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AGRONOMY AND SOILS

Evaluation of Cover Crop Species Termination Timing Prior to Cotton Production in Mississippi

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ABSTRACT

The termination timing of cover crops varies by farm. This research was conducted to determine whether the timing of cover crop termination alters cotton growth and development. The effects of cover crop (crimson clover, cereal rye, oat, and a blend of cereal rye + crimson clover) and termination timing (targeted dates 01 February, 01 March, 01 April, and 01 May) on cotton emergence, plant height, nodes above white flower and yield was evaluated near Starkville, MS on a Leeper silty clay loam (fine, smectitic, nonacid, thermic Vertic Epiaquepts) in 2017 and 2018 and near Tribbett, MS on a Dundee silty clay loam (Fine-silty, mixed, active, thermic type Typic Endoqualfs) in 2017. Timing of cover crop termination had a transient effect on cotton emergence. Relative to terminating cover crops in March or April, terminating in February or May decreased cotton emergence at 7 days after planting (DAP) by up to 26%. However, by 14 DAP, cotton stand averaged 74,190 plants/ha and there was no effect of cover crop termination timing on emergence. There were modest interaction effects of cover crop and termination timing on cotton development including plant height, number of nodes, and nodes above white flower. Cotton lint yield did not differ due to cover crop species but increased up to 8% when cover crop termination was delayed from February until May. This research indicates that April and May are the optimal times to terminate a cover crop in a Mississippi cotton production system, provided there is a suitable environment for healthy cotton growth.

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Cover crops are defined as any living ground cover grown in between the harvest and planting of a cash crop (Hartwig and Ammon, 2002; Parvin et al., 2004). Recently, there has been renewed interest in the implementation of cover crops in agricultural systems. Oftentimes, monetary benefits from government agencies are the driving force behind cover crop adoption. However, increased adoption of cover crops could also be attributed to pressure from environmental groups to be more environmentally friendly, or producers simply attempting to maximize productivity and conservation.

The implementation of cover crops in production systems is not widespread, although the potential benefits are well known (Wortman et al., 2012). Potential benefits of cover crops include, but are not limited to: reduced soil erosion, weed suppression, improved soil quality and soil fertility, increased beneficial insect populations, decreased nutrient losses due to leaching, and/or improved water quality (Balkcom et al., 2016; Hartwig and Ammon, 2002; SARE, 2012; Varco et al., 1991). However, potential benefits from cover crop utilization depend on the species planted (Chu et al., 2017). For example, grass species tend to be high biomass producers which suppress germination of weed species, lowers erosion potential, and scavenges nutrients from the soil (SARE, 2012). Legume species are planted with the goal of providing N to the following cash crop through symbiotic relationships with nitrogen-fixing bacteria (Varco et al., 1991). Cover crop blends are also planted to take advantage of benefits provided by individual species (Chu et al. 2017).

However, regardless of reasoning for implementation of winter cover crops, management decisions should be focused on maximizing the benefits from a cover crop. Cover crops are typically planted in the fall at or near the time of the cash crop harvest. In some situations, cover crops are seeded following cash crop harvest aid application but prior to crop harvest. This practice was reported in 27% of participants in the 2017 Annual Cover Crop Survey (CTIC, 2017). Early planting in the fall is important for establishment prior to the first frost and maximization of biomass production (Balkcom et al., 2016).

After successful cover crop establishment, cover crop termination timing must be considered. Cover crop termination can be accomplished by winter-kill, mechanical termination, chemical termination, or a combination of mechanical and chemical termination (Montgomery, 2016). Typically, cover crops are terminated with a non-selective, systemic herbicide (Nascente et al., 2013). Boquet (2016) suggested terminating cover crops two weeks prior to the planting of a cash crop to lower the risk of decreased seedling germination of the cash crop. However, it is not uncommon for producers to plant into living cover crop stands and terminate the cover crop at, or after planting. Thirty-nine percent of participants in the 2017 Annual Cover Crop Survey Report terminated cover crops at or after planting of the cash crop (CTIC, 2017).

