The *Journal of Cotton Science 19:375–386 (2015)*
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ENGINEERING AND GINNING

Cotton Population and Yield Following Different Cover Crops and Termination Practices in an Alabama No-Till System

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ABSTRACT

In Alabama, typically, a three-wk period is required after rolling down a cover crop to achieve termination rates >90%, and to eliminate competition for water between the cover crop and cash crop. Cover crop termination can be sped up by applying herbicides during the rolling process. However, for organically grown cotton, synthetic herbicides cannot be used. This experiment evaluated the effectiveness of terminating two cover crops using a roller/crimper alone and with glyphosate, or two organic herbicides at different application rates to determine the effects of cover crop termination practices on cotton population and yield. In the three growing seasons, rye termination rates were between 99% and 100% for all rolling treatments three wk after rolling. Similar rates were generated for crimson clover but only in 2011, as crimson clover termination rates in two yr were lower. Organic herbicides did not increase cover crop termination compared with glyphosate and roller alone. In 2009 there was no difference in cotton population following rye and crimson clover. In 2010, cotton population following clover was higher than with cereal rye, although, in 2011, cotton population following rye was higher compared to crimson clover. In three growing seasons, seed cotton yield following rye was significantly higher compared to crimson clover. In 2010, rainfall deficit and high temperatures negatively impacted cotton growth and substantially reduced yields compared to 2009. Overall, rolling treatments did not affect cotton population and yield. In contrast, cotton population and yield were affected by different weather conditions during 2009, 2010, and 2011 growing seasons.

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In conservation agriculture, cover crops provide important benefits that enhance soil quality and plant growth. To maximize these benefits, cover crops must produce optimum biomass (Brady and Weil, 1999). Commonly used cover crops in the Southern United States are cereal rye (*Secale cereale* L.) and crimson clover (*Trifolium incarnatum* L.). Rye produces up to 10,000 kg ha^{-1} of biomass (Bowen et al., 2000) and crimson clover, a legume, which in addition to biomass production (up to 7,000 kg ha^{-1}) is an important alternative to fertilizers as a nitrogen source (Hargrove and Frye, 1987; Hubbell and Sartain, 1980). Major benefits of cover crops include soil protection from impact of rainfall energy, reduced runoff, decreased soil compaction, and increased infiltration (Kern and Johnson, 1993; McGregor and Mutchler, 1992; Reeves, 1994). Cover crops also provide a physical barrier on the soil surface, which inhibits weed emergence and growth (Creamer et al., 1996). In addition to providing a physical barrier, rye has allelopathic properties that provide control similar to applying a pre-emergence herbicide (Barnes and Putman, 1986; Hoffman et al., 1996). Long-term soil quality effects are associated with improving soil physical/chemical properties due to increasing soil organic carbon, resulting in better crop growth for sustainable agricultural practices.

Rolling/crimping technology has been used to manage tall cover crops by flattening and crimping these crops such as cereal rye in conservation systems. Crimping cover crop tissue causes plant injury and accelerates its termination rate. In southern United States (U.S.) conservation systems, terminating cover crops should be carried out three wk prior to planting the cash crop. Typically, three wk after rolling, the termination rate for rye is above 90% when rolling is performed at an optimal growth stage (Ashford and Reeves, 2003; Kornecki et al., 2006). Most agricultural extension services recommend terminating the cover crop at least two wk prior to planting the cash crop to prevent the cover crop from competing for valuable spring soil moisture that could be used by the main cash crop after planting. Hargrove and Frye (1987) reported that a minimum time from cover crop termination should be at least two wk before planting of the cash crop to enable soil water recharge prior to planting the cash crop.

When late winter months and early spring months are unusually cold and wet or too dry, producers must wait longer for the cover crop to produce an optimum biomass and to achieve the appropriate growth stage for mechanical termination, and thus could compromise timeliness of planting cash crops. On the other hand, using herbicides such as glyphosate in addition to rolling can effectively accelerate the cover crop termination process and reduce the waiting time between terminating cover crops and planting the cash crop, allowing more time for the cover crop to obtain more biomass. Results from a field study conducted by Kornecki et al. (2009a) indicated that when applying glyphosate in addition to rolling, termination rates for cereal rye one wk after rolling were between 96% and 98%.

Synthetic herbicides (glyphosate) are prohibited in organically grown commodities such as no-till cotton, thus available organic herbicides should be used. United States organic cotton production continues to increase, stimulated by the consumer and corporate demand, higher price for farmers, and regulatory changes that result in clear labeling for organic cotton products. According to the Organic Trade Association (2014), in 2012 the U.S. harvested 3,983 ha of organic cotton producing 1930 t of cotton (8,867 bales). Based on the United States Department of Agriculture-Agricultural Marketing Service (USDA-ARS) (2014) data, in 2013 United States produced 2413 t (11,085 bales) of organic cotton which is a 15% increase compared to 2012. A survey conducted by the Textile Exchange (TE) Organization (2014) indicated that the U.S. is among the top five countries (India, China, Turkey, and Tanzania) producing organic cotton accounting for 97% of the global organic cotton production.

