Effectiveness of Different Herbicide Applicators Mounted on a Roller/Crimper for Accelerated Rye Cover Crop Termination

T. S. Kornecki, A. J. Price, R. L. Raper, J. S. Bergtold

Abstract. *In a weed-free field with ideal weather conditions, a cash crop can be planted 3 weeks after rolling a mature cereal rye winter cover crop without using herbicides. However, cloudy and wet weather can delay the rolling and/or desiccation of rye, thereby delaying cash crop planting which can negatively impact yield. One effective way to reduce the time between rolling and planting is to spray herbicide while rolling. However, a continuous spray may not be required if a roller/crimper is used due to the additive effect of the roller. Two different methods of applying glyphosate (Roundup^{TM}) to rolled rye were compared. First, a felt strip saturated with herbicide was attached to the roller's crimping bar to provide glyphosate application with every crimp. The second method consisted of a boom (five nozzles controlled by solenoid valves) mounted on the roller applying a spray continuously, and intermittent spray every second crimp, or every fourth crimp. The average results over three growing seasons showed that 7 days after rolling, rye termination rates for all rolled/glyphosate treatments surpassed 90% (91% for glyphosate saturated felt strip and 98% for continuous spray), exceeding the termination rates for rye recommended to planting cash crops into rye residue cover. For the roller/crimper alone and the non-treated check (standing rye), termination rates were 82% and 54%, respectively. Since spraying glyphosate every fourth crimp provided a 93% termination rate one week after rolling, this method may facilitate planting the cash crop in a timely fashion while reducing input costs. Economic savings of \$12.63 to \$36.87 ha^{1} may be attained by incorporating herbicide applications with rolling activities. One and two weeks after the rolling treatment, volumetric soil moisture content for all rolled rye/chemical treatments were significantly higher than the non-treated check.*

Keywords. *Chemical termination, Conservation agriculture, Cover crop, Glyphosate, Mechanical termination, Roller/crimper.*

Cover crops are an essential component in conservation agriculture systems because they provide important benefits to soils and plants. To maximize the benefits of cover crops, they must produce maximum biomass (Brady and Weil, 1999). Rye (*Secale cereale* L) is a widely used cover crop in the southern United States which can produce 3400 to 11200 kg/ha (Bowen et al., 2000). Primary cover crop benefits include soil protection from impact energy of rainfall, reduced runoff, decreased soil compaction, and increased infiltration (McGregor and Mutchler, 1992; Kern and Johnson, 1993; Reeves, 1994; Raper et al., 2000a, 2000b). Cover crops also provide a physical barrier on the soil surface which inhibits weed emergence and growth. In addition to providing a physical barrier, rye also has alleopathic properties that provide weed control similar to a pre-emergence herbicide (Barnes and Putman, 1986; Hoffman et al., 1996). Long-term soil quality effects associated with cover crop use include improved soil physical/chemical properties due to increasing soil organic carbon, resulting in better crop productivity and a more sustainable agriculture system (Brady and Weil, 1999; Tennakoon and Hulugalle, 2006).

Rolling/crimping technology is used to manage mature cover crops by flattening and crimping cover crops such as rye in conservation agriculture systems. The main action of rolling/crimping is to crush, but not completely cut the rolled plant tissue at equal intervals in the same direction that a cash crop will be planted. Crimping cover crop tissue causes plant injury and accelerates senescence. In a southeastern United States conservation agriculture system, terminating cover crops should be accomplished three weeks prior to planting the cash crop, which is similar to standard burndown recommendations (Reeves, 1994). Most agricultural extension services recommend terminating the cover crop at least two weeks prior to planting the cash crop to prevent competition for valuable spring soil moisture that could be used by the main cash crop after planting (Jost et al., 2004). Typically, three weeks after rolling, the termination rate for rye is above 95% when rolling is performed at an optimal growth stage (Ashford and Reeves, 2003; Kornecki et al., 2006). According to Hargrove and Frye (1987), the minimum time between rolling/crimping and planting the cash crop is

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at least 14 days, allowing soil water recharge prior to planting.