Cover crop termination timing can have an impact on cover crop biomass production, soil moisture and temperature, cash crop germination, and nutrient supply (Duiker, 2014). Balkcom et al. (2016) found that terminating cover crops in mid-March greatly reduced cover crop biomass compared to cover crops terminated a month later. Soil temperature and moisture levels are also affected by cover crop termination timing. A living cover crop stand will typically reduce soil moisture due to the active uptake of water and nutrients (Basche et al., 2016). However, once the cover crop is terminated, the residue on the soil surface can trap soil moisture and lower soil temperatures. Spring rainfall amounts can vary greatly in the Mid-South which can impact cover crop termination timing decisions. Lower soil temperatures and increased soil moisture in the spring due to a cover crop may translate to lower soil temperatures and higher soil moisture levels later in the season in comparison to fields without cover crop residue (Wortman et al., 2012).

Issues with cash crop germination in cover crop systems may be attributed to poor seed to soil contact and/or allelopathic compounds leached from cover crop roots or decomposing residues (Bauer and Reeves, 1999). However, cover crop residues on the soil surface block sunlight which can reduce germination of small-seeded weed species and in turn reduce the number of herbicide applications required (Balkcom et al., 2016; SARE, 2012). When planting into cover crops, the use of row cleaners can reduce the risk of poor seed to soil contact (Balkcom et al., 2016). Without row cleaners, there is a greater risk for cover crop residues to become trapped in the seed furrow which can result in decreased germination due to poor seed to soil contact and/or the presence of allelopathic compounds (Hicks et al., 1989). Hicks et al. (1989) reported a 9% decrease in cotton (*Gossypium hirsutum* L.) emergence due to allelopathic compounds released from wheat (*Triticum aestivum* L.) cover crop residue when cotton seed were planted directly into wheat residue. However, terminating cover crops prior to cash crop planting allows for allelopathic compounds to leach from the soil and reduce the risk of negative impacts on cash crop germination (Balkcom et al., 2016).

Nutrient supply to cash crops is also affected by cover crop termination timing (Blanco-Canqui et al., 2015). Legume species can provide N to the cash crop through a symbiotic relationship with N-fixing bacteria (SARE, 2012). Production of N from legumes can reduce the amount of N fertilizer required in-season (SARE, 2012). In addition, other cover crop species act as scavengers and mine nutrients that are then available to the cash crop. When cover crops are terminated and begin to decompose, nutrients acquired during their growth are released into the soil. Unfortunately, in the case of N in grass species, the N is immobilized in the soil as the cover crop decomposes (Balkcom et al., 2016). Higher C:N ratios are commonly observed in cover crops specifically the cereals that produce high biomass (Balkcom et al., 2016).

Previous research recommends terminating cover crops two weeks prior to planting of the cash crop (Boquet, 2016). However, data regarding cover crop termination timing is lacking. Therefore, research was conducted to determine optimum cover crop termination timing in a cotton production system to achieve optimal cotton growth, development, and yield.

MATERIALS AND METHODS

Research was conducted at the R.R. Foil Plant Science Research Center near Starkville, MS on a Leeper silty clay loam (fine, smectitic, nonacid, thermic Vertic Epiaquepts) in 2017 and 2018 and near the Delta Research and Extension Center in Tribbett, MS on a Dundee silty clay loam (Fine-silty, mixed, active, thermic type Typic Endoqualfs) in 2017. A factorial arrangement of treatments within a randomized complete block design with four replications was utilized for all experiments. Factor A consisted of cover crop species and included: crimson clover (*Trifolium incarnatum* L.), oat (*Avena sativa* L.), cereal rye (*Secale cereale* L.), and cereal rye + crimson clover. Factor B was targeted cover crop termination timing and included: 01 February, 01 March, 01 April, and 01 May (Table 1). Experimental units were four 97 cm spaced rows that were 12.2 m in length. Crimson clover, oat, cereal rye, and cereal rye + crimson clover were seeded following previous cash crop (cotton) harvest using hand spreaders at 11, 56, 56, and 50 + 6 kg ha^{-1}, respectively. Prior to cover crop seeding each fall, fields were disked, and beds were formed with a ridge till implement. Immediately following cover crop seeding, the upper 8 to 13 cm of previously formed beds were rolled flat in preparation for cash crop planting the following spring. Cover crop seeding in fall 2016 was delayed due to drought conditions (Table 1). Harvest of the previous cash crop in 2017 was delayed due to weather which in turn delayed cover crop seeding.