Continuous herbicide application during mechanical crimping may exceed the amount of herbicide necessary to effectively terminate a cover crop. Thus applying herbicides in short spray intervals to the area of injured cover crop tissue by crimping bars may result in reduced herbicide use. The premise was to first damage the protective shield called the cuticle that surrounds much of the exterior plant surface and then apply herbicide directly on this damaged (by crimping) cover crop tissue so herbicides can penetrate the plant tissue faster. The undamaged cuticle would otherwise prevent rapid penetration of herbicides into the cover crop. According to Reed and Tukey Jr (1982), the cuticle functions as a barrier because of the highly impermeable nature of the cuticular waxes and the rigid structure of the cutin matrix. The cuticle is an effective barrier to the transport of solutes and gases in and out of the leaf, and serves to maintain solute concentrations within the tissue and inhibits the penetration of pesticides (Price, 1982). In organic no-till cotton with cover crops, the effectiveness of commercially available organic herbicides to enhance cover crop termination needs to be evaluated as well.

The objectives of this study were:

- Determine the effectiveness of different application rates for three herbicides (glyphosate and two commercially available organic herbicides) combined with a rolling/crimping operation on cereal rye and crimson clover termination.
- Evaluate the effect of different cover crops and their herbicide termination treatments combined with rolling/crimping on cotton population and yield in a conservation system.

MATERIALS AND METHODS

The three-yr experiment was initiated in fall 2008 (for 2009) at the E.V. Smith Research Station near Shorter, Alabama, when winter cover crops, cereal rye (Elbon variety, 100 kg ha^{-1}) and crimson clover (Dixie variety, 28 kg ha^{-1}) were seeded on 10 November 2008 using a no-till drill. In 2010 and 2011, these same cover crops were planted 4 November 2009 and 10 October 2010, respectively. Cover crops were fertilized (34 kg N ha^{-1}) in January of 2009, 2010, and 2011. The test was conducted on a Compass loamy sand (thermic Plinthic Paleudults) soil. All rolling/herbicide treatments were applied in late April for 2009 (27 April), 2010 (29 April), and 2011 (22 April) when rye was between the early milk (Zadoks #73) to early dough growth (Zadoks #83) stages (Zadoks et al., 1974), and when crimson clover was at the flowering (full blossom) growth stage utilizing a two-stage patented experimental roller/crimper (Fig. 1; Kornecki, 2011). This experiment was a split plot design with two main plots (cereal rye and crimson clover). To each main plot, 11 treatments were randomly assigned (individual sub-plots 15 m long and 1.8 m wide) which also included standing (non-treated, no roller) rye and clover as the controls. Each treatment was repeated four times (four replications). Treatment description is shown in Table 1.

Figure 1. Two-stage roller/crimper (Kornecki, 2011, U.S. Patent Number 7,987,917 B1) with 53 L plastic tank and boom with five nozzles each controlled by fast acting solenoid valve to discharge herbicides on crimped cover crop residue.

Table 1. Treatment description for rolling treatments with supplemental herbicide applications to terminate cereal rye and crimson clover

Treatment No.	Description of rolling treatment applied to both cover crops (cereal rye and crimson clover)
1	No roller (standing cover crops as control)
2	Roller only (2-stage roller/crimper)
3	Roller + Weed-Zap as a continuous spray
4	Roller + Weed-Zap every other crimp
5	Roller + Weed-Zap every 3rd crimp
6	Roller + Vinegar 20% as a continuous spray
7	Roller + Vinegar 20% every other crimp
8	Roller + Vinegar 20% every 3rd crimp
9	Roller + Glyphosate as a continuous spray
10	Roller + Glyphosate every other crimp
11	Roller + Glyphosate every 3rd crimp

Application rate for a systemic, non-selective glyphosate (Roundup™ Weather Max) was a continuous spray at 1.6 L ha^{-1} (660 g of active ingredient of glyphosate in 1.0 liter of potassium salt solution, i.e.; 1.06 kg a.i. ha^{-1} with water spraying dilution of 140 L ha^{-1}). Rate for an organic herbicide Weed-Zap™ (clove oil 45%, cinnamon oil 45%, lactose and water 10%) was a continuous application at 7.0 L ha^{-1}; and for a Natural Horticultural Vinegar™ with 20% acidity of acetic acid (as indicated on the container's label) was a continuous spray at 139 L ha^{-1}. Vinegar (20% acidity) and Weed-Zap are non-selective contact herbicides and cause phytotoxicity to the plant after entering the tissue. The roller's operating speed was 4.8 km h^{-1}. To supply an equal amount of herbicide while controlling the flow and pressure of water solution, a plastic 53 L tank (Fig. 1) equipped with a pressure compensated vane pump powered by a 12-Volt electric motor from FlowJet™ (model # 4300-504) and flow regulator were used. Operating system working pressure was set to 207 kPa. When the solenoids were energized, they activated the fast acting valves, and herbicides were discharged through the nozzles (Fig. 2) for a very short period of time (0.54 s and 0.36 s for every other and every third crimp, respectively) on the crimped cover crop residue. Components of the control system included an electric micro-switch mounted to the roller's structural frame of the crimping drum (Fig. 3) and custom engagement bars used to trigger the switch. The electrical switch was comprised of an adjustable engagement arm, which could be adjusted by changing the arm's length and its initial angle of engagement with the crimping bar. Three engagement bars (for every other crimp) and two bars (for every third crimp) were fastened to the end of the crimping bars at equal intervals. When the engagement bar was in contact with the micro-switch arm, the arm was rotated and energized/de-energized the solenoid valves through the ON-OFF micro-switch (Fig. 3).