Under ideal weather conditions in the Southeast, rye cover crop termination for cotton is usually accomplished at the end of March, followed by planting of the cash crop 3 to 4 weeks after rolling. However, if late winter months and early spring months are unusually cold and wet or too dry, producers must wait longer for rye to reach optimum growth stage for better rolling/crimping and biomass production. This results in late planting of the cash crop, which can compromise yield. Delays in terminating the cover crop can decrease the time between rolling and planting the cash crop and can also create problems with managing cover crop residue during planting. Optimum residue conditions for planting a cash crop are usually attained 3 weeks after termination, at which time the residue is dry, crisp, brittle, and easy to penetrate with equipment. However, if the time between cover crop termination and planting of a cash crop is insufficient, the cover crop might not completely lose its elasticity, strength, and moisture, making planting difficult due to frequent wrapping and accumulation of rye residue on planting units, as well as increasing the possibility of hair-pinning, a condition resulting when residue prevents adequate seed-soil contact.

One way to speed-up the termination process of cover crops is to apply herbicide while using rollers/crimpers. This practice has been implemented by some progressive conservation agriculture producers in the southeastern United States who spray rolled/crimped cover crop with glyphosate after rolling operation. However, mechanical crimping and a broadcast application of herbicide might exceed the amount of herbicide actually needed to effectively terminate a cereal cover crop. An alternative method is to apply herbicide in short spray intervals to the area of injured rye tissue. Thus questions arise as to how much herbicide is needed and what is the most efficient method to apply herbicide in conjunction with rolling/crimping.

The objectives of this study were to determine the effectiveness of different methods of herbicide application used with the roller/crimper to apply glyphosate (Roundup™) directly to crimped rye tissue, and to measure the rolling/herbicide treatment effects on volumetric soil moisture content.

Methods and Materials

A 3-year experiment was conducted at the E.V. Smith Research Station near Shorter, Alabama on a Compass loamy sand soil (thermic Plinthic Paleudults) from 2005-2008. The six treatments and their arrangement are shown in figure 1.

Rye as a winter cover crop was planted in the fall of 2005 (27 October), 2006 (25 October) and 2007 (15 November) using a John Deere 1700 grain drill. Roller/herbicide treatments were applied 19 April 2006, 18 April 2007, and 22 April 2008. The 2006 experiment was conducted when rye was at the soft dough growth stage; according to Nelson et al. (1995), this is a desirable growth stage for mechanical rye termination. In the 2007 and 2008 growing seasons, experiments were conducted when rye was in the early milk growth stage. A randomized complete block design (RCBD) was utilized with four replications. Each plot was 15 m (50 ft) long and 1.8 m (6 ft) wide. Roller operating speed was set to 4.8 km/h (3.0 mph). Two methods of Roundup™ WeatherMax (glyphosate) application were compared to a roller crimper only and a non-treated check. In the first method, a #95 medium density gray felt material (Western Felt & Fiber, Alhambra, Calif.), which was 1.4 cm (5/8 in.) thick, 4.4 cm (1 ¾ in.) wide, and 180 cm (6 ft) long, was mounted directly on the roller's crimping bar. A custom-made 180-cm (6-ft) long aluminum housing was used to contain the felt material. A soaker hose was silicone sealed inside the housing and supplied herbicide directly to the felt material which was positioned below the soaker hose (fig. 2).

The aluminum housing/felt assembly was attached directly to the back side of the crimping bar. The felt material was positioned 0.5 cm (0.25 in) below the crimping edge of the crimping bar.

When the crimping bar was in contact with the rolled cover crop, the glyphosate saturated felt material was compressed against the cover crop releasing glyphosate from the felt strip onto the injured rye tissue. In this manner, herbicide was applied with every crimp. To supply an equal amount of herbicide and control the flow and pressure of the glyphosate solution, a 53-L plastic tank with a pressure-compensated vane pump (FlowJet model #4300-504, Enviroharvest Inc., Ontario, Canada) powered

