The *Journal of Cotton Science 13:238–245 (2009)*
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AGRONOMY

Comparison of Mechanical and Chemical Winter Cereal Cover Crop Termination Systems and Cotton Yield In Conservation Agriculture

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ABSTRACT

An integral component of conservation agriculture systems in cotton (*Gossypium hirsutum* L.) is the use of a high-residue winter cover crop; however, terminating cover crops is an additional expense and planting into high-residue can be a challenge. An experiment was conducted using black oat (*Avena strigosa* Schreb.), rye (*Secale cereale* L.), and wheat (*Triticum aestivum* L.) cover crops established in early November at three locations. In mid-April each year all winter cover crops were flattened with a straight-blade mechanical roller-crimper alone or followed by three rates of glyphosate (0.84, 0.42, 0.21 kg ae/ha). Additionally, glyphosate alone at each rate and a non-treated check were included to complete the factorial treatment arrangement. Cotton was then planted 3 weeks after treatments were administered following in-row sub-soiling at E.V. Smith and direct seeding at Tennessee Valley and Robertsdale. Results showed that rolling followed by reduced glyphosate rates as low as 0.42 kg ae/ha can effectively and reliably terminate mature cereal winter cover crops; thus maintaining cotton population and protecting growth. Additionally, reduced glyphosate rates applied as low as 0.84 kg ae/ha alone can effectively terminate immature cereal covers while conserving soil moisture. Rolling mature winter cereal cover crops will likely conserve more soil moisture compared to standing covers; however, rolling immature cereal cover crops provides no benefit. In 2005 at E.V. Smith and at Tennessee Valley in 2006, increasing glyphosate rate increased cotton yield likely due to less mature cereal covers at time of treatment application. However, the inclusion of glyphosate did not increase cotton yield for any other comparison.

Conservation agriculture systems which include winter cover crop residues are primarily used to reduce soil erosion, improve soil quality, and increase water availability (Blevins et al., 1971; Kaspar et al., 2001; Reeves, 1997). Cotton is the main cash crop for many growers in the Southeast and the cotton acreage planted in conservation tillage systems is estimated to be 30% in the U.S. and approaches 60% in the southeastern U.S (Anonymous, 2003). Approximately 90% of the U.S. cotton grown in 2001 received herbicides (Anonymous, 2005). Practical alternatives to the intensive use of herbicides in cotton production offer economical as well as environmental benefits.

Cereal rye and soft red winter wheat are the two most common winter cover crops recommended for cotton production in the U.S (Mask et al., 1994; McCarty et al., 2003; Monks and Patterson, 1996). In southern Brazil, black oat is the predominant cover crop on millions of hectares of conservation-tilled soybean [*Glycine max* (L.) Merr.], due in part to its weed-suppressive capabilities (Derpsch et al., 1991). Black oat has recently been introduced as a winter cover crop in the southeastern U.S. through a joint release between Auburn University and The Institute of Agronomy of Paraná, Brazil, and is currently marketed as *SoilSaver* Black Oat (Bauer and Reeves, 1999).

Historically, cover crop desiccation has been achieved using preplant burndown (PP) herbicides prior to planting row crops. Typically, cooperative extension service recommendations in the southeastern U.S. encourage growers to terminate cereal winter covers relatively early, citing concerns for excessive residue interfering with planting operations or excessive moisture depletion (Jost et al., 2004; McCarty et al., 2003). Cooperative extension service recommendations also generally recommend waiting approximately 2 to 4 weeks after desiccating cereal winter covers before planting cotton to avoid allelopathic effects (Reeves, 1994).