Cover crops were terminated using glyphosate (Roundup PowerMAX, Monsanto Co., St. Louis, MO) at 1.5 kg ae ha^{-1}. An additional application of glufosinate (Liberty 280SL, Bayer Crop Science, Research Triangle Park, NC) was made immediately after cotton planting at 0.6 kg ai ha^{-1}. All applications were made with a CO_2-powered backpack sprayer operated at a pressure of 317 kPa and an application volume of 140 L ha^{-1}. In 2018, zeta-cypermethrin (Mustang Maxx, FMC Corporation, Philadelphia, PA) at 0.009 kg ai ha^{-1} was included with each termination timing to control cutworm (*Feltia subterranean*) populations.

PhytoGen 444 WRF (Dow Agrosciences, Indianapolis, IN) was seeded at a rate of 111,150 seeds ha^{-1} at a depth of approximately 2.5 cm with a John Deere MaxEmerge XP planter (Deere and Co., Moline, IL) equipped with floating row cleaners (Martin-Till, Elkton, KY), Keeton Seed Firmers (Precision Planting, Tremont, IL) and cast-iron pinch-style closing wheels (Deere and Co., Moline, IL). Cotton seeding depth was adjusted for each plot to place seed in adequate moisture for germination. Cotton seed were factory treated with azoxystrobin, fludioxonil, imidacloprid, mefenoxam, myclobutanil, and sedaxane (TRiO™ seed treatment). Fertility, pest management, plant growth regulator, and harvest aid applications were made based upon Mississippi State University Extension recommendations. Fertilizer N (32% UAN) was injected 5 cm into the soil in two applications (56 and 67 kg N ha^{-1}) with the first being immediately after planting and second at pinhead square (~35 DAP) at both experimental locations.

Data collection consisted of cotton stand counts at seven, 14, and 21 days after planting (DAP). Cotton height, total node count, and node above white flower (NAWF) counts were measured from five plants per experimental unit at first bloom (~65 DAP). Prior to harvest, cotton height and total node counts were taken from five plants in each experimental unit. The center two rows of each experimental unit were harvested with a spindle picker modified for small plot research. Hand-collected 25-boll samples were obtained from each plot and ginned using a 10-saw laboratory gin (Continental Eagle, Prattville, AL). The mass of cotton lint obtained after ginning was divided by the mass of seed cotton prior to ginning and the turnout obtained was used to determine lint yield from each plot.

Data were analyzed in SAS (v. 9.4, SAS Institute Inc., Cary, NC) using the PROC MIXED procedure. Outliers in the dataset were removed if the value of a given variable was greater than 2.5 σ of the mean for that variable. For any given parameter, less than 1.7% of total data were removed as outliers. Environment was considered a random effect, and data were pooled over environment to allow for treatment inferences over a range of environments (Carmer et al. 1989). Data were subjected to analysis of variance and means were separated using Fisher's Protected LSD at $\alpha = 0.05$.

