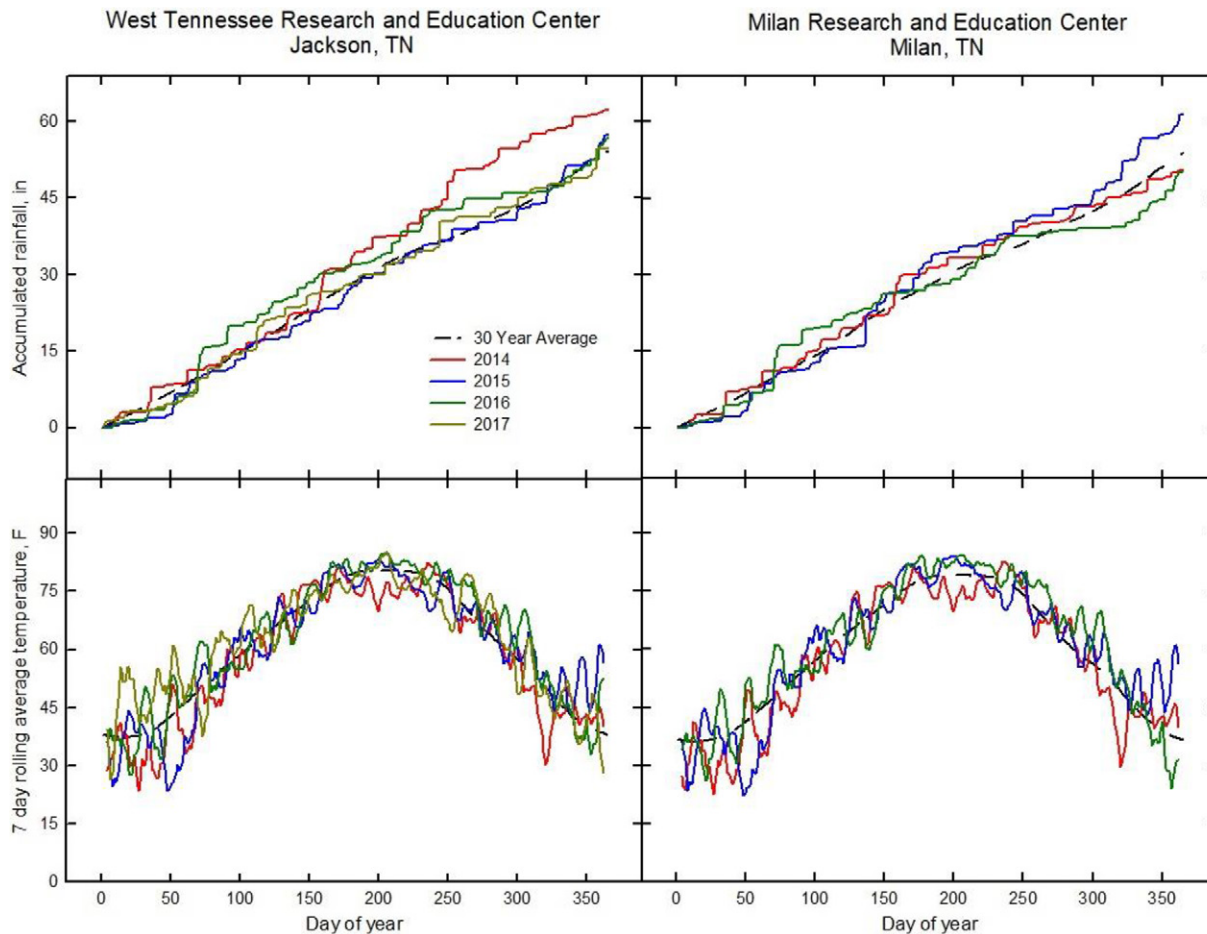
Fig. 1. Accumulated rainfall and 7-day rolling average temperatures for the West Tennessee Research and Education center (WTREC) and Milan Research and Education Center (MREC) during the 2014–2017 seasons graphed against the 30-yr average calculated from 1980–2010.

control. Visual weed control ratings were not collected on the wheat for grain treatments because preemergence applications could not be applied to the wheat for grain treatments at the same time as the other cover treatments. Visual weed control ratings were conducted on a 0–100 scale, with 0 representing no suppression and 100 representing complete suppression (no weeds present; Frans et al., 1986). Weed species present were similar across rated site-years; dominant species included Palmer amaranth, broadleaf signalgrass (*Brachiaria platyphylla* Griseb.), marestail (*Erigeron Canadensis* L.), and goosegrass (*Eleusine indica* L.). Immediately after this rating, a broadcast application of glyphosate was applied. Weeds remaining after the glyphosate application were removed by hand.