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The Brazilian conservation-tillage system is based on terminating cover crops during early reproductive growth by treating with glyphosate and mechanically rolling winter covers, forming a dense mat of residue (>4,500 kg/ha) on the soil surface into which crop seeds are planted (Derpsch et al., 1991; Reeves, 2003). In the southeastern U.S., winter cereal cover crops typically reach anthesis and can be terminated in a timely fashion prior to the recommended planting window for cotton. Ashford and Reeves (2003) reported that a mechanical roller-crimper may be viable as an alternative kill method for cover crops. Ashford and Reeves (2003) also reported that using a roller-crimper with a half-rate (0.56 kg ae/ha) of glyphosate, a typical PP burndown herbicide, was as effective as a full-rate (1.12 kg/ha) herbicide application alone. Lower glyphosate rates alone or in combination with a roller-crimper may provide effective termination; however, further reduced rates have not been evaluated. Additionally, rollers without the use of herbicides may be an attractive alternative to some producers and rollers may help facilitate planting operations. Therefore, field studies were conducted utilizing black oat, rye and wheat to evaluate cover termination utilizing a roller alone or in combination with reduced rates of glyphosate. In addition, cotton stand establishment, growth, and yield were evaluated.

MATERIALS AND METHODS

Field experiments were established at the E.V. Smith Research and Extension Center located near Shorter, AL in the fall of 2003, 2004, and 2005. Additionally, experiments were established in fall of 2004 at the Tennessee Valley Research and Extension Center near Belle Mina, AL and at a grower's field near Robertsdale, AL. In all years black oat (var. SoilSaver), rye (var. Elbon), and winter wheat (var. Pioneer P26r61) were drill-seeded at 70 kg/ha at E.V. Smith in early October. Wheat was similarly established at Tennessee Valley and Robertsdale in early October. Soils at E.V. Smith, Tennessee Valley and Robertsdale were a Compass loamy sand, a Decatur silt loam, and a Faceville fine sandy loam, respectively.

In the spring, covers were terminated 3 weeks prior to cotton planting. Cover termination treatments included a combination of four glyphosate rates (0, 0.21, 0.42 and 0.84 kg ae/ha) with or without the use of a straight-blade mechanical roller. The non-treated check consisted of the 0 kg ae/ha rate of glyphosate with and without a roller. Glyphosate was applied using a compressed CO_2 backpack sprayer delivering 140 L/ha at 147 kPa.

The cotton variety DP 5242 BG/RR was planted at E.V. Smith following in-row subsoiling in 2004, 2005, and 2006. The cotton variety DP 444 BG/RR was direct seeded at Tennessee Valley and DP488 BG/RR was direct seeded at the Robertsdale location. Plots were four-rows (102 cm row spacing) wide at E.V. Smith and Tennessee Valley while the site in Robertsdale used eight-row plots (97 cm row spacing). Weeds were controlled until harvest utilizing Alabama Cooperative Extension System recommended herbicide applications.

Evaluations included cover crop biomass, cover crop growth stage using the Zadoks scale at termination, cotton population establishment, cotton mid-season height, and cotton yields determined by machine-harvesting the middle two rows of each plot with a spindle picker. Additionally, cover termination was determined by visual ratings (0% = no termination, 100% = complete termination) at three weekly intervals following treatment application. Only cover termination ratings determined at 3 weeks after treatment are reported. Cereal growth stage was assessed using the Zadoks plant development scale (Zadoks et al., 1974). Volumetric soil water content was measured one and two weeks after glyphosate application and the rolling operation at E.V. Smith during the 2006 season. A portable soil moisture sensor based on the time-domain reflectometry (TDR) principle was used to collect and record soil moisture data (TDR-300; Spectrum Technologies Inc.; Plainfield, Illinois). The sensor was equipped with 20-cm long rods and was inserted vertically into the soil surface, thus the measurement depth was from 0- to 20-cm. Five readings were taken from the middle of each plot, about 50 cm apart.

Analysis of variance (ANOVA) was performed on winter cover crop biomass, winter cover crop termination, soil moisture, cotton population, cotton height, and cotton yield using the Mixed procedure in SAS (2006). Non-transformed data for visual winter cover termination evaluations were presented because transformation did not affect data interpretation. Glyphosate rate, winter cover crop, and rolling treatments were considered fixed effects, while location and year effects were considered random variables. Means for appropriate main effects and interactions were separated using Fisher's protected LSD test at P = 0.05 a priori. Where interactions occurred for locations and years, data were presented separately, and where interactions did not occur, data were combined.