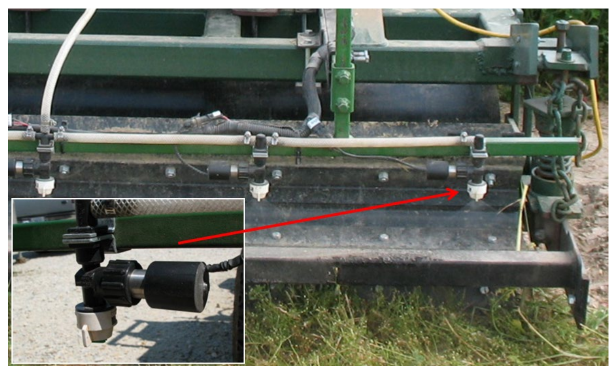

Figure 2. High speed solenoid valves to control nozzle discharge (flat pattern) of herbicides, with a close-up of the single discharge nozzle-valve-solenoid assembly.

Figure 3. Two-stage roller/crimper with electric switch mounted on the pivoted roller's frame to be energized by the 12.7 mm (½ inch) diameter engagement bars mounted on the crimping bars of the crimping drum.

Rye termination, based on visual observation, was estimated on a scale of 0% (no injury symptoms) to 100% (complete death of all plants) (Frans et al., 1986) and was evaluated one, two, and three wk after rolling treatments. Cotton (Stoneville 4427 variety) was planted 21 May, 20 May, and 17 May, in 2009, 2010, and 2011 growing seasons, respectively, using a John Deere 1700 Emergence Plus planter and DAWN™ row cleaners (100 cm row spacing with a seeding rate of 180,380 seeds ha^{-1}). In each growing season, after cotton emergence, cotton stand data were collected (four counts per each plot) using the 1.52 m long linear edge. Cotton population in each plot was calculated using number of plants at 6.08 m distance and the row spacing. Cotton was harvested on 26 October, 30 September, and 18 October, in 2009, 2010, and 2011, respectively, utilizing a two-row cotton picker, John Deere model 9920. Data were subjected to analysis of variance using the ANOVA GLM procedure and treatment means were separated with Fisher's protected Least Significant Differences (LSD) test at the 10 % probability level (SAS, 2009). Because significant differences in termination rates and cotton yield occurred between rye and crimson clover, data for each cover crop were analyzed separately.

RESULTS AND DISCUSSION

Cover crop biomass and height. In each growing season, significant differences in plant biomass production were detected between rye and crimson clover (Table 2). In 2009, dry biomass produced by rye was significantly higher (9430 kg ha^{-1}) than crimson clover which produced 6558 kg ha^{-1}. Average rye height was 167 cm, and 74 cm for crimson clover. Significantly lower rye biomass was obtained in 2010, 4098 kg ha^{-1}, whereas crimson clover produced even lower biomass (3435 kg ha^{-1}). The main reason for low biomass production was the unusually low winter temperatures, with periods of below freezing conditions, and excess precipitation in January, in combination with wet periods during the early spring of 2010 (Fig. 4), which inhibited cover crop growth. Heights for cereal rye and crimson clover in 2010 were also lower (141cm for rye and 54 cm for crimson clover, Table 2).

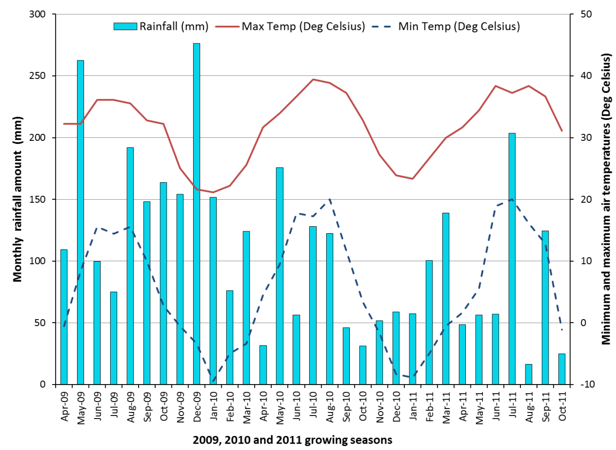

Figure 4. Monthly rainfall amounts and monthly maximum and minimum temperatures during three growing seasons for cotton in 2009, 2010, and 2011. Data were obtained from the AWIS Agricultural Weather Information Service, Inc. (AWIS, 2014).

In 2011, biomass production of cereal rye was 6804 kg ha^{-1}, (which is an average amount for central Alabama), but was lower than in 2009. Abnormally low temperatures in winter months was a most likely reason for inhibited rye growth in 2011 (Fig. 4). Biomass production for crimson clover was higher (8046 kg ha^{-1}) than for rye. The height for cereal rye was 154 cm and 49 cm for crimson clover. On average, during three growing seasons, dry biomass production and plant heights for cereal rye and crimson clover were similar to results from a four-yr field study conducted in Cullman, Alabama (Kornecki and Arriaga, 2011), where different weather conditions had an impact on the cover crop biomass.