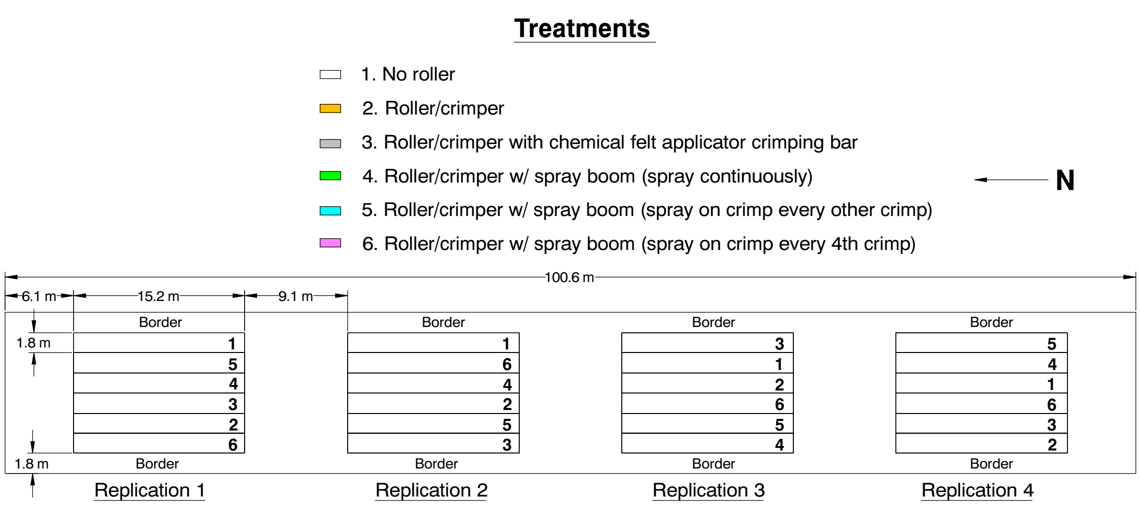

Figure 1. A randomized complete block design (RCBD) experiment layout with four replications.

Figure 2. Glyphosate discharge assembly from felt strip mounted to the crimping bar: (A) sealed soak-type garden hose; (B) crimping bar; (C) felt strip material.

by a 12-V electric motor and flow regulator were used. Operating system pressure was set to 207 kPa (30 PSI).

The second application method consisted of a steel boom with five nozzles mounted to the roller to provide spray glyphosate continuously, intermittent spray every second crimp and every fourth crimp using five fast-acting solenoid valves from Capstan Ag System (fig 3).

The same plastic tank, pump, and flow regulator as described in the first method were used in the second method to supply glyphosate to the nozzles. Five nozzles manufactured by TeeJet Co. (model # 110015VS, spray angle 110°, generating fine drop size) spaced 37 cm (14.5 in.) apart were mounted to the steel boom 50 cm (20 in.) above the ground surface, providing a 1.8-m (6-ft) spraying width (fig. 3). Each nozzle assembly was comprised of a narrow band nozzle, a fast-acting solenoid valve attached to the nozzle body in place of the check valve (fig. 3A, B, C). Components of the control system included an electric micro-switch mounted to the roller's structural bar (fig. 4A) and custom bolts used to trigger the switch (fig. 4B). The electrical switch was fitted with an adjustable engagement arm; both length and angle of engagement could be adjusted.

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Four engagement bolts (for every second crimp) and two bolts (for every fourth crimp), as shown in figure 4B, were fastened to the cam mechanism at equal intervals 10 cm (4 in.) from the center of the roller's rotation. In operation, as the roller rotated, the engagement bolts also rotated. When the bolt 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. 4).

When the solenoids were energized and activated the fast-acting valves, glyphosate was discharged through the nozzles for an instant. To determine the amount of glyphosate discharged through the nozzles, the system was calibrated prior to each treatment application. This was done by attaching plastic graduated cylinders to the nozzles and driving 15 m (50 ft) at 4.8 km h^{-1} (3.0 mph) with the pump working pressure set to 207 kPa (30 PSI). The effluent was collected during the time of driving 15 m (50 ft) at speed of 4.8 km h^{-1} (3.0 mph).

Volumetric moisture content was measured the day of rolling (immediately after rolling operation) and after the one, two, and three weeks using a portable time domain reflectrometry moisture meter (TDR300) from Spectrum Technologies (Plainfield, Ill.). The sensor was equipped with 12-cm (4-¾-in.) long stainless steel rods and was inserted vertically into the soil surface. This rod length was selected to measure soil volumetric moisture content available for germination of cash crop seeds planted into the residue cover.