RESULTS AND DISCUSSION

Cover Crop Biomass. At E.V. Smith in spring of 2004, black oat dry matter biomass (8,900 kg/ha) was higher than wheat (7,460 kg/ha). Rye (4,150 kg/ha) yielded the least biomass, reflecting maturity at time of treatment application. In 2005 winter covers performed poorly due to lack of moisture and colder temperatures. Wheat biomass was highest (3,280 kg/ha) followed by black oats (2,740 kg/ha) and rye (1,560 kg/ha) at E.V. Smith. During this same year, wheat biomass at Tennessee Valley was 3,060 kg/ha and 6,300 kg/ha at Robertsdale. In 2006, wheat biomass in E.V. Smith was again highest (6,950 kg/ha) followed by rye (6,480) and black oats (6,200 kg/ha).

Cover Crop termination. In 2004 at E. V. Smith (Figure 1), rye (Zadoks Growth Scale 50, first spikelet of head just visible) termination was similar with rolling followed by (fb) glyphosate at any rate alone, providing ≥ 97% termination. Rye termination was 85% with rolling alone or glyphosate alone at 0.21 kg ae/ha, a 124% increase over non-treated plots. There were no treatment differences in wheat termination at E.V. Smith in 2004 due to wheat maturation (Zadoks 59, all heads out of sheath), with all treatments providing ≥ 97% termination. Black oat (Zadoks 50) termination was ≥ 98% when glyphosate was applied at 0.42 kg ae/ha alone or fb rolling. Glyphosate applied at 0.21 kg ae/ha provided 65% termination, while the addition of rolling increased control to 98%. Rolling alone provided 12% termination, whereas the termination rate of non-treated control was 2%.

At E.V. Smith in 2005, rye (Zadoks 53, one-quarter of heading process completed) termination ≥ 96% was observed with glyphosate treatments at rates ≥ 0.42 kg ae/ha with no increase in termination with rolling (Figure 2). Glyphosate alone at 0.21 kg ae/ha provided 51% termination while the addition of rolling increased termination by 39%. Rolling alone provided 35% termination, a 133% increase compared to non-treated control. Wheat (Zadoks 59) termination provided by glyphosate at 0.21, 0.42, and 0.84 kg ae/ha was 37%, 63%, and 98%, respectively. Rolling did not increase wheat termination. Black oat (Zadoks 50) termination provided by glyphosate at 0.21, 0.42, and 0.84 kg ae/ha was 17%, 80%, and 95%, respectively. Similar to wheat, rolling did not increase black oat termination. The lack of control at lower glyphosate rates or with rolling alone was likely due to cover crop immaturity at time of rolling.

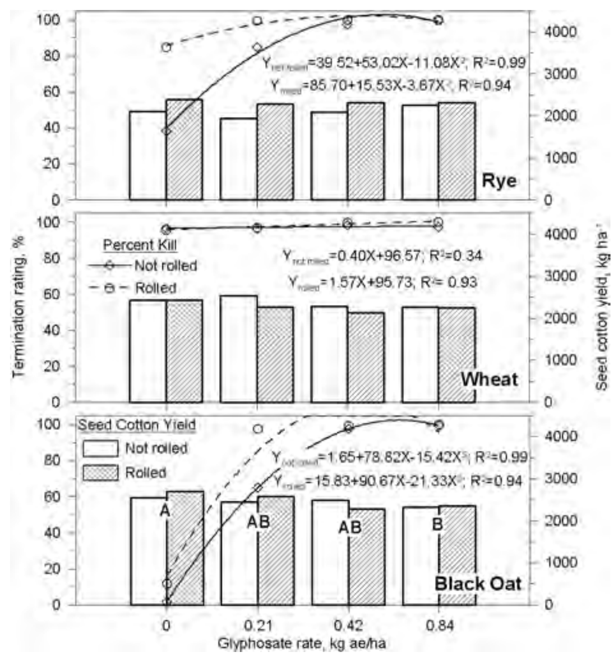

Figure 1. Rye, wheat, and black oat termination rating (line graphs) and cotton seed yield (bar graphs) following 0, 0.21, 0.42 or 0.84 kg ae/ha of glyphosate, with or without mechanical-roller treatment 3 weeks after termination at E.V. Smith in 2004. Capital letters within bar graphs denote statistical significance between glyphosate rate treatment main effect (α = 0.05).