Immediately after wheat harvest, the double-crop soybean plots were planted (Table 2). All soybean treatments were harvested by a plot combine at maturity and adjusted to 13% moisture. Yields from plots that received preemergence herbicide applications were analyzed to determine the impact of cover treatment on soybean yields. Immediately after soybean harvest, main plot cover treatments were again established within the same main-plot units (Table 2).

Statistical analyses were conducted within SAS Version 9.4 and JMP Version 14 (SAS Institute, Cary, NC). Due to variations in weather conditions experienced at the WTREC and MREC locations during the 2014–2017 seasons, each location within each year was considered an independent site-year, and each was analyzed separately. Analyses of variance were conducted using PROC GLM. Both cover treatment and herbicide treatment were considered fixed effects while replication was considered a random effect. When appropriate, means were separated at the 0.05 level of significance using Fisher's protected least significant difference (LSD).

Growing Conditions

Accumulated rainfall tracked above 30-year averages and average temperature tracked below the 30-year averages during 2014, particularly during the period following establishment of the cover treatments (Fig. 1). The WTREC station received considerably more total rainfall than MREC. Accumulated rainfall during 2015 and 2017 tracked very closely to the 30-year average for both the WTREC and MREC locations. However, accumulated rainfall during 2016 exceeded the 30-year average beginning around 5 Mar. 2016

Table 3. Dry biomass accumulation observed during the 2014–2017 growing seasons at the West Tennessee Research and Education Center (WTREC) and the 2014–2016 growing seasons at the Milan Research and Education Center (MREC).

| Treatment | Dry biomass, lb/acre | | | | |
| | 2015 | | 2016 | | 2017 |
	MREC	WTREC	MREC	WTREC	WTREC
Fallow	1198 d†	1751 c	1698 d	2062 b	1387 c
Clover	1426 d	2045 bc	1984 cd	4401 a	2242 bc
Mix‡	2710 c	2313 bc	4305 ab	4180 a	4103 a
Cereal rye	4483 ab	2272 bc	4603 a	4851 a	3116 ab
Wheat (cover)	3449 bc	2807 b	3130 bc	3611 a	2690 bc
Wheat (grain)	5563 a	4062 a	4004 ab	3995 a	2847 ab
LSD§	1161	955	1264	1803	1396
CV (%)¶	24.5	24.9	25.5	29.6	33.9

† Means in a column not sharing any letter are significantly different by the Fisher's Protected LSD test at the 5% level of significance.

‡ Mix includes a mixture of cereal rye, oats, oilseed radish, crimson clover, and hairy vetch at 15, 20, 2, 4, and 6 lb/acre, respectively.

§ Fisher's protected least significant difference.

¶ Coefficient of variation.

and continued to track above the 30-year average until 7 Sept. 2016, at which point it began to decline. Temperatures during the spring of 2016 and 2017 were considerably greater than the 30-year average.

Cover Crop Biomass Accumulation

Dry cover crop biomass at termination ranged from 1198 to 5563 lb/acre. While treatment separations were noted within each site-year, considerable variability in measured biomass was noted within each treatment (Table 3). Captured variability is largely attributed to the variability of stand density and biomass throughout each plot, particularly in the mixture treatment. Typically, the cereal rye treatments reached Feekes growth stage 11.1 prior to termination while wheat treatments typically only reached Feekes growth stage 10.5.3. Planted legumes (both vetch and crimson clover) typically fell between early- and mid-bloom prior to termination.