Table 2. Height and biomass (dry basis) for cereal rye and crimson clover in 2009, 2010, and 2011 growing seasons

Cover crop		Growing season			Statistics	
		2009	2010	2011	P-value	LSD
Cereal rye	Height (cm)	166.8 a^{Z}	140.7 c	153.7 b	<0.0001	2.2
Crimson clover		74.1 a	54.2 b	49.1 c	<0.0001	1.6
Cereal rye	Biomass (kg ha^{-1})	9430 a A^{Y}	4098 c A	6804 b B	<0.0001	478
Crimson clover		6558 b B	3435 c B	8046 a A	<0.0001	418
P-value		<0.0001	0.0105	<0.0001		
LSD		458	420	487		

^{Z}**Different lower case letters in rows indicate significant differences in height and biomass among years.**

^{Y}**Different upper case letters in columns indicate significant differences between cover crops within each year.**

Cover crop termination. Significant differences in cover crop termination rates were detected for each cover crop in each growing season (P<0.0001), thus data were analyzed separately in each yr for each cover crop. In addition, because termination for cereal rye and crimson clover was significantly different each wk after termination (P<0.0001) within each yr, data were analyzed separately for each wk.

Cereal rye termination rates.

2009

Results indicate that one wk after rolling, the roller alone generated 90% rye termination compared to the control (49%, Table 3). There were no differences between roller alone and roller/crimper with Weed-Zap at any application rate which generated between 90% and 91% rye termination, and roller with vinegar applied every other and every third crimp (from 90% to 92%). Rates for roller with continuous spray of vinegar generated 93% rye termination. Significantly higher rye termination rates were generated by roller with glyphosate application (96% to 97%) compared to no roller, roller alone, Weed-Zap, and vinegar treatments. No significant differences were observed among continuous, every other, and every third crimp and Weed-Zap and glyphosate treatments, implying that spraying these herbicides every third crimp was as effective as the continuous spray. For the vinegar treatment, no differences were detected between continuous spray (93%) and every other crimp (92%). Two wk after rolling, no significant differences were detected among all rolling and herbicide treatments generating rye termination rates between 99% and 100%. These termination rates were significantly higher compared to the standing rye control (85%). Three wk after rolling, all rolling treatments generated 100% rye termination rates, the standing rye control generated 97% rye termination.

2010

One wk after rolling, rye termination rate for roller alone was 83%, whereas the control was 46%. Higher rye termination rates were obtained with rolling and supplemental application of herbicides. Weed-Zap generated 86%, 85%, and 85% for continuous, every other, and every third crimp, respectively. Compared to Weed-Zap, vinegar generated slightly higher rye termination rates with continuous spray (91%) and every other crimp (88%), but not with spraying every third crimp (85%). Rolling with glyphosate generated the highest rye termination rates (between 96%

Table 3. Termination rates (%) for cereal rye in 2009, 2010, and 2011 growing seasons

Treatment		Growing season								
		2009			2010			2011		
		Weeks after rolling								
		1	2	3	1	2	3	1	2	3
No Roller (control)		49d[Z]	85b	97b	46f	76d	92b	50d	86d	98b
Roller only		90c	100a	100a	83e	94c	100a	88bc	96c	100a
Roller + Weed-Zap	Continuous spray	90c	99a	100a	86cd	96bc	100a	93ab	98ab	100a
	Every other crimp	91bc	100a	100a	85d	96bc	100a	92abc	97bc	100a
	Every 3rd crimp	91bc	99a	100a	85d	96bc	100a	87c	98ab	100a
Roller + Vinegar	Continuous spray	93b	100a	100a	91b	97ab	100a	96a	99a	100a
	Every other crimp	92bc	100a	100a	88b	96bc	100a	95a	99a	100a
	Every 3rd crimp	90c	100a	100a	85d	96bc	99a	93ab	98ab	100a
Roller + Glyphosate	Continuous spray	97a	100a	100a	98a	99a	100a	97a	99a	100a
	Every other crimp	96a	100a	100a	97a	99a	100a	95a	99a	100a
	Every 3rd crimp	96a	100a	100a	96a	99a	100a	95a	99a	100a
LSD at 0.1 level		2.55	1.57	0.29	2.20	2.45	0.78	5.54	1.12	0.46

[Z] Same letters in columns indicate no significant differences among treatments.

and 98%) and no differences were found between herbicides applications. Two wk after rolling, roller alone generated 94% rye termination rates compared to 76% for control. Higher rye termination rates were detected for rolling and glyphosate application (99%) compared to Weed-Zap (96%) and vinegar (from 96% to 97%), while no differences were found among herbicide application rates. Three wk after rolling, all rolling treatments generated 100% rye termination rates compared with 92% for the control.