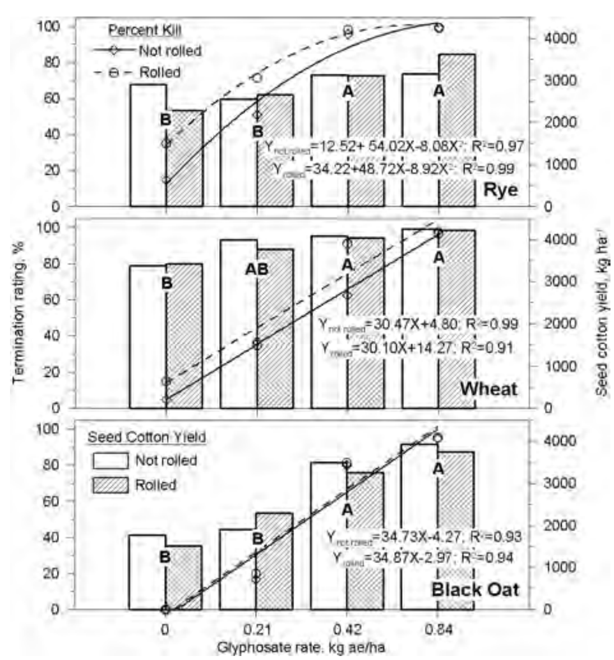

Figure 2. Rye, wheat, and black oat termination rating (line graphs) and cotton seed yield (bar graphs) following 0, 0.21, 0.42 or 0.84 kg ae/ha of glyphosate, with or without mechanical-roller treatment 3 weeks after termination at E.V. Smith in 2005. Capital letters within bar graphs denote statistical significance between glyphosate rate treatment main effect (α = 0.05).

At E.V. Smith in 2006, rye (Zadoks 59) termination was similar with rolling fb glyphosate at any rate or glyphosate alone at a rate ≥ 0.42 kg ae/ha, providing ≥ 97% termination (Figure 3). Rye termination was ≥ 90% with rolling alone, a 9% increase over the non-treated control. No differences were found for wheat (Zadoks 59) or black oat (Zadoks 59) termination due to maturity, with treatments providing ≥ 90% termination.

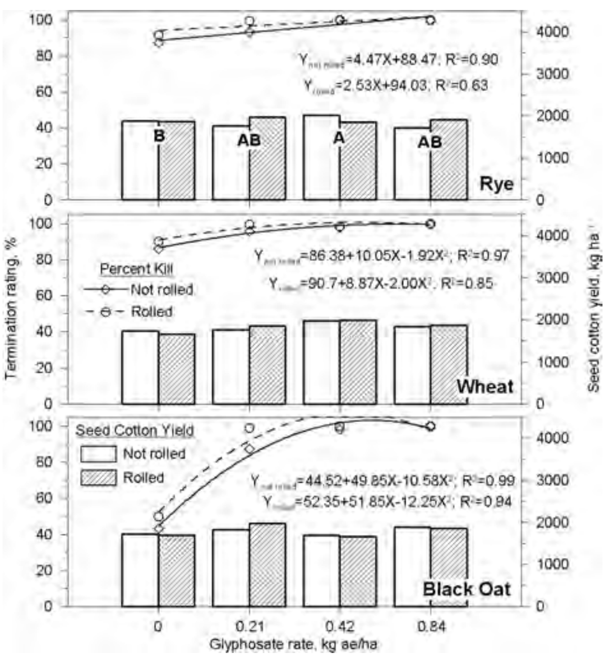

Figure 3. Rye, wheat, and black oat termination rating (line graphs) and cotton seed yield (bar graphs) following 0, 0.21, 0.42 or 0.84 kg ae/ha of glyphosate, with or without mechanical-roller treatment 3 weeks after termination at E.V. Smith in 2006. Capital letters within bar graphs denote statistical significance between glyphosate rate treatment main effect (α = 0.05).