Table 1. Cover crop planting and termination dates and cotton planting and harvest dates for Starkville (2017-2018) and Tribbett, MS (2017)

Location	Cover Crop Planting Date	Cover Crop Termination Date				Cotton	
		February	March	April	May	Planting Date	Harvest Date
Starkville 2017	18 Nov 16	03 Feb	03 Mar	31 Mar	09 May	08 May	10 Nov
Starkville 2018	17 Nov 17	15 Feb	01 Mar	09 Apr	01 May	11 May	08 Oct
Tribbett 2017	22 Nov 16	03 Feb	03 Mar	31 Mar	10 May	26 May	18 Oct

RESULTS AND DISCUSSION

Cotton emergence was initially impacted by cover crop termination timing, but recovered by 14 DAP. At seven DAP, cover crop termination timing affected cotton emergence when data were pooled over cover crop species (p = 0.0003) (Table 2). Cotton emergence at seven DAP where cover crops were terminated in March and April was greater by at least 9,000 plants ha^{-1} than cotton emergence where cover crops were terminated in February or May (Table 3). Acharya et al. (2017) reported corn (*Zea mays* L.) stand reductions when cereal rye cover crops were terminated near the time of corn planting. At both 14 and 21 DAP, no differences in cotton emergence were observed due to cover crop termination timing (p ≥ 0.0566 and 0.8189, respectively) with plant populations ranging from ~70,000 – 77,000 plants ha^{-1} (Table 2). No differences in cotton emergence were observed due to cover crop species at seven, 14, and 21 DAP (p ≥ 0.2760) (Table 2).

Table 2. Analysis of variance (p-values) for main effects and main effect interactions on cotton stand at 7, 14, and 21 days after planting.

Effect	DF [z]	Cotton Emergence		
		Days After Planting		
		7	14	21
Cover Crop	3	0.6588	0.7739	0.2479
Termination Timing	3	0.0003	0.0566	0.8189
Cover Crop * Termination Timing	9	0.5426	0.9441	0.6669

[z] Degrees of freedom

Table 3. Cotton stand counts at seven, 14, and 21 DAP.

Effect	Cotton Stand (plants ha^{-1})		
	Days After Planting		
	7	14	21
Cover Crop			
Clover	55,422	75,799	78,217
Oat	51,561	73,688	73,843
Cereal Rye	50,482	73,070	74,769
Cereal Rye + Clover	52,796	74,204	73,226
LSD (0.05)	NS	NS	NS
Timing			
February	49,015	76,674	75,026
March	58,663	76,158	75,901
April	59,048	73,996	75,592
May	43,534	69,933	73,534
LSD (0.05)	8,140	NS	NS

[z] Visual ratings made using a scale from 0 (no plant injury) to 5 (complete plant death).

At first bloom, an interaction of cover crop species and termination timing affected cotton height and total nodes (p = 0.0054 and 0.0115, respectively) (Table 4). No differences in cotton height at first bloom were observed when cover crops were terminated in February (Table 5). Crimson clover terminated in February, March, or April resulted in cotton with similar height (70 – 70 cm) at first bloom, and cotton was taller at first bloom than when crimson clover was terminated in May (62 cm). Cotton height at first bloom was similar at 67 – 70 cm and 65 – 68 cm regardless of when oat or cereal rye cover crops, respectively, were terminated. The March and April terminated blend of cereal rye + crimson clover resulted in shorter cotton at first bloom (62 – 64cm) than cotton following crimson clover and oat cover crops terminated in May (71 cm). However, cotton height at first bloom was similar when cereal rye + crimson clover cover crops were terminated in February, March, or April. Overall, the least amount of risk with respect to cotton height at first bloom, was observed with an oat or cereal rye cover crop in that no differences in cotton height at first bloom were observed due to termination timing.

Cotton node count at first bloom was affected by an interaction between termination timing and cover crop species (p = 0.0155) (Table 4). For February terminated cover crops, no differences in cotton node count at first bloom was observed due to cover crop species (Table 5). Cotton following cereal rye + crimson clover cover crops terminated in March had 0.6 fewer nodes at first bloom than cotton following oat cover crops terminated in March. However, total cotton nodes at first bloom were similar (13.3 – 13.8) when crimson clover, oat, and cereal rye cover crops were terminated in March. Cotton following April terminated crimson clover and oat had 0.6 – 0.9 more nodes at first bloom than cotton following cereal rye and cereal rye + crimson clover cover crops terminated in April. No differences in total cotton nodes at first bloom were observed due to cover crop species when terminated in May. Cotton node counts at first bloom following a crimson clover cover crop were maximized at 13.8 when the cover crop was terminated April compared to May. However, when utilizing oat as a cover crop, cotton node counts at first bloom were maximized at 13.8 when the cover crop was terminated in March compared to May. No differences in cotton node counts at first bloom regardless of when cereal rye was terminated. Cotton grown after a cereal rye + crimson clover cover crop had the greatest node counts at first bloom when the cover crop was terminated in May compared to March or April.