A significant ($p \leq 0.05$) interaction between cover treatment and site-year was noted. Subsequently, each site-year was analyzed separately. The wheat-for-grain treatment generated the largest quantities of biomass in the 2015 MREC and 2015 WTREC site-years (5563 and 4062 lb/acre, respectively) and was not significantly different from the treatment that generated greater quantities of biomass during other site-years (Table 3). The relatively low total quantity of biomass generated by the wheat-for-grain treatment at the 2017 WTREC site-year (2847 lb/acre) may be due to a delayed application of N and early-season weed pressure noted within the wheat-for-grain plots. The cereal rye treatment generated the greatest quantity of biomass during the 2016 MREC and 2016 WTREC site-years (4603 and 4851 lb/acre, respectively) and was also not significantly different from the other treatments that generated greater quantities of biomass during other site-years.

Although the mix treatment generated significantly less biomass than the wheat-for-grain and cereal rye treatment during the 2015 MREC site-year and significantly less biomass than the wheat-for-grain treatment during the 2015 WTREC site-year, the mix treatment was not significantly different from the wheat-for-grain or cereal rye treatments during the other site-years. Dominant species within the mix treatment were typically cereal rye and vetch. The wheat-for-cover treatment consistently generated less biomass than the wheat-for-grain and cereal rye treatment, but quantities of biomass were comparable to the mix treatment in all site-years except the 2017 WTREC site-year. The clover treatment consistently generated one of the lowest quantities of biomass with the exception of the 2016 WTREC site-year; the clover treatment was only significantly different from the fallow treatment during the 2016 WTREC site-year. Although the fallow treatment always generated the lowest levels of biomass, winter weeds generated considerable levels of biomass in each site-year (between 1198 and 2062 lb/acre, depending on site-year).

Visual Weed Control Ratings

Consistent, ratable weed pressure was not noted during the 2015 WTREC site-year, likely due a reduced weed seedbank from prior commercial production practices. During the 2016 and 2017 WTREC site-years, however, enough weed pressure was present to collect visual weed control ratings. Ratable weed pressure was noted at the 2015 MREC site-year (Fig. 2). Visual weed control ratings were not collected from the 2016 MREC site-year. Analysis of visual weed control ratings resulted in several significant ($p \leq 0.05$) interaction terms between site-year, cover, and herbicide. Subsequently, each site-year was analyzed separately (Table 4).

Analysis of weed control ratings within the 2015 MREC site-year revealed a significant interaction between cover
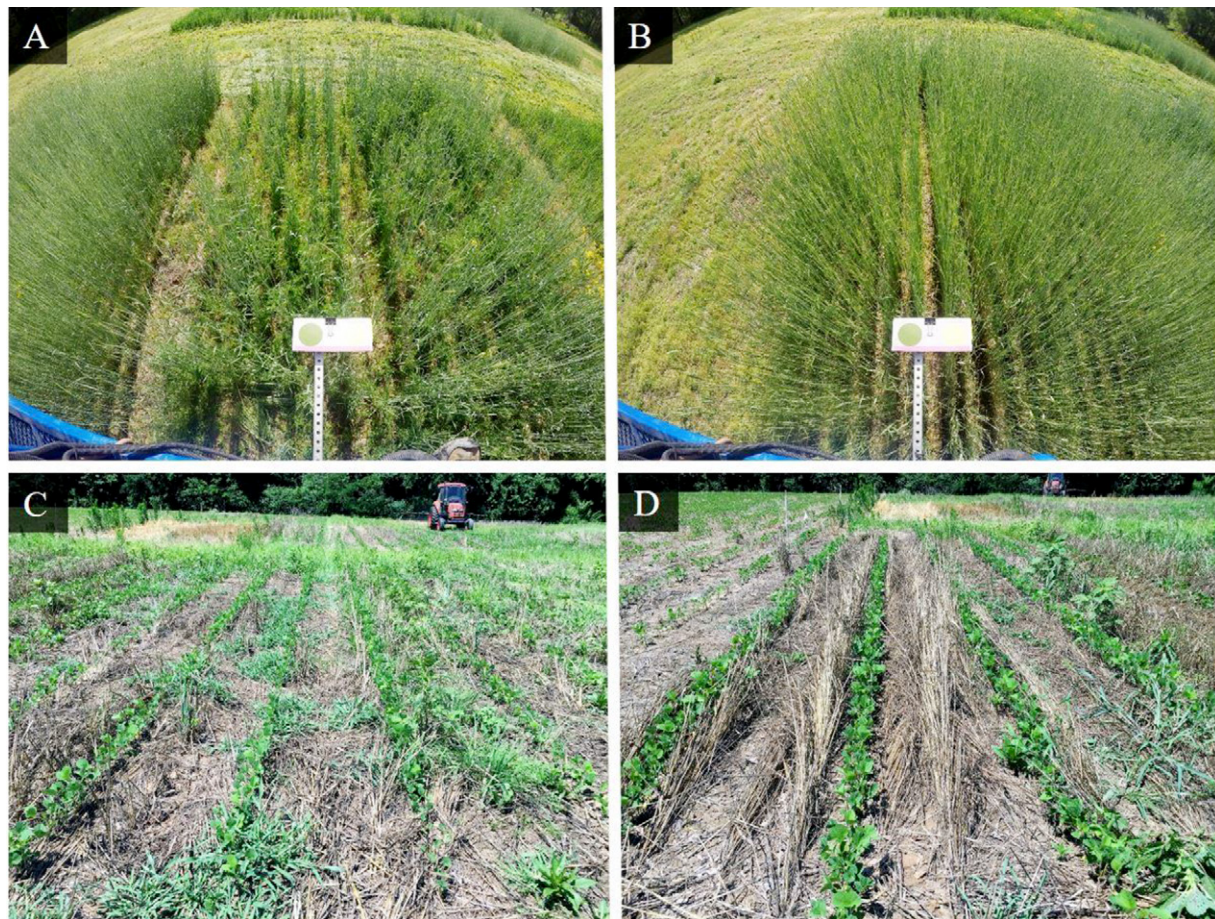
Fig. 2. Images of the mix cover treatment with no preemergence herbicide at termination (A), the cereal rye cover treatment with no preemergence herbicide at termination (B), the mix cover treatment with no preemergence herbicide at 21 days after termination (C), and the cereal rye cover treatment with no preemergence 21 days after termination (D) collected at the 2015 Milan Research and Education Center in Milan, TN.