At Robertsdale in 2005, wheat (Zadoks 55, half of heading process completed) termination ≥ 99% was observed with glyphosate treatments at rates ≥ 0.42 kg ae/ha with no increase in termination with rolling (Figure 4). However, glyphosate alone at 0.21 kg ae/ha provided 86% termination while the addition of rolling increased termination 11 percentage points. Rolling alone provided 63% termination, which was 29% greater than the non-treated control.

At Tennessee Valley in 2005, 84% wheat (Zadoks 50) termination was observed with the highest glyphosate treatment rate alone (0.84 kg ae/ha) (Figure 5). Rolling increased termination by 12%. Glyphosate alone at 0.21 or 0.42 kg ae/ha provided inadequate control while the addition of rolling increased termination eightfold and by a third, respectively. Rolling alone provided 25% termination, where there was no scenecence with the non-treated control. Similar to E.V. Smith in 2005 ,the lack of control of all covers at lower glyphosate rates or rolling alone is likely due to wheat immaturity at time of rolling.

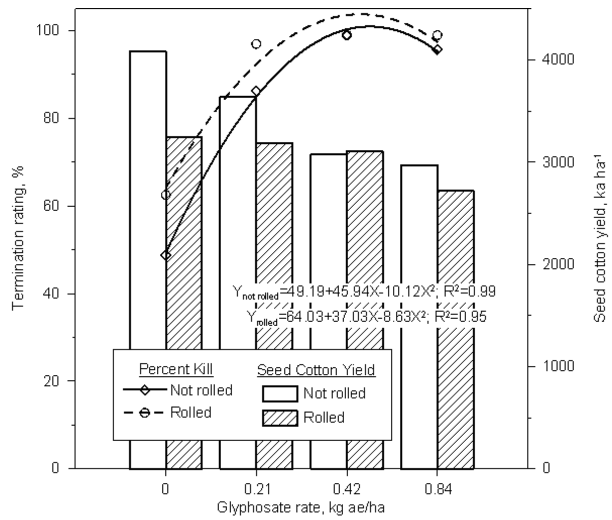

Figure 4. Wheat termination rating (line graphs) and cotton seed yield (bar graphs) following 0, 0.21, 0.42 or 0.84 kg ae/ha of glyphosate, with or without mechanical-roller treatment 3 weeks after termination at Robertsdale in 2006. Capital letters within bar graphs denote statistical significance between glyphosate rate treatment main effect (α = 0.05).

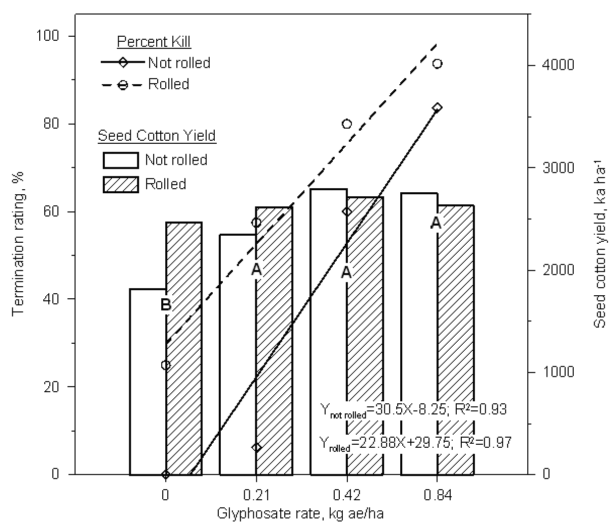

Figure 5. Wheat termination rating (line graphs) and cotton seed yield (bar graphs) following 0, 0.21, 0.42 or 0.84 kg ae/ha of glyphosate, with or without mechanical-roller treatment 3 weeks after termination at Tennessee Valley in 2006. Capital letters within bar graphs denote statistical significance between glyphosate rate treatment main effect (α = 0.05).