Table 4. Analysis of variance (p-values) for main effects and main effect interactions for cotton growth parameters and lint yield at the end of the season.

Effect	DF [z]	First Bloom			End of Season		
		Height	Total Nodes	NAWF [y]	Height	Total Nodes	Lint Yield
Cover Crop	3	0.0281	0.1036	0.1143	0.8689	0.9415	0.1734
Termination Timing	3	0.7219	0.7562	0.7965	0.6073	0.6138	0.0341
Cover Crop * Termination Timing	9	0.0054	0.0115	0.0439	0.0095	0.3387	0.0957

[z] Degrees of freedom

[y] Node above white flower at first bloom

Table 5. Cotton height and total nodes at first bloom and at the end of season as well as nodes above white flower (NAWF) at first bloom as affected by an interaction between cover crop species and termination timing.

Cover Crop	Termination Timing	First Bloom			End of Season	
		Height	Total Nodes	NAWF	Height	Total Nodes
		------ cm ------	---------------- # ----------------		------ cm ------	------- # -------
Crimson Clover	February	70	13.3	7.2	95	19.7
	March	71	13.4	7.1	94	19.5
	April	73	13.8	7.5	92	19.1
	May	62	13.1	7.0	88	19.0
Oat	February	70	13.5	7.3	92	19.2
	March	73	13.8	7.3	93	19.1
	April	73	13.5	7.3	96	19.5
	May	67	13.1	7.1	88	19.0
Cereal Rye	February	67	13.2	7.2	91	19.4
	March	67	13.3	7.3	93	19.5
	April	65	12.9	6.7	87	18.8
	May	68	13.3	7.0	94	19.3
Cereal Rye + Crimson Clover	February	69	13.4	6.9	92	19.4
	March	64	13.0	6.9	91	18.8
	April	62	13.0	7.2	86	19.0
	May	71	13.6	7.1	97	19.8
LSD (0.05)		6.7	0.5	0.4	6.9	NS

At first bloom, cotton nodes above white flower (NAWF) were affected by an interaction between cover crop species and termination timing (P = 0.0439) (Table 4). When cover crops were terminated in February or May, no difference in cotton NAWF was observed due to cover crop species (Table 5). However, when cover crops were terminated in March, cotton grown following cereal rye + crimson clover cover crops had 0.4 fewer NAWF than cotton grown following oat cover crops. Similar cotton NAWF counts were observed when crimson clover, oat, or cereal rye were terminated in March. When cover crops were terminated in April, utilization of crimson clover, oat, or cereal rye + crimson clover resulted in 0.5 – 0.8 greater cotton NAWF counts at first bloom than cotton grown following a cereal rye cover crop. No differences in cotton NAWF counts at first bloom were observed regardless of when oat or cereal rye + crimson clover cover crops were terminated. Crimson clover cover crops terminated in April resulted in greater cotton NAWF counts at first bloom than when terminated in May. Cereal rye cover crops terminated in April resulted in reduced cotton NAWF counts at first bloom than when the cover crop was terminated in February or March. While differences in NAWF counts were observed, the magnitude of these differences was 0.8 NAWF. At first bloom, varieties under stress may have six or less NAWF whereas varieties grown under optimum conditions may have more than 12 NAWF (Guthrie et a. 1993). Minor differences with respect to NAWF counts indicates minimal effects on maturity were present at first bloom due to cover crop species and termination timing (Bourland et al. 2001).