and herbicide treatments ($p \le 0.05$). Results from the 2015 MREC site-year captured the substantial weed suppression provided by cover crops alone; for the wheat and cereal rye cover treatments, the preemergence herbicide did not significantly increase weed control 21 days after planting. However, significant increases in weed control were noted when a preemergence herbicide was applied to the clover, mix, and fallow cover treatments; application of the preemergence herbicide increased control by 32, 24.25, and 25 for the clover, mix, and fallow treatments, respectively. Reductions in weed control provided by the clover and mix cover treatments are likely due to inconsistent stands and lower biomass compared with the wheat and cereal rye cover treatments. The lowest level of weed control was noted within the clover treatment, which did not receive the preemergence herbicide.

Analysis of weed control ratings within the 2016 WTREC site-year also revealed a significant interaction between cover and herbicide treatments ($p \le 0.05$). Weed control ratings collected during the 2016 WTREC site-year were similar to the 2015 MREC site-year with few exceptions. First, the only cover treatment for which the preemergence herbicide did not significantly increase weed control was cereal rye; control

for the preemergence and no preemergence treatments were 92.5 and 80, respectively. The fallow treatment that did not receive the preemergence herbicide resulted in the least weed suppression at 32.5. The clover treatment that did not receive the preemergence herbicide provided significantly more control than the fallow treatment that did not receive the preemergence herbicide, but the clover treatment provided significantly less weed control than the mixture and wheat treatments that did not receive the preemergence herbicide.

The interaction term between cover and herbicide treatments for weed control noted at the 2017 WTREC site-year was not significant. The fallow treatment resulted in significantly less weed control than any cover treatment (40.63 for the fallow versus 62.25–71.19 depending on cover crop species/mixture), but none of the cover crops differed in their ability to suppress weeds. The application of the preemergence herbicide doubled the weed control noted 21 days after planting regardless of the cover crop planted (81.07 with preemergence herbicide versus 41.95 without).

Table 4. Visual weed control ratings collected from the 2015 Milan Research and Education Center (2015 MREC), 2016 West Tennessee Research and Education Center (2016 WTREC), and 2017 West Tennessee Research and Education Center (2017 WTREC) site-years.