Soil Water Content. Soil water content was measured during the 2006 season at E.V. Smith one and two weeks after glyphosate application and rolling operation. Glyphosate application rate had a significant effect on soil water content both sampling times. Soil water content increased significantly with increasing glyphosate for rye ($p \leq 0.01$), wheat ($p \leq 0.01$) and black oat ($p \leq 0.01$) one week after application (Figure 6). The same effect was observed two weeks after glyphosate application (Figure 7). In general, soil water content was significantly greater with the highest glyphosate rate compared to the two lowest rates of 0 and 0.21 kg ae/ha for the three cover crops. There were some differences between the 0.84 and 0.42 kg ae/ha rates, but these were minor. Soil water content was significantly lower with the 0.42 kg ae/ha rate one week after application to wheat when compared to 0.84 kg ae/ha. A similar effect was observed with rye two weeks after glyphosate application. Although there was a trend of greater soil water content by rolling the winter cover crops, rolling operation did not significantly affected soil water content. These data suggest that proper cover crop termination is critical to maintain soil water content, which is crucial for the subsequent crop's germination.

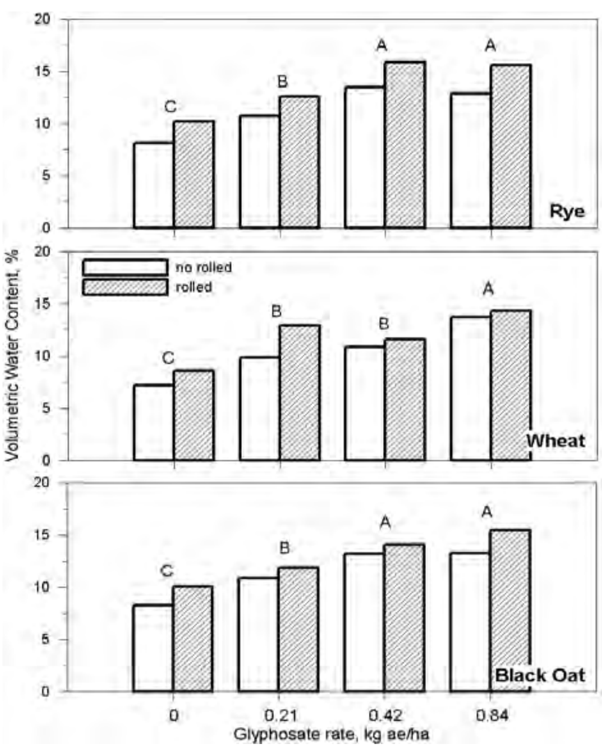

Figure 6. Volumetric soil water content for rye, wheat and black oat following 0, 0.21, 0.42 or 0.84 kg ae/ha of glyphosate, with or without mechanical-roller treatment one week after termination at E.V. Smith in 2006. Capital letters within bar graphs denote statistical significance between glyphosate rate treatment main effect (α = 0.05).

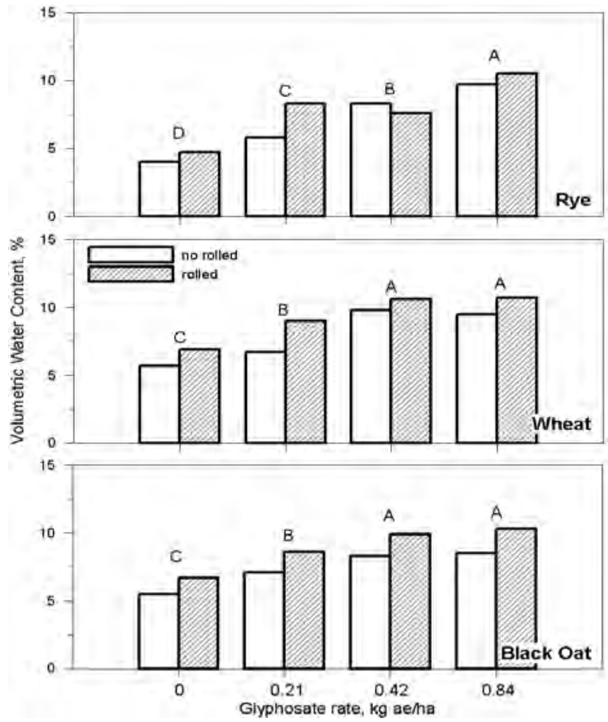

Figure 7. Volumetric soil water content for rye, wheat and black oat following 0, 0.21, 0.42 or 0.84 kg ae/ha of glyphosate, with or without mechanical-roller treatment two weeks after termination at E.V. Smith in 2006. Capital letters within bar graphs denote statistical significance between glyphosate rate treatment main effect (α = 0.05).