2011

One wk after rolling, the roller without herbicide treatment generated 88% rye termination compared to 50% for the control. Except for Weed-Zap every third crimp (87%), no differences in rye termination were detected among other treatments (92% to 97%). Two wk after rolling, rye termination rates for the control and roller alone were 86%, and 96 %, respectively, compared to higher termination rates generated by Weed-Zap (between 97% and 98%), vinegar (between 98% and 99%) and glyphosate (99%) for all herbicide spray rates. Three wk after rolling, all rolled treatments generated 100% rye termination rates compared to 98% for the control. Results indicate that during three growing seasons, using the roller alone, rye termination rates exceeded 90% rye termination two wk after rolling. Adding glyphosate with rolling with all spray rates exceeded 90% rye termination (between 95% and 98%) one wk after rolling, indicating that glyphosate was beneficial to accelerate the rye termination process. Continuous and every other crimp spray were not necessary since similar termination rates were generated by spraying glyphosate every third crimp. On the other hand, at two wk after rolling, the roller alone generated rye termination rates that were comparable with adding organic herbicides Weed-Zap and vinegar to rolling. Considering the high cost for organic herbicides ($58 ha^{-1} for Weed-Zap, and $270 ha^{1} for vinegar spraying continuously, Table 4), it is not economically feasible to use these herbicides with rolling. In contrast, the low cost and high effectiveness of glyphosate at terminating rye, even spraying every third crimp ($2.95 ha^{-1}), is economically justifiable for use with rolling in non-organic conservation systems using cover crops. Nevertheless, rye termination rates exceeding 90% by roller alone indicate that termination rates were high enough to allow planting a cash crop into rye residue cover two wk after rolling (Ashford and Reeves, 2003). In three growing seasons, rye termination rates generated by the roller/crimper alone and roller/crimper with supplemental glyphosate application agreed with results obtained from several field experiments (Kornecki et al, 2006; Kornecki et al., 2009b; Kornecki and Price, 2011).

Crimson clover termination rates

2009

Termination rates for crimson clover were significantly lower than for rye one wk after rolling, and for glyphosate it was between 38% (every third crimp) and 41% (for continuous and every other crimp spray) (Table 5). Termination rates by roller alone were between 34% and 36% compared to 0% for the control. No significant differences in clover termination rates were observed among continuous, every other, and every third crimp for Weed-Zap and vinegar herbicide applications. Two wk after rolling, spraying glyphosate continuously resulted in the highest clover termination (95%), although no differences were found between continuous spray and every other crimp (88%). Applying glyphosate every third crimp produced an 84% termination rate, and except for vinegar continuous spray (70% clover termination), no differences among Weed-Zap, vinegar, and roller alone were detected and resulted in between 73 and 80% (for roller alone) clover termination. Two wk after rolling, the termination rate for the control (untreated clover) was only 4%. Three wk after rolling, spraying glyphosate continuously produced 98% termination rates, but no significant differences were observed among continuous spray, every other (93%), and every third crimp (92%). There were no significant differences among roller alone (86%), Weed-Zap (all spray treatments), which generated clover termination rates between 84 and 89%, and vinegar (all spray treatments) generated termination rates between 81 and 84%.

2010

Termination rates for crimson clover one wk after rolling were significantly lower than for rye. There were no significant differences between roller only (64%), Weed-zap (65% for all spray treatments), vinegar (65% every other and every third crimp), and glyphosate every third crimp (65%). Roller with a continuous spray of vinegar generated higher clover termination rates (69%), but rates were no different than termination rates for glyphosate every other crimp (69%). The highest termination rate of 74% was generated by rolling, and continuous spray of glyphosate compared to the control (5% only). Two wk after rolling, roller alone generated similar clover termination rates (81%) as generated by rolling and spraying Weed-Zap and vinegar with all spray treatments (between 78% to 84%). Higher clover termination rates were generated by glyphosate (all spray treatments) with rates between 93% and 96% compared with the untreated control of 19%. Three wk after rolling, clover termination increased slightly, and no differences in clover termination were detected between roller alone (84%), and Weed-Zap and vinegar for all spray treatments (between 79% and 84%). Three wk after rolling adding glyphosate with rolling generated higher clover termination rates (94 to 99%) for all spray treatments with no differences between continuous spray, and spraying every other and every third crimp. In 2010, adding glyphosate with rolling exceeded 90% clover termination rates two and three wk after rolling. In contrast, applying organic herbicides with rolling did not generate higher clover termination rates, which were similar to the roller alone.

Table 4. Amount of herbicides used for different spray treatments and herbicide cost per hectare

Treatment	Herbicide	Herbicide Formulation applied (L ha^{-1})	% Herbicide amount of continuous spray and herbicide cost[Z]	
Continuous spray	Glyphosate	1.6[Y]	100	$5.00
	Vinegar	139.4		$270.00
	Weed Zap	7.0		$58.00
Spray every other crimp	Glyphosate	1.1	69	$3.45
	Vinegar	96.2		$186.30
	Weed Zap	4.8		$40.00
Spray every 3rd crimp	Glyphosate	0.9	58	$2.95
	Vinegar	80.8		$159.30
	Weed Zap	4.0		$34.22

[Z]Cost of chemicals (retail price) was obtained from purchasing invoices.

[Y](1.06 kg ha^{-1} of active ingredient with spraying water solution of 140 L ha^{-1}).