2015 MREC		2016 WTREC		2017 WTREC	
Cover, herbicide	Visual weed control rating†	Cover, herbicide	Visual weed control rating	Cover	Visual weed control rating
Wheat, Pre§	96.00 a‡	Cereal rye, Pre	92.50 a	Mix	71.19 a
Wheat, No Pre	93.00 a	Clover, Pre	90.00 a	Cereal rye	67.81 a
Cereal rye, Pre	92.00 ab	Mix, Pre	90.00 a	Wheat	65.68 a
Cereal rye, No Pre	91.75 ab	Fallow, Pre	87.50 a	Clover	62.25 a
Mix,¶ Pre	90.50 ab	Wheat, Pre	87.50 a	Fallow	40.63 b
Fallow, Pre	90.00 ab	Cereal rye, No Pre	80.00 ab		
Clover, Pre	84.50 b	Wheat, No Pre	72.50 b		
Mix, No Pre	66.25 c	Mix, No Pre	70.00 b	Herbicide	Weed control rating
Fallow, No Pre	65.00 c	Clover, No Pre	52.50 c	Pre	81.07 a
Clover, No Pre	52.50 d	Fallow, No Pre	32.50 d	No Pre	41.95 b

† Visual weed control ratings utilized ranged from 0 (complete large weed coverage) to 100 (no weeds present).

‡ Means in a column not sharing any letter are significantly different by the Fisher's Protected LSD test at the 5% level of significance.

§ Pre = S-metolachlor + metribuzin.

¶ Mix includes a mixture of cereal rye, oats, oilseed radish, crimson clover, and hairy vetch at 15, 20, 2, 4, and 6 lb/acre, respectively.

Soybean and Wheat Yields

Of the five analyzed site-years, yields were greatest at the 2015 MREC site-year (Table 5). While yields at the 2015 MREC, 2015 WTREC, and 2016 MREC site-years (55, 46, and 49 bu/acre, respectively) met or exceeded state average yields noted within each year (46, 45, and 50 bu/acre in 2015, 2016, and 2017, respectively), yields at the 2016 WTREC and 2017 WTREC site-years (40 and 38 bu/acre, respectively) were lower than the state average (USDA-NASS, 2018). Reduced yields noted at the 2016 WTREC and 2017 WTREC site-years are likely due to the limited soil water-holding capacity of the selected site relative to the typical acre within Tennessee coupled with the dry late summer/early fall periods experienced during those site-years (Fig. 1). Acceptable soybean stands were achieved in every treatment.

Delaying soybean planting until after wheat harvest (double-cropping soybeans behind wheat) significantly reduced soybean yields for all site-years except the 2016 MREC site-year. Since double-crop soybean yields within the region are closely linked to rainfall and late-season temperatures, it is suspected late-season rainfall noted at the 2016 MREC location supported the noted soybean yields following wheat-for-grain treatments (Fig. 1). No significant differences in soybean yields were noted between other tested single-species cover crops, the cover crop mix, and the winter fallow cover treatments.

Wheat yields for the 2015 MREC, 2015 WTREC, 2016 MREC, and 2016 WTREC site-years averaged 67.0, 66.7, 86.5, and 66.2 bu/acre, respectively. Due to the delayed application of N and weed pressure within the 2017 WTREC site-year wheat-for-grain plots, interpretable yield data were not collected.

Table 5. Soybean yield (bushels/acre) during the 2014–2017 growing seasons at the West Tennessee Research and Education Center (WTREC) and the 2014–2016 growing seasons at the Milan Research and Education Center (MREC).

| Treatment | 2015 | | 2016 | | 2017 |
	MREC	WTREC	MREC	WTREC	WTREC
Fallow	61.37 a†	45.96 a	49.62	41.34 a	39.20 a
Clover	59.55 a	48.13 a	49.12	42.54 a	43.77 a
Mix‡	57.88 a	46.38 a	48.95	44.55 a	43.66 a
Cereal rye	59.17 a	47.83 a	49.30	41.63 a	43.19 a
Wheat (cover)	63.19 a	48.89 a	50.94	41.38 a	38.73 a
Wheat (grain)	26.06 b	37.19 b	45.95 ns	29.39 b	18.27 b
LSD§	5.55	8.30	5.96	8.66	9.04
CV (%)¶	6.7	12.07	8.08	14.03	16.03

† Means in a column not sharing any letter are significantly different by the Fisher's Protected LSD test at the 5% level of significance.