Cotton Population. Rolling did not influence cotton population compared to non-rolled treatment, therefore, data were pooled. Cotton populations in black oat, rye, and wheat residue were affected by glyphosate rate at E. V. Smith in 2005 (Tables 1, 2, and 3). Additionally, the cotton population at Tennessee Valley in 2005 was affected by glyphosate rate (Table 3). In all cases, as glyphosate rate increased, population increased. The observed population decrease following reduced glyphosate rates was likely due to excessive moisture depletion by the surviving cover crop.

Cotton Height. Rolling did not influence cotton height compared to non-rolled treatments, therefore data were pooled. Cotton height was reduced ≥ 16 cm in non-treated plots compared to plots receiving only 0.42 kg ae/ha at E.V. Smith in 2005 and Tennessee Valley in 2005 (Tables 5 and 6). This was, again, likely due to excessive moisture depletion by the surviving cover crop.

Cotton Yield. In 2004 at E. V. Smith (Figure 1), seed cotton yield planted in black oats following rolling alone were reduced compared to yield following rolling plus glyphosate at any rate. Lower yield in plots with no glyphosate application may be due to continued soil moisture uptake by black oat, thus depleting moisture available to cotton at time of germination and emergence.

Table 1. Mid-season cotton population after seeding into black oats and following a glyphosate burndown application of 0, 0.21, 0.42, or 0.84 kg ae/ha. Means within a column are separated according to LSD value at P = 0.05.

Glyphosate rate	E. V. Smith 2004		2005		2006	
	Population (no. plants/ha)					
Non-treated	112326	a	49025	b	108824	a
0.21g ae/ha	118252	a	56836	b	113404	a
0.42g ae/ha	120946	a	108824	a	127141	a
0.84g ae/ha	120946	a	134145	a	136838	a
LSD	12270		35110		39230	

Table 2. Mid-season cotton population after seeding into rye and following a glyphosate burndown application of 0, 0.21, 0.42, or 0.84 kg ae/ha. Means within a column are separated according to LSD value at P = 0.05.

Glyphosate rate	E. V. Smith 2004		2005		2006	
	Population (no. plants/ha)					
Non-treated	123101	a	114750	b	112596	a
0.21g ae/ha	126603	a	119060	b	116636	a
0.42g ae/ha	126872	a	126872	a	119330	a
0.84g ae/ha	127680	a	138455	a	123101	a
LSD	13710		13800		29120	

Table 3. Mid-season cotton population after seeding into wheat and following a glyphosate burndown application of 0, 0.21, 0.42, or 0.84 kg ae/ha. Means within a column are separated according to LSD value at P = 0.05.

Glyphosate rate	E. V. Smith 2004		E. V. Smith 2005		E. V. Smith 2006		Robertsdale 2005		Tennessee Valley 2005	
	Population (no. plants/ha)									
Non-treated	126603	a	116636	b	134145	a	45747	a	53537	b
0.21g ae/ha	122831	a	131990	ab	126872	a	51129	a	60204	b
0.42g ae/ha	122562	a	135223	ab	125794	a	54717	a	70305	a
0.84g ae/ha	122293	a	136030	a	113134	a	61892	a	73133	a
LSD	15200		19140		33080		16820		9590	

Table 4. Mid-season cotton height after seeding into black oats and following a glyphosate burndown application of 0, 0.21, 0.42, or 0.84 kg ae/ha. Means within a column are separated according to LSD value at P = 0.05.