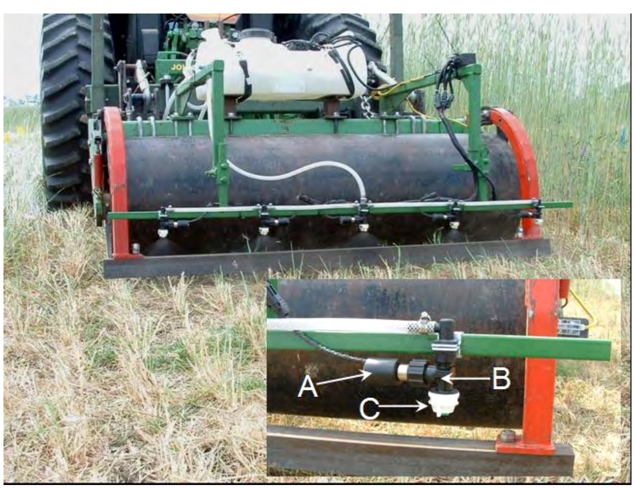

Figure 3. Back view of the smooth roller with crimping bar and the attached high speed solenoid valve: (A) solenoid valve, (B) nozzle body, (C) nozzle.

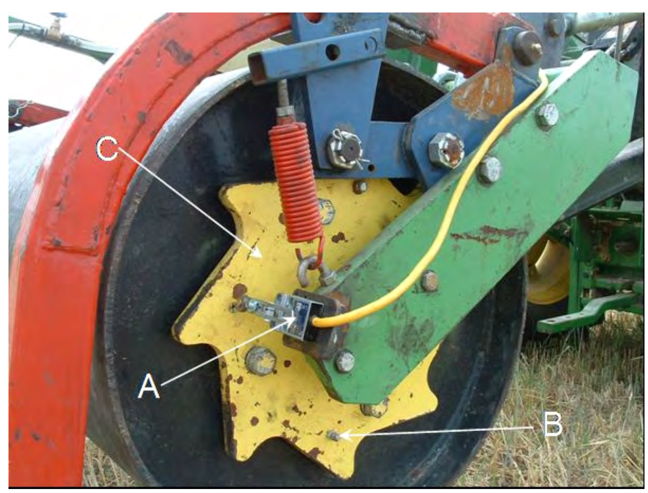

Figure 4. Side view of the smooth roller with crimping bar. (A) Micro-switch, (B) engagement bolt with the switch's arm, (C) eight-cam crimping bar control mechanism with clockwise rotation.

Four readings were taken close to the middle of each plot at marked locations spaced about 1.0 m (39 in.) apart.

On 18, 17, and 21 April of 2006, 2007, and 2008, respectively, the day before rolling/crimping of rye, plant biomass and heights were collected. The height was measured at eight randomly chosen locations throughout the plot using a custom-made scale rod and then averaged. Biomass was collected from two different space locations of each plot using a 0.25-m^2 (2.7-ft^2) area [0.5 -× 0.5-m (1.64- × 1.64-ft) square] frame. The collected rye biomass was oven dried for 72 h at 55°C using an electric oven (Model No. SC-350 from Grieve Corporation, Round Lake, Ill.). Rye mortality, based on visual observation, was estimated on a scale of 0% (no injury symptoms) to 100% (complete death of all plants) as described by Frans et al. (1986) and was evaluated at one, two, and three weeks after rolling treatments. Analysis of variance (ANOVA) was performed on rye cover crop biomass, height, and termination rate. Treatment means were separated by the Fisher's protected LSD test at the 0.10 probability level (SAS, 2001). Percentages of rye termination were transformed using an arcsine square-root transformation method (Steel and Torie, 1980), but this transformation did not result in a change to analysis of variance. Thus, non-transformed means are presented. Treatments were considered fixed effects and years were considered random effects. Where interactions among treatments and years occurred, data were presented separately and where no interactions were present, data were combined (Gomez and Gomez, 1984).

Costs of treatments were examined using the mean rates of glyphosate applied for each treatment. All cost data was obtained from Mississippi State University (2007). To scale up operations to that potentially seen on-farm, it was assumed the roller/crimper and sprayer were 9.1 m (30 ft) in width and pulled by a 170-hp tractor.