‡ Mix includes a mixture of cereal rye, oats, oilseed radish, crimson clover, and hairy vetch at 15, 20, 2, 4, and 6 lb/acre, respectively.

§ Fisher's protected least significant difference.

¶ Coefficient of variation.

Although wheat yields from this study were similar to average state wheat yields (68, 73, and 70 bu/acre in 2015, 2016, and 2017, respectively) across site-years (USDA-NASS, 2018), care must be taken in interpreting wheat yield data from this experiment; small blocks of wheat grown for grain were surrounded by other treatments and alleys that harbored pests. Although these pests were managed within wheat plots, it is likely that actual wheat yields would have been greater if the entire trial block had been managed for wheat grain production.

Summary and Discussion

Biomass Accumulation

Quantities of biomass characterized in this study are larger than studies conducted at more northern latitudes (Basche et al., 2016; Coombs et al., 2017) and similar to slightly lower than those conducted at similar or more southern latitudes (Wiggins et al., 2015; Reiter et al., 2008; Sainju et al., 2005). The largest quantities of biomass were typically noted with the wheat-for-grain, cereal rye, or mix treatments. Failure of multiple-species mixtures to produce significantly more biomass than single-species cover crops has been previously noted by Appelgate et al. (2017), Ospitan et al. (2018), and Wortman et al. (2012). Low total amounts of biomass accumulated by the clover and mix treatments during the 2015 site-years are likely due to poor winter-hardiness. Winter hardiness was also identified as a limitation for biomass accumulation by Appelgate et al. (2017).

Weed Control Ratings

While the cereal rye, wheat, and five-way blend cover crop treatments generally provided acceptable weed control, weed control was not consistent enough to replace the pre-emergence herbicide. Osipitan et al. (2018) also noted cover crops to be capable of providing levels of weed control similar to chemical control, and single- and multipl- species cover crop mixes provide similar levels of weed suppression. Still, the importance of including herbicides in the cover crop system has been previously highlighted by Mischler et al. (2010), Reddy et al. (2003), Wiggins et al. (2015), and Yenish et al. (1996). It is possible, albeit beyond the power of these experiments, that a cover crop (single species or multi-species mixture) treatment could eliminate the need for a postemergence herbicide application.

Soybean and Wheat Yields

No significant impacts on soybean yield were noted from any evaluated cover crop treatment. As expected, soybean yields observed from the wheat-for-grain followed by soybean treatments were largely a function of late-season rainfall and temperatures. Results from these experiments contrast the positive and negative soybean yield responses to cover crops previously reported by Gallagher et al. (2003) and Reddy (2001). Instead, results mirror the lack of soybean yield response noted by Duval et al. (2016), Osipitan et al. (2018), and Wortman et al. (2012).

Failure of cover crop species selection to impact soybean yield may be partially explained by termination date of the cover crops (Table 2). As termination date is moved closer to planting, yield penalties have been noted and are hypothesized to be a function of poor seed-to-soil contact and/or release of allelopathic chemicals by the cover crop (Liebl et al., 1992). All treatments resulted in acceptable stands during these experiments. Additionally, while N-fixing cover crops have occasionally been associated with increased yields in cash crops that do not fix N (Coombs et al., 2017; Daniel et al., 1999), increased yields are not always noted in soybeans (Moore et al., 1994).

Practical Implications

The decision to plant a multiple-species cover crop to participate in a conservation program instead of a wheat–soybean double crop or full-season soybeans with no cover remains more complex than the sum of all short-term benefits minus short-term expenses. Still, based on results from our experiments, benefits for incorporation of a cover crop will likely not include soybean yield increases or elimination of the preemergence herbicide application. Selection of a rainfed, wheat–soybean double crop system will likely result in reduced soybean yields compared with full-season soybean treatments in rainfall-normal years. Market prices, system incentives, and long-term benefits may be more important than short-term costs/benefits when selecting a production system.