Table 5. Termination rates (%) for crimson clover in 2009, 2010, and 2011 growing seasons

Treatment		Growing season								
		2009			2010			2011		
		Weeks after rolling								
		1	2	3	1	2	3	1	2	3
No Roller (control)		0d[Z]	4f	25e	5d	19d	48d	30e	81d	96b
Roller only		35bc	80bcd	86bcd	64c	81bc	84bc	61d	95bc	100a
Roller + Weed-Zap	Continuous spray	36bc	78cde	84cd	65bc	84b	84bc	65bcd	96abc	100a
	Every other crimp	35bc	76cde	89bc	65bc	82b	83c	64cd	95bc	100a
	Every 3rd crimp	35bc	76cde	84cd	65bc	78c	79c	63cd	95bc	100a
Roller + Vinegar	Continuous spray	35bc	70e	84cd	69b	84b	84bc	73a	97ab	100a
	Every other crimp	35bc	80bcd	83cd	65bc	83b	83c	69ab	95bc	100a
	Every 3rd crimp	34c	73de	81d	65bc	84b	84bc	63cd	95bc	100a
Roller + Glyphosate	Continuous spray	41a	95a	98a	74a	96a	99a	66bc	97ab	100a
	Every other crimp	41a	88ab	93ab	69b	96a	98a	63cd	96abc	100a
	Every 3rd crimp	38b	84bc	92ab	65bc	93a	94ab	66bc	97ab	100a
LSD at 0.1 level		2.72	9.34	7.32	3.75	4.13	10.25	4.55	1.96	0.18

[Z]Same letters in columns indicate no significant differences among treatments.

2011

Similar to the two previous growing seasons, at one wk after rolling, the crimson clover termination rates were lower than for cereal rye. With roller alone, clover termination rate was 61%. This rate was not different than for rolling with Weed-Zap (between 63% and 65%), vinegar every third crimp (63%), and glyphosate every other crimp (63%). One wk after rolling, higher clover termination was observed with vinegar sprayed continuously (73%) and every other crimp (69%), but these rates were no different than for glyphosate sprayed continuously and every third crimp (66%). Clover termination rate one wk after rolling for the control was 30%. Two wk after rolling, there were no differences in clover termination rates among all rolling treatments (between 95% and 97%), compared to lower termination for the control of 81%. Similarly, three wk after rolling, clover termination rates were no different for all treatments (100%), except for the control, which produced 96% termination.

Results showed that in 2011, at one wk after rolling, adding herbicides to rolling increased clover termination rates (from 63% for Weed-Zap every third crimp to 73% for continuous vinegar spray) compared with rolling alone (61%). Very high cost of vinegar ($270.00 ha^{-1}, Table 4), does not justify the cost in organic systems to increase clover's termination rates only by 11%, especially since at two wk after rolling, there was no differences in clover termination rates between roller alone and herbicide sprays and these exceeded the recommended minimum 90% termination rates (from 95% to 97%) to plant a cash crop into desiccated clover residue (Ashford and Reeves, 2003).

Organic herbicides such as vinegar with 20% acidity and Weed-Zap are recommended by their manufactures to use for weed control in organic systems, although as found in this investigation, these products are not effective in terminating cereal rye and crimson clover cover crops (in addition to rolling), and are very expensive compared to glyphosate. Alternatively, in organic systems, to keep cover crop termination cost down and to speed up the termination process (decrease time between mechanical termination and planting cash crop) multiple rolling/crimping over the same cover crop may be necessary to accomplish complete mechanical termination of cover crops.

Amount of herbicide used. Herbicide application amounts were reduced by 31% for every other crimp and 42% for every third crimp compared with the continuous rate, based on herbicide discharge collected during calibration, shown in Table 4. The cost of organic herbicides applied continuously with rolling is very high: $270 ha-1 for vinegar and $58 ha-1 for Weed-Zap. Even when applying these herbicides every third crimp with the two-stage roller, the cost is still relatively high reaching $159.30 ha-1 for vinegar, and $34.22 ha-1 for Weed-Zap. In contrast, applying glyphosate as a continuous spray reduced the cost to only $5.00 ha-1 and for every third crimp the cost is reduced to $2.95 ha-1.

Cotton population. There were highly significant differences in final cotton populations among yr ($P<0.0001$). Cotton population measured across three growing seasons is presented in Table 6. In 2009, there were no significant differences in cotton population due to different covers ($P=0.1617$) nor due to treatments effects ($P=0.7500$). Cotton plant populations for cereal rye were 104395 plants ha^{-1}, which was slightly higher than the 97717 plants ha^{-1} for crimson clover. In 2010, however, cotton populations following clover were significantly higher (105604 plants ha^{-1}) compared to the cotton population established into cereal rye residue (78378 plants ha^{-1}). The main reason for this reduction was low biomass resulting in a very poor rye residue cover in 2010 (biomass two times lower compared to 2009) which most likely did not provide adequate soil coverage allowing a rainfall event (34 mm) one d after planting to push cotton seeds further down in the furrow, thereby limiting cotton emergence. One wk later, there was a three-d rainfall event totaling 75 mm which caused a flood in the experimental area that may have further reduced cotton emergence. In 2011, cotton population following cereal rye was similar to 2009 (101311 plants ha^{-1}) and was highly significantly greater ($P<0.0001$) than for crimson clover (65462 plants ha^{-1}). Results for cotton stands obtained during three yr in this investigation are comparable to cotton stands (from 90465 to 126378 plants ha^{-1}) evaluated by Kornecki et al. (2012) where differences in cotton stands among three yr were related to different weather conditions in each growing season, and to cover crop (cereal rye) management methods within each yr resulting in higher cotton stands for rolled residue compared to lower cotton stands observed with standing cereal rye.