Results and Discussion

Rye Height and Biomass

There was no interaction among treatments and year with respect to height (P=0.75) and biomass (P=0.69), therefore, rye biomass and height data analyses were combined. Rye height (cm) and biomass (kg/ha) are shown in table 1. In 2006 and 2007 no differences in rye height were detected and measured 169 and 163 cm, respectively. A significantly lower rye height of 154 cm was recorded in 2008 compared with previous years. In 2006, the rye height was between 163 and 175 cm; in 2007, the rye height was more uniform between 162 and 164 cm; in 2008, rye height was between 148 and 157 cm. No significant differences in rye biomass were found between 2006 (7472 kg/ha) and 2007 (7241 kg/ha). However, in 2008, rye biomass was significantly lower (5577 kg/ha) compared to previous growing seasons.

Table 1. Average height and biomass of rye in 2006, 2007, and 2008 growing seasons.

Year	2006	2007	2008	LSD
Height (cm)	169a[a]	163a	154b	8.04
Biomass (kg/ha)	7472a	7241a	5577b	1077

[a] Means followed by the same letter in rows are not significantly different at P ≤ 0.10.

There were no significant differences in rye biomass among experimental plots in each growing season.

Rye Termination

Interactions among years and treatments for termination rates occurred (P < 0.0001), therefore, years were analyzed separately. Rye termination rates results for 2006, 2007, and 2008 are shown in table 2.

2006

One week after rolling, the highest termination rate (100%) was obtained with the roller/crimper and continuous broadcast glyphosate application from a spray boom. The second highest termination rate of 98% was found with glyphosate application from a spray boom at every fourth crimp; however, there were no significant differences among these treatments (LSD=1.66). Significantly lower termination rates (95%) were recorded for the roller with felt material attached to the crimping bar and roller/crimper with glyphosate application from a spray boom at every other crimp. The roller/crimper alone produced 92% rye termination. The lowest termination rate of 70% was obtained with senescing non-treated rye.

Two weeks after rolling treatments, all glyphosate-added treatments produced 100% termination. Significantly lower termination rates (LSD=2) were produced by the roller/crimper alone (97%) and non-treated check (87%). Three weeks after treatment, termination rates for the roller/crimper alone and non-treated check increased to 99%. Ashford and Reeves (2003) indicated that termination rates above 90% were acceptable for planting a cash crop into the rolled/crimped rye residue cover. Thus, based on our 2006 results (except for non treated rye), planting a cash crop may be feasible as early as one week after rolling for all rolling plus chemical treatments. Additional economical and environmental benefits of using roller/crimper and intermittent chemical application (every fourth crimp) may be attained when compared to a continuous broadcast application.

2007

One week after rolling, significantly higher termination rates were observed for continuous spray (96%) and every other crimp (94%) compared to every fourth crimp (84%) and felt application (78%). Roller/crimper without glyphosate produced 70% termination rate. The lowest termination rate was recorded for the non-treated check (53%). Two weeks after rolling, rolled rye treatments with glyphosate application produced between 94% (felt applicator) and 100% termination (continuous spray). Termination rates for spray every other crimp and every fourth crimp were 100% and 98%, respectively. For non-treated check, the termination rate was 73%. Three weeks after rolling, termination rates for all rolled rye treatments were between 97% and 100%. Termination rate for the non-treated check was 95%. Since termination rates after one week from rolling were above 90% for continuous spray and spray every other crimp, planting of a cash crop following these treatments was possible. Comparing rye termination rates generated by the roller with felt material applicator and spray every fourth crimp between the 2006 and 2007 growing seasons, lower termination for these treatments might be associated with

Table 2. Termination rates of rye (%) for different rolling treatments at one, two, and three weeks after rolling.