References

Appelgate, S.R., A.W. Lenssen, M.H. Wiedenhoeft, and T.C. Kaspar. 2017. Cover crop options and mixes for Upper Midwest corn–soybean systems. Agron. J. 109:968–984. doi:10.2134/agronj2016.08.0453

Basche, A.D., T.C. Kaspar, S.V. Archontoulis, D.B. Jaynes, T.J. Sauer, T.B. Parkin, and F.E. Miguez. 2016. Soil water improvements with the long-term use of a winter rye cover crop. Agric. Water Manage. 172:40–50. doi:10.1016/j.agwat.2016.04.006

Bowling, B., A. Smith, and T. Johnson. 2017. 2017 planted acreage for corn, cotton, grain sorghum, soybeans and wheat in Tennessee by county. W 442. University of Tennessee Extension, Knoxville.

Clark, A. 2007. Managing cover crops profitably. Sustainable Agriculture Research and Education Program. Handbook Series 9. https://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition.

Clark, A.J., A.M. Decker, and J.J. Meisinger. 1994. Seeding rate and kill date effects on hairy vetch-cereal rye cover crop mixtures. Agron. J. 86:1065–1070. doi:10.2134/agronj1994.00021962008600060025x

Coombs, C., J.D. Lauzon, B. Deen, and L.L. Van Eerd. 2017. Legume cover crop management on nitrogen dynamics and yield in grain corn systems. Field Crops Res. 201:75–85. doi:10.1016/j.fcr.2016.11.001

Dabney, S. 1998. Cover crop impacts on watershed hydrology. J. Soil Water Conserv. 53:207–213.

Daniel, J.B., A.O. Abaye, M.M. Alley, C.W. Adcock, and J.C. Maitland. 1999. Winter annual cover crops in a Virginia No-till cotton

production system: II. Cover crop and tillage effects on soil moisture, cotton yield, and cotton quality. J. Cotton Sci. 3:84–91.

Duval, M.E., J.A. Galantini, J.E. Capurro, and J.M. Martinez. 2016. Winter cover crops in soybean monoculture: Effects on soil organic carbon and its fractions. Soil Tillage Res. 161:95–105. doi:10.1016/j.still.2016.04.006

Frans, R., R. Talbert, D. Marx, and H. Crowley. 1986. Experimental design and techniques for measuring and analyzing plant responses to weed control practices. In: N.D. Camper, editor, Research methods in weed science. 3rd ed. Southern Weed Sci. Soc., Champaign, IL. p. 29–46.

Gallagher, R.S., J. Cardina, and M. Loux. 2003. Integration of cover crops with postemergence herbicides in no-till corn and soybean. Weed Sci. 51:995–1001. doi:10.1614/P2002-062

Givens, W.A., D.R. Shaw, G.R. Kruger, W.G. Johnson, S.C. Weller, B.G. Young, R.G. Wilson, M.D.K. Owen, and D. Jordan. 2009. Survey of tillage trends following the adoption of glyphosate-resistant crops. Weed Technol. 23:150–155. doi:10.1614/WT-08-038.1

Liebl, R., F.W. Simmons, L.M. Wax, and E.W. Stoller. 1992. Effect of rye (*Secale cereale*) mulch on weed control and soil moisture in soybean (*Glycine max*). Weed Technol. 6:838–846. doi:10.1017/S0890037X00036356

McClure, A. 2017. A guide to Tennessee soybeans. University of Tennessee Extension, Knoxville.

McClure, A., L. Steckel, T.B. Raper, V. Sykes, G. Montgomery, H. Kelly, and S.D. Stewart. 2017. W417: Cover crop quick facts. University of Tennessee Extension, Knoxville.

Mischler, R.A., W.S. Curran, S.W. Duiker, and J.A. Hyde. 2010. Use of a rolled-rye cover crop for weed suppression in no-till soybeans. Weed Technol. 24:253–261. doi:10.1614/WT-D-09-00004.1

Moore, M.J., T.J. Gillespie, and C.J. Swanton. 1994. Effect of cover crop mulches on weed emergence, weed biomass, and soybean (*Glycine max*) development. Weed Technol. 8:512–518. doi:10.1017/S0890037X00039609

Nichols, R.L., J. Bond, A.S. Culpepper, D. Dodds, V. Nandula, C.L. Main, M.W. Marshall, T.C. Mueller, J.K. Norsworthy, A. Price, M. Patterson, R.C. Scott, K.L. Smith, L.E. Steckel, D. Stephenson, D. Wright, and A.C. York. 2009. Glyphosate-resistant palmer amaranth (*Amaranthus palmeri*) spreads in the southern United States (U.S.). Resist. Pest Manage. Newsl. 18:8–10.