Table 6. Cotton population in three growing seasons

Cover crop	Growing season 2009	2010	2011
	Cotton population (plants ha^{-1})		
Cereal Rye	**104395**	**78378 b^{Z}**	**101311 a**
Crimson clover	**97717**	**105604 a**	**65462 b**
P-value	**0.1617**	**<0.0001**	**<0.0001**
LSD (plants ha^{-1})	**N/S**	**5185**	**8936**
Average cotton population P<0.0001, LSD =6662 plants ha^{-1}	**101056 A^{Y}**	**91991 B**	**83386 C**

^{Z}**Comparison between cover crops for each year in columns (different lower case letters indicate significant difference between cover crops).**

^{Y}**Comparison of cotton population in the last row (different upper case letters indicate significant differences among years).**

Seed cotton yield. Seed cotton yield for different covers is presented in Table 7. Significant differences in cotton yield were observed between all three yr and between rye and crimson clover covers (P<0.0001). Comparing across all three growing seasons, the highest seed cotton yield was obtained in 2009 (3169.4 kg ha^{-1}), and the lowest was observed in 2010 (1711.9 kg ha^{-1}). In 2011, the cotton seed yield was 2068.0 kg ha^{-1}. These differences are associated with different weather conditions in each growing season. Examining cover crop effects on seed cotton yield showed that consistently higher cotton yield during all three growing seasons was observed following cereal rye: 3486.4 kg ha^{-1}, 1789.0 kg ha^{-1}, and 2376.7 kg ha^{-1} compared to the yield following crimson clover producing 2852.4 kg ha^{-1}, 1634.8.4 kg ha^{-1}, and 1759.3 kg ha^{-1} for 2009, 2010, and 2011, respectively. Cotton plants following crimson clover were taller than with rye: 125 cm vs. 111 cm in 2009 (P<0.0001) and 105 cm vs. 101 cm in 2010 (P =0.0003). No difference in cotton height was detected between rye and crimson clover in 2011 (120 cm vs.119 cm, P = 0.4642).

Rolling treatment effects on seed cotton yield in all three growing seasons for cereal rye and crimson are presented in Table 8. In the 2009 and 2010 growing seasons, seed cotton yield following cereal rye was not affected by rolling treatments (P = 0.5213 for 2009, and P =0.4321 for 2010). In contrast, 2011 seed cotton yields for standing rye was lower (1873 kg ha^{-1}) compared to all rolled rye treatments (P = 0.0905), although, there was no difference among rolling treatments in seed cotton yields, which was between 2360.0 9 kg ha^{-1} and 2599.9 kg ha^{-1}. In 2009, significant seed cotton yield differences were detected among rolling treatments for crimson clover (P =0.0698). Higher seed cotton yield (between 2935.5 kg ha^{-1} and 3087.8 kg ha^{-1}) was reported for roller only, with continuous spraying of Weed-Zap, and with glyphosate (in addition to rolling) for all three spray rates. In contrast, significantly lower seed cotton yield was generated with standing crimson clover and vinegar spray every other crimp but no different than seed cotton yield measured following Weed-Zap (every other and every third crimp) and vinegar (every third crimp) treatments. In 2010, significant differences were detected among rolling treatments following crimson clover (P = 0.0149), however, seed cotton yield was reduced by unfavorable weather conditions that included high temperatures during summer months (up to 39 ºC) (Fig. 4). These effects, although statistically different, may not represent the influence of rolling treatments on seed cotton yield. The highest cotton seed yield of 1735.6 kg ha^{-1} due to crimson clover was observed following rolled residue and Weed-Zap (every third crimp) and glyphosate (ever third crimp). The lowest seed cotton yield was observed with vinegar continuous spray (1499.0 kg ha^{-1} and every third crimp 1500.8 kg ha^{-1}). In 2011, no significant differences in seed cotton yield were found among all treatments following crimson clover (P=0.9355) and the cotton yield ranged from 1550.8 kg ha^{-1} to 1918.8 kg ha^{-1} which was significantly lower than with rye. The main reason for the yield reduction was unusually hot and dry weather. As in 2010, the high temperature continued (up to 37 ºC) and there was not sufficient rainfall in the summer months of 2011. An exception was July (Fig. 4). Between July 10th and 31st, there were 13 d with rainfall events totaling 204 mm of rainfall. This excess water and experimental area flooding had a negative effect on cotton seed yield.

Table 7. Cover crop effect on seed cotton yield averaged across rolling treatments in 2009, 2010 and 2011 growing seasons

Cover crop	Growing season		
	2009	2010	2011
	Seed Cotton yield (kg ha^{-1})		
Cereal Rye	3486.4 a^Z	1789.0 a	2376.7 a
Crimson clover	2852.4 b	1634.8 b	1759.3 b
LSD (α = 0.1)	112.0	53.1	124.1
P-value	<0.0001	<0.0001	<0.0001
Average cotton yield P<0.0001, LSD =83.3 kg ha^{-1}	3169.4 A^Y	1711.9 C	2068.0 B

^{Z}Values of the means within columns having different lower case letters are significantly different at the 10% level.

^{Y}Comparison of seed cotton yield in the last row (different upper case letters indicate significant differences among years).