Year	2006			2007			2008		
Rolling treatment	1 week	2 weeks	3 weeks	1 week	2 weeks	3 weeks	1 week	2 weeks	3 weeks
Non-treated check	70d[a]	88c	99b	53d	73c	95.0c	39d	54c	88b
Roller/crimper	93c	98b	99b	70c	90b	96.5b	80c	92b	98a
Felt applicator	97b	100a	100a	78b	94ab	97.8b	99a	99a	100a
Continuous spray	100a	100a	100a	97a	100a	100.0a	99a	99a	100a
Spray every 2nd crimp	97b	100a	100a	94a	100a	100.0a	97b	99a	100a
Spray every 4th crimp	99a	100a	100a	84b	98a	99.5a	96b	99a	100a
LSD at 0.1	1.7	2.0	0.01	6.2	4.1	1.3	1.8	1.9	2.0

[a] Within each column means followed by the same letters are not significantly different at P ≤ 0.10.

slightly lower growth stage of rye in 2007, taking into consideration that similar rye biomass was produced in both growing seasons. However, comparing the lower 2007 rye termination rate for these treatments with 2008, it appears that lower biomass in 2008 allowed for better penetration of glyphosate through the residue mat, thus generating higher termination rates for rye.

2008

One week after rolling, the roller and glyphosate treatments produced between 96% and 99% termination rates. Roller/crimper alone produced 80% termination rates, whereas non-treated check termination was less than 40%. Results indicate that one week after rolling, all combinations of rolling/crimping and herbicide application allowed for planting a cash crop into rolled residue. Despite higher termination rate (99%), the felt-strip required additional time to become saturated before starting the experiment and dripping of glyphosate solution from the felt material occurred after the experimental run was concluded. Two weeks after rolling, all rolled treatments with glyphosate application produced the same termination rate of 99%. For non-rolled rye and roller/crimper without herbicide termination, rates were 54% and 92%, respectively. As already indicated, the 2008 rye biomass was lower than in the previous two years, while termination rates were higher, for both chemical and rolled only treatments. It appears that the lower rye biomass allowed for better herbicide penetration into the rolled mat.

Soil moisture

Similar to rye termination rates, there were interactions present among years and treatments with respect to volumetric moisture content (VMC) ($P < 0.0001$), so years were analyzed separately. Rolling and glyphosate treatment effects on volumetric soil moisture content in three growing seasons are shown in table 3.

2006

On the day of rolling, VMC for non-treated check was significantly lower compared to roller only, felt chemical and spraying every fourth crimp treatments. No differences were found among the non-treated check, continuous spray and every other spray treatments, although VMC for these treatments was slightly higher. Even though VMC was measured on the same day that the rolling treatments were completed, VMC measurements were not obtained until 3 hours after rolling/spraying application. The lower VMC for non-treated check can be associated with higher water evapotranspiration of living rye and the amount of bare soil surface compared to rolled rye, which created residue mulch that provided complete soil protection after rolling and better conservation of soil moisture. One, two, and three weeks after rolling, VMC for the non-treated check was consistently and significantly lower than rolled rye treatments. The difference between VMC for the untreated check and the lowest VMC for all rolled rye treatments was 3.2%, 3.5%, and 3.2%, one, two, and three weeks after rolling, indicating that rolled residue conserved soil moisture much better than non-rolled rye. Based on these differences it appears that there was limited, if any, water and nutrient uptake rye stems that had been rolled and injured by the crimping action of the rollers and fast acting herbicide.

2007

The day of rolling operations, all rolled rye treatments had VMC between 6.7% and 7.3%, whereas VMC for the non-treated check was significantly lower (5.3%). One week

Table 3. Rolling/chemical treatment effect on volumetric soil moisture (%) measured on the rolling day and one, two, and three weeks after rolling/crimping of rye.

	Day of Rolling[a]			One Week after Rolling			Two Weeks after Rolling			Three Weeks after Rolling		
Roller Type	2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008
Non-treated check	5.8c	5.3c	6.2b	5.1c	0.9c	2.3c	1.8c	0.0b	2.5c	15.1c	0.0b	4.3c
Smooth roller with crimping bar	7.2ab	7.3a	7.5a	8.8ab	2.4b	4.8b	5.8b	1.0a	5.0b	18.3b	0.4a	7.4b
Felt chemical	8.1a	7.1ab	7.3a	10.2a	3.0ab	5.2ab	6.8a	0.8a	5.7a	20.0a	0.3ab	8.0ab
Continuous	6.8bc	6.8ab	7.9a	9.1ab	3.3a	5.7a	6.0ab	1.2a	5.8a	19.7ab	0.4a	8.8a
Every other crimp	6.6bc	6.7b	8.3a	9.0ab	3.3a	5.7a	5.3b	1.2a	5.9a	19.0ab	0.6a	8.3ab
Every 4-th crimp	7.6ab	7.0ab	7.6a	8.3b	2.7ab	5.4ab	5.8b	1.2a	5.6a	20.1a	0.4a	8.0ab
LSD,a=0.1	1.21	0.53	0.99	1.88	0.68	0.76	0.81	N/S	0.58	1.60	N/S	0.99