Osipitan, O.A., J.A. Dille, T. Assefa, and S.Z. Knezevic. 2018. Cover crop for early season weed suppression in crops: Systematic review and meta-analysis. Agron. J. 110:1–11.

Price, A.J., K.S. Balkcom, S.A. Culpepper, J.A. Kelton, R.L. Nichols, and H. Schomberg. 2011. Glyphosate-resistant Palmer amaranth: A threat to conservation tillage. J. Soil Water Conserv. 66:265–275. doi:10.2489/jswc.66.4.265

Raper, T.B. 2014. Tennessee wheat quick facts. Publication W321. University of Tennessee Extension, Knoxville.

Reddy, K.N. 2001. Effects of cereal and legume cover crop residues on weeds, yield, and net return in soybean (*Glycine max*). Weed Technol. 15:660–668. doi:10.1614/0890-037X(2001)015[0660:EOCALC]2.0.CO;2

Reddy, K.N., R.M. Zablotowicz, M.A. Locke, and C.H. Koger. 2003. Cover crop, tillage, and herbicide effects on weeds, soil properties, microbial populations, and soybean yield. Weed Sci. 51:987–994. doi:10.1614/P2002-169

Reiter, M.S., D.W. Reeves, C.H. Burmester, and H.A. Torbert. 2008. Cotton nitrogen management in a high-residue conservation system: Cover crop fertilization. Soil Sci. Soc. Am. J. 72:1321–1329. doi:10.2136/sssaj2007.0313

Rhoton, F.E., and D.D. Tyler. 1990. Erosion-induced changes in the properties of a fragipan soil. Soil Sci. Soc. Am. J. 54:223–228. doi:10.2136/sssaj1990.03615995005400010035x

Rhoton, F.E., D.D. Tyler, and D.L. Lindbo. 1996. Fragipan soils in the Lower Mississippi River Valley: Their distribution, characteristics, erodibility, productivity, and management. USDA-ARS.

Ruffo, M.L., D.G. Bullock, and G.A. Bollero. 2004. Soybean yield as affected by biomass and nitrogen uptake of cereal rye in winter cover crop rotations. Agron. J. 96:800–805. doi:10.2134/agronj2004.0800

Sainju, U.M., W.F. Whitehead, and B.P. Singh. 2005. Biculture legume-cereal cover crops for enhanced biomass yield and carbon and nitrogen. Agron. J. 97:1403–1412. doi:10.2134/agronj2004.0274

Tehranchian, P., J.K. Norsworthy, S. Powles, M.T. Bararpour, M.V. Bagavathiannan, T. Barber, and R.C. Scott. 2017. Recurrent sublethal-dose selection for reduced susceptibility of Palmer amaranth (*Amaranthus palmeri*) to dicamba. Weed Sci. 65:206–212. doi:10.1017/wsc.2016.27

USDA-NASS. 2018. Statistics by state: Tennessee. https://www.nass.usda.gov/Statistics_by_State/Tennessee/ (accessed 26 Dec. 2018).

USDA-NRCS. 2006. Land resource regions and major land resource areas of the United States, the Caribbean, and the Pacific Basin. USDA Handb. 296. USDA-NRCS, Washington, DC

USDA-NRCS. 2014. Natural Resources Conservation Service Tennessee Environmental Quality Incentives Program Soil Health Fund Code. USDA.

Wiggins, M.S., A. McClure, R.M. Hayes, and L.E. Steckel. 2015. Integrating cover crops and POST herbicides for glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) control in corn. Weed Technol. 29:412–418. doi:10.1614/WT-D-14-00145.1

Wortman, S.E., C.A. Francis, M.L. Bernards, R.A. Drijber, and J.L. Lindquist. 2012. Optimizing cover crop benefits with diverse mixtures and an alternative termination method. Agron. J. 104:1425–1435. doi:10.2134/agronj2012.0185

Yenish, J.P., A.D. Worsham, and A.C. York. 1996. Cover crops for herbicide replacement in no-tillage corn (*Zea mays*). Weed Technol. 10:815–821. doi:10.1017/S0890037X00040859