Glyphosate rate	E. V. Smith 2004		2005		2006	
	Height (cm)					
Non-treated	64.8	a	86.2	b	93.1	a
0.21g ae/ha	61.3	a	87.9	b	95.6	a
0.42g ae/ha	63.3	a	100.2	a	96	a
0.84g ae/ha	62.6	a	102.3	a	94.9	a
LSD	6.6		10		5.6	

Table 5. Mid-season cotton height after seeding into rye and following a glyphosate burndown application of 0, 0.21, 0.42, or 0.84 kg ae/ha. Means within a column are separated according to LSD value at P = 0.05.

Glyphosate rate	E. V. Smith 2004		2005		2006	
	Height (cm)					
Non-treated	59	a	86.7	ab	87.9	a
0.21g ae/ha	58.6	a	83.6	b	87.6	a
0.42g ae/ha	58.2	a	90.4	ab	88.6	a
0.84g ae/ha	58.6	a	91.2	a	88.9	a
LSD	4.1		7.5		8.8	

Table 6. Mid-season cotton height after seeding into wheat and following a glyphosate burndown application of 0, 0.21, 0.42, or 0.84 kg ae/ha. Means within a column are separated according to LSD value at P = 0.05.

Glyphosate rate	E. V. Smith 2004		E. V. Smith 2005		E. V. Smith 2006		Robertsdale 2005		Tennessee Valley 2005	
	Height (cm)									
Non-treated	59.6	b	100.3	b	103.7	a	98.3	a	92.7	b
0.21g ae/ha	60.3	b	104.4	ab	103.9	a	96.1	a	100.8	a
0.42g ae/ha	62.9	ab	106.2	a	103.3	a	97.6	a	103.1	a
0.84g ae/ha	66	a	107.9	a	102.7	a	96.5	a	102.5	a
LSD	4.7		5.1		4.3		8.6		5	

At E.V. Smith in 2005 (Figure 2), seed cotton yield increased with increasing glyphosate rates for both rolled and non-rolled plots. Rolling rye without glyphosate or reduced rates of glyphosate decreased yield, likely due to rye immaturity at time of rolling. Rolling rye with the highest rate of glyphosate resulted in higher yield. Rolling immature rye may delay glyphosate translocation and reduce efficacy.

At E.V. Smith in 2006 (Figure 3), seed cotton yield following rolled rye was similar to yield following non-rolled rye. Lower yield was observed when glyphosate was excluded, similar to cotton planted into black oats in 2004.

At Robertsdale in 2005, yield was highest following non-treated and non-rolled treatments. Rolling alone decreased yield by over 700 kg/ha. Increasing glyphosate rates in either rolled or non-rolled wheat decreased seed cotton yield. This phenomenon was unexpected and does not agree with other data in this experiment. Perhaps the higher clay content soil at this location was saturated, and the less injured wheat dried waterlogged soil, thus benefiting cotton in these treatment.

At Tennessee Valley in 2005, rolling alone increased yield compared to nonrolled plots. No increase in yield was observed by increasing glyphosate rates over rolling alone, reflecting adequate termination by the rolling treatment.

In summary, results showed that rolling followed by a reduced glyphosate rate as low as 0.42 kg ae/ha can effectively and reliably terminate relatively mature cereal winter cover crops [Zadoks stage 60 to 73 (full anthesis to early milk stage)]; thus maintaining cotton population and protecting yield potential. Additionally, reduced glyphosate applied at 0.84 kg ae/ha alone can effectively terminate less mature cereal covers (Zadoks ≤ 59). Rolling more mature winter cereal cover crops may conserve more soil moisture compared to standing covers; however, rolling less mature cereal cover crops provides no benefit. This research agrees with results published by Ashford and Reeves (2003) who stated that risk-averse farmers could use one-half label rate plus use a roller while organic famers using a roller will benefit by delaying termination.

ACKNOWLEDGEMENTS

The authors would like to thank Bobby Durbin (Superintendent, E. V. Research and Education Center, Auburn University), Tim Mullek (cotton producer, Baldwin Co. Alabama), Jarrod Jones (Assistant Superintendent, Fairhope Research and Extension Center, Auburn University), and Chet Norris (Superintendent, Tennessee Valley Research and Extension Center, Auburn University) for their assistance in conducting these experiments.

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