[a] Within each column means followed by the same letters are not significantly different at P ≤ 0.10.

after rolling, the VMC for all rolled rye treatments were between 2.4% and 3.3%, while for the non-treated check the VMC dropped to 0.9%. Although VMC for all treatments were lower compared with VMC measured the day of rolling, in contrast to the non-treated check, rolled residue was still effective in protecting soil from moisture loss. These lower VMC values were associated with a late 2007 spring drought in Alabama that caused severe soil-water depletion. Because of continuing drought, VMC further decreased and the non-treated check measured 0.0% to 1.2% and 0.0% to 0.6%, two and three weeks after rolling, respectively. No significant differences were detected among rolling treatments and the non-treated check two weeks (P=0.120) and three weeks (P=0.110) after rolling. Volumetric moisture content of 0.0% does not imply that the soil moisture at the top soil (0 to 12 cm) was in fact zero (oven dried); it implies that the TDR meter was unable to read very low volumetric moisture content in drought conditions.

2008

In 2008, VMC for the non-treated check on the day of rolling was 6.2% and was significantly lower compared to all rolled rye treatments, which ranged from 7.3% to 8.3%. No significant difference in VMC was found among the rolled treatments. One week after rolling, VMC was 2.3% for non-rolled standing rye compared to 4.8% and 5.7% for rolled/glyphosate application rye treatments. Two weeks after rolling, the VMC was similar to that measured one week after rolling; VMC measured 2.5% for non-treated rye and was between 5.0% and 5.9% for rolled rye treatments. Three weeks after rolling VMC measured 4.3% for the non-treated rye and was significantly lower than VMC of 7.4% to 8.3% for all rolled rye residue treatments. The increase in VMC three weeks after rolling was associated with a rainfall event which occurred after the second and before the third week after rolling.

Overall, in all growing seasons, at the day of rolling, volumetric moisture content for all rolled rye treatments was significantly higher compared with the non-treated check. It appears that rolling operations better conserved soil moisture by minimizing evaporation, whereas, with non-treated check, evapotranspiration of the living plant utilized more soil water. Generally, in all growing seasons, there were no differences in VMC between roller only and rolling with glyphosate application. Although, in 2008, one, two, and three weeks after rolling there was a trend that rolling with glyphosate application resulted in slightly higher VMC compared to the rolling only treatment.

Amount of Chemical Use

The amount of herbicide discharged in each treatment is shown in table 4.

As already stated, in cover crops management, applying herbicide may be necessary to speed up termination of cover crops, so planting of a cash crop can be accomplished in the optimum time especially when weather is not typical (i.e., cold and wet spring).

The highest glyphosate usage was measured with the roller/crimping and continuous spray treatment which resulted in 96.5% to 100% rye termination rates one week after rolling. This glyphosate application represents recommended rates used in typical burndown applications for weed control. With felt application the reduction in glyphosate usage was 47% compared to the continuous spray. Termination rates following the glyphosate application from felt treatment were between 78% and 99% one week after rolling. When spraying glyphosate every other crimp, the reduction in glyphosate with respect to continuous spray was 71% and termination rates were 94% to 97% one week after rolling. The lowest glyphosate usage was measured for spraying herbicide every fourth crimp which reduced glyphosate usage 87% from the continuous spray treatment and caused between 84% and 99% rye termination one week after treatment application.

Economics

Cost data for each treatment are provided in table 5. Traditional termination practices of spraying herbicides and rolling the cover crop in two separate passes over the field is included for comparison purposes. By incorporating the continuous spray herbicide application and rolling activities, based on these cost estimates, a farmer could save \$12.63 ha^{-1} by reducing the number of passes over the field. By further reducing the amount of herbicide used via application during crimping, the farmer could save an additional \$13.10 to \$24.25 ha^{-1} depending on the application method used. These numbers will obviously differ based on the burndown herbicide applied. Thus, total savings compared to applying the herbicide separate from the rolling can amount to as much as \$36.87 ha^{-1}. Given increasing production costs and present economic volatility, these cost savings may be substantial for a farmer seeking to increase the margin earned on his cropping enterprises. From a conservation standpoint, applying herbicides during rolling in a non-continuous manner (vs. traditional burndown at \$43.15 ha^{-1}) will help to reduce the cost of implementing a cover crop on-farm (by as much as \$21.90 ha^{-1}), improving the adoption incentives for farmers to integrate this practice into their cropping systems.