Table 8. Treatment effect on seed cotton yield for rye and crimson clover cover crops in 2009, 2010, and 2011 growing seasons

Name of the treatment		Growing season					
		2009	2010	2011	2009	2010	2011
		Seed Cotton yield after cereal rye (kg ha^{-1})			Seed Cotton yield after crimson clover (kg ha^{-1})		
No roller		3049.3	1873.2	1873.0 b^Z	2621.8 d	1596.2 bc	1744.8
Roller/crimper only		3564.8	1787.0	2360.0 a	3019.9 ab	1598.0 bc	1689.9
Roller + Weed-Zap	Continuous spray	3599.7	1792.5	2402.1 a	2935.5 abc	1671.4 ab	1913.3
	Every other crimp	3478.6	1779.7	2493.7 a	2695.2 cd	1680.6 ab	1862.0
	Every third crimp	3418.1	1897.1	2389.3 a	2801.6 bcd	1735.6 a	1918.8
Roller + Vinegar	Continuous spray	3577.7	1796.2	2308.8 a	2891.5 abcd	1499.0 c	1797.9
	Every other crimp	3412.6	1653.1	2413.1 a	2618.1 d	1684.3 ab	1552.6
	Every third crimp	3621.7	1710.0	2469.9 a	2810.8 bcd	1500.8 c	1816.2
Roller + Glyphosate	Continuous spray	3590.5	1757.7	2444.2 a	3087.8 a	1713.6 ab	1867.5
	Every other crimp	3546.9	1792.5	2599.9 a	2981.4 ab	1735.6 a	1638.7
	Every third crimp	3570.3	1880.6	2389.3 a	2977.7 ab	1605.4 bc	1550.8
LSD (α = 0.1)		N/S	N/S	326.7	274.3	122.6	N/S
P-value		0.5213	0.4321	0.09	0.0698	0.0149	0.9355

^{Z}Values of the means within columns (each year) having the same lower case letters are not significantly different at the 10% level.

It appears that in all three growing seasons, cotton seed yield was weather related and substantial cotton seed yield reduction was associated with unusual weather conditions rather than with rolling treatment effects. Overall, seed cotton yield obtained in this investigation during the three growing seasons agreed with results from a study (Kornecki et al., 2009c) at E.V. Smith Research Station in Alabama where seed cotton yield was between 1563 kg ha^{-1} and 3718 kg ha^{-1}. At the same location in another field experiment, Kornecki and Price (2011) reported that seed cotton yield fluctuated between 2150 kg ha^{1} and 2462 kg ha^{-1}, where the main reason for differences in yield were related to different weather conditions in each particular yr, rather than with cover crop residue management treatments.

CONCLUSIONS

Across all growing seasons, two and three wk after rolling, resulted in cereal rye termination rates for all rolling treatments between 94% and 100%. Similarly, in 2009, one wk after rolling produced rye termination rates between 90% and 97% (across rolling treatments). Adding organic herbicides with rolling cereal rye did not increase rye termination rates compared with the roller alone. However, adding glyphosate for all spray rates generated statistically higher rye termination rates, especially one wk after rolling. Compared to cereal rye, termination rates for crimson clover were lower in 2009 and 2010 at one, two, and three wk after rolling. In 2011, two and three wk after rolling resulted in clover termination rates between 95% and 100%. In 2009 and 2010, adding glyphosate significantly increased clover termination at one, two, and three wk after rolling compared with roller alone and organic herbicides. Applying organic herbicides with rolling did not increase clover termination rates. In all growing seasons, rolling treatments did not influence cotton population, however, hot weather and insufficient rainfall in 2010 and 2011 negatively impacted cotton population.

In 2009, cotton population was not affected by either cover crop averaging 101056 plants ha^{-1}. In 2010, cotton population planted into cereal rye residue was 58% lower (78378 plants ha^{-1}) compared to 105604 plants ha^{-1} for crimson clover cover, which was associated with poor rye residue cover in 2010 (50% lower rye biomass compared to 2009). In 2011, cotton population following cereal rye was 101311 plants ha^{-1} and was lower for crimson clover (65462 plants ha^{-1}) most likely due to wet field conditions in July and unusually hot weather in the summer of 2011. In 2009 and 2010, no differences in seed cotton yield due to cereal rye were detected among all treatments. Similarly, in 2011 no differences in seed cotton yield were detected among all rolling treatments due to crimson clover, but seed cotton yield was reduced by the hot and dry summer. In 2011, no differences in cotton seed yield were detected among all rolled rye treatments (between 2360.0 kg ha^{-1} and 2493.7 kg ha^{-1}) and were higher than cotton seed yield in the standing rye control (1873.0 kg ha^{-1}). In 2009 and 2010, differences in cotton seed yield were detected among crimson clover rolling treatments, with higher cotton seed yield for roller alone (3019.9 kg ha^{-1}) and continuous glyphosate spray (3087.8 kg ha^{-1}). In 2010, despite these differences, seed cotton yield was substantially lower (between 1499.0 kg ha^{-1} and 1735.6 kg ha^{-1}) due to hot and dry weather in the summer of 2010.

Lower seed cotton yield and taller cotton plants with crimson clover suggests that selecting crimson clover as a cover crop for no-till cotton is not practical under these management practices. The taller cotton plants in two growing seasons were most likely associated with the nitrogen released by crimson clover residue that increased vegetative growth of cotton plants that hindered seed cotton development. However, different management in no-till cotton that include reducing N rates or additional plant growth regulators while using crimson clover as the cover crop could have improved yields.

ACKNOWLEDGMENT

The authors wish to thank Mr. Corey Kichler, for his invaluable assistance with conducting field experiments, instrumentation data collection, and preparation.

DISCLAIMER

The use of trade or company names does not imply endorsement by the USDA-ARS.

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