At the end of the season, a cover crop by termination timing interaction was present for cotton height ($p = 0.0095$) (Table 4). No differences in cotton height at the end of the season were observed due to cover crop species when terminated in both February and March (Table 5). When cover crops were terminated in April, utilization of oat cover crops resulted in greater end of season cotton height than when cereal rye + crimson clover cover crops were utilized. Similar end of season cotton height was observed when crimson clover, cereal rye, or cereal rye + crimson clover cover crops were terminated in April. Crimson clover, oat, and cereal rye cover crops terminated in May resulted in similar end of season cotton height (88 – 94 cm). In addition, utilization of cereal rye + crimson clover cover crops terminated in May resulted in 9 cm taller cotton at the end of the season than cotton grown following crimson clover or oat cover crops terminated in May. As with cotton height at first bloom, no differences in cotton height were observed following a cereal rye cover crop, regardless of termination timing. When crimson clover or oat cover crops were utilized, cotton height at the end of the season was similar (92 – 96 cm) to when cover crops were terminated in February, March, or April. When crimson clover was terminated in May, end of season cotton height was similar to when crimson clover was terminated in March or April. When oat was terminated in May, end of season cotton height was similar to when oat was terminated in February or March. Cereal rye + crimson clover cover crops terminated in February, March, or May resulted in similar end of season cotton height. In addition, when crimson clover + cereal rye was terminated in April, end of season cotton height was similar when the cover crop was terminated in February or March.

No differences in cotton node count was observed due to cover crop species or termination timing or an interaction thereof ($p \geq 0.3387$) (Table 4). Total nodes at the end of the season ranged from 18.8 – 19.7 (Table 5).

Differences in cotton lint yield were observed due to cover crop termination timing when pooled across cover crop species ($p = 0.0341$) (Table 6). Cotton yield ranged from 1,098 kg ha^{-1} to 1172 kg ha^{-1}. Cover crops terminated in April and May resulted in greater cotton yields than yields following February cover crop termination. Similar cotton yields were observed when cover crops were terminated in March, April, or May. No significant differences in cotton lint yield were observed due to cover crop species ($p = 0.1734$). Crop yield improvements due to cover crops are rarely reported in literature, especially in short-term studies (Blanco-Canqui et al., 2015). Wortman et al. (2012) observed no differences in corn, soybean (*Glycine max* L. Merr.), or sunflower (*Helianthus annuus* L.) yield due to cover crop treatments.

Overall, initial cotton emergence was impacted by cover crop termination timing; however, by 14 DAP, cover crop termination timing had no effect on cotton emergence. Cover crops, regardless of species, terminated in March or April resulted in greater cotton emergence than emergence following cover crops terminated in February or May. In terms of cotton growth and development, cotton following a rye cover crop had no differences in height or total nodes due to termination timings during or at the conclusion of the growing season. Differences in cotton height and node counts were observed due to cover crop termination timings of clover, oat, and the blend of rye + clover. Differences reported in cotton growth and development did not translate to yield effects as cover crop species had no effect on lint yield. Termination timing did; however, affect lint yield. While cotton yields were greatest following May terminated cover crops, it is important to understand the risks involved with planting into living cover crops. These risks include reduced stands due to allelopathic compounds, poor seed to soil contact, or planting into inadequate moisture and in turn relying on rainfall or irrigation for emergence in a dry spring. Having proper equipment and using best judgement when making cover crop termination decisions will aid in maximizing yield of a cash crop. If a grower chooses to implement cover crops into their cotton production system, it is recommended to terminate these cover crops 7 to 35 days prior to cotton planting. These data indicate that terminating cover crops at this time maximized yield and minimized effects on cotton growth and development during the growing season.

Table 6. Effect of cover crop species and termination timing on lint yield.

Effect	Lint Yield
	-------- Kg ha^{-1} --------
Cover Crop	
Clover	1,141
Oat	1,189
Rye	1,108
Rye + Clover	1,142
LSD (0.05)	NS
Termination Timing	
February	1,098
March	1,125
April	1,172
May	1,190
LSD (0.05)	72

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