Table 4. The amount of glyphosate spray solution and glyphosate formulation used for different treatments. The continuous spray application was calibrated to apply 2.3 L/ha (32 fl oz/acre) of the glyphosate formulation.

Treatment	Glyphosate Spray Solution Applied (L/ha)	Glyphosate Formulation Applied (L/ha)	% Glyphosate Formulation Amount of Continuous Spray	Rye Termination (%) One Week after Rolling		
				2006	2007	2008
Continuous spray	139.2	2.3	100	100	97	99
Felt application every crimp	73.8	1.2	53	97	78	99
Spray every other crimp	40.2	0.7	29	97	94	97
Spray every 4th crimp	17.7	0.3	13	99	84	96

Table 5. Cost ($ ha^{-1}) of alternative rolling/chemical treatments, 2008[a].

Expense/Treatment	No Chemicals ($)	Rolling/Chemical Applied Separately[b] ($)	Continuous Spray ($)	Felt Application (every crimp) ($)	Spray (every 2nd crimp) ($)	Spray (every 4th crimp) ($)
Roller/Crimper[c]	14.97	14.97	14.97	14.97	14.97	14.97
Sprayer equipment[d]	0.00	15.47	2.84	2.84	2.84	2.84
Herbicide[e]	0.00	27.68	27.68	14.58	7.93	3.43
Total	14.97	58.12	45.49	32.40	25.75	21.25

[a] Costs include variable and fixed costs of application.
[b] This treatment, not part of the study, was included for comparison purposes, representing the traditional cover crop termination practice in the Southeast.
[c] Based on the cost of 9.1-m width roller from Mississippi State University (2007).
[d] Sprayer costs for experimental treatments are estimated based on the fixed cost, repair and maintenance, and hand labor costs when the sprayer is attached to the roller.
[e] Herbicide costs are based on rates taken from table 4 and cost of glyphosate (RoundupTM WeatherMax) of $11.83 L^{-1}.

Conclusion

Two different methods of glyphosate application (nozzle and herbicide saturated felt systems) combined with rolling/crimping of rye and rolling/crimping by itself were compared during three growing seasons (2006-2008) for their effectiveness in terminating the rye cover crop and their influence on soil moisture.

Rolling/crimping combined with different glyphosate applications generated rye termination rates from 78% (by felt-strip applicator in 2007) to 100% (by continuous spray in 2006) one week after the rolling operation.

One week after rolling, the felt-strip system generated kill rates comparable to the nozzle system; 97% in 2006 and 99% in 2008. In 2007, rye termination by this method was lower (78%) one week after rolling due to uneven soil surface, preventing uniform contact of glyphosate saturated felt with rolled rye.

In two of three growing seasons, spraying glyphosate every fourth crimp provided excellent kill rates (99% in 2006 and 96% in 2008) one week after rolling, whereas in 2007, applying glyphosate every fourth crimp generated 84% rye termination rate. This lower rate was likely associated with early rye growth stage (i.e., early milk). Substantially reduced amounts of herbicide (up to 87%) were used by this process; this could save producers up to $36.87 ha^{-1} compared to rolling and continuous spraying in two separate passes.

In 2006, rolling/crimping alone and with glyphosate conserved more than 3% soil moisture as compared to the non-treated check one, two, and three weeks after rolling. In 2007 during a severe drought period, rolled residue was effective in conserving soil-water up to one week after rolling, compared to the non-treated check. Similar to 2006, in 2008 volumetric moisture content for rolled rye by roller alone and with supplemental glyphosate application compared to the non-treated check was consistently higher by at least 2.5% one and two weeks after rolling, and at least 3.1% three weeks after rolling, indicating that the rolled rye residue cover provided higher soil water conservation than standing rye.

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