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ENGINEERING AND GINNING

Effect of Rye Cover Crop Management Methods on Cotton Growth in a Conservation System

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ABSTRACT

In conservation agriculture, cover crops must produce sufficient biomass for effective soil coverage and managed appropriately to avoid planting problems. Producers have been inquiring about proper cover crop management including suitable rolling cover crop directions (with respect to planting cash crop) and row cleaner type to be successful in a conservation system. A field experiment evaluated the effects of different rolling directions of cereal rye relative to cotton planting. A no-till planter with commercial row cleaners and a custom residue pusher was evaluated based on cotton stand, emergence rate index (ERI), and cotton yield. Two Alabama locations were chosen to account for different climatic and soil conditions. Cereal rye was terminated with a roller/crimper and glyphosate. Parallel rolling to planting cotton and non-rolled residue using any of the tested row cleaners generated the highest cotton stand when compared to no row cleaner. The Dawn™ row cleaner with pusher had a higher cotton stand, especially for non-rolled rye, by effectively pushing residue against the soil surface while planting. Stand was highly correlated with ERI (R2 = 0.99); the fastest ERI was obtained with the parallel rolling with all tested row cleaners. The slowest ERI was with perpendicular and diagonal directions with no row-cleaner. Cotton yield mostly depended on weather; however, row-cleaner treatments had an effect on yield with a lower yield for no row-cleaner. Higher rye accumulation on row cleaners was for standing rye and the Dawn row cleaner due to wrapping and required more time to clean from the planter.

Utilization of cover crops in no-till systems has steadily increased, and effective management of cover crop residue is necessary to plant successfully and efficiently cash crops into residue without seeding skips or residue accumulation on planting units. Planting cash crops into heavy residue cover is an important field operation in terms of providing the best possible soil environment for optimum cash crop growth. Winter cover crops are an integral part of conservation systems such as no-till cotton.

Rye (*Secale cereale* L.) is a commonly used winter cover crop in the Southeast. To maximize benefits from rye, the cover crop must be terminated at the appropriate growth stage and in sufficient time before planting a cash crop. Ashford and Reeves (2003) noted an appropriate growth stage for rye termination was soft dough, a maturity that provided optimum levels of rye biomass. Most agricultural extension services recommend terminating the cover crop at least 2 wks prior to planting the cash crop. This is important to prevent the cover crop from competing with a planted cash crop for valuable soil moisture and nutrients (Hargrove and Frye, 1987).

Major benefits of cover crops include weed suppression (allelopathy and mulch effects), as well as improved soil properties due to increased soil organic matter. Several studies have identified other benefits such as increased water infiltration, reduced runoff, reduced soil erosion, reduced soil compaction, and improved crop yield stability (Ashford and Reeves, 2003; Dinnes et al., 2002; Kasper et al., 2001; Kern and Johnson, 1993; McGregor and Mutchler, 1992; Raper et al., 2000a, b; Reeves, 1994; Snapp et al., 2005).

To prevent problems by planting directly into cover crop residue, cover crops must be managed appropriately. The most common problem is “hairpinning”, where residue is pushed into the soil rather than being cleanly sheared, creating a condition where the seeds are unable to have good seed-soil contact (Kornecki et al., 2012). As a result, in-row skips of the cash crop can occur, negatively affecting crop emergence and yield. Another major problem is accumulation of cover crop residue on planting units, which might result in frequent stops to clean the equipment and decreased planting efficiency and quality.

In the U.S., cover crops commonly have been terminated with herbicides, because spraying is

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relatively fast and effective. Another effective way to manage cover crops is mechanical termination using rollers/crimpers. Rolling technology originated in Brazil where rollers have been used successfully for many years with conservation agriculture (Derpsch et al., 1991). Rollers typically consist of a steel drum with attached crimping bars equally spaced on the drum's circumference (Fig. 1). Managing cover crops using improved rolling technology has been introduced in the southern U.S. (Kornecki et al, 2006). Rollers have been shown to be beneficial by flattening the cover crop to provide a flat mat over the surface of the field and preventing multiple direction lodging. However, based on repeated questions during conferences and regional meetings with farmers, especially from producers who do not have much experience in no-till systems or who are in a transition of switching from conventional tillage to conservation systems, there is a need to help these producers select the appropriate direction of rolling relative to planting operations. Commercial row-cleaner attachments are available to producers, but some wrapping of cover crop residue on rotating row cleaners can be a problem. A planting aid attached to a no-till planter (forward residue mover) was fabricated to help manage cereal rye residue for non-rolled cover (Torbert et al., 2007, 2015) by using a frame with attached, flexible, plastic water hoses to brush away residue from the planting path, but not all residue was controlled by this device. To improve performance of this aid, a custom-designed residue pusher attached to a commercial row cleaner was developed (spring preloaded ski-like device on both sides of the furrow) to firmly press residue against the soil surface (Kornecki et al., 2014) and its performance needed to be evaluated.

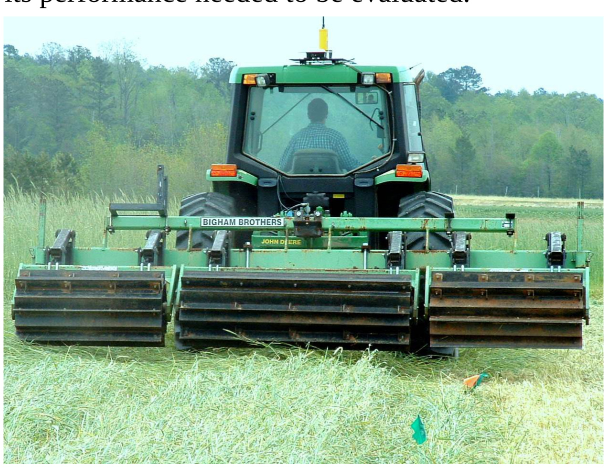

Figure 1. Three-section roller/crimper with straight crimping bars 4.1-m wide.

Producers also inquired about what is the best combination of rolling direction with respect to cash crop planting direction and row cleaners to properly manage cover crops and optimize no-till cotton production; thus, identifying a need to field test several rolling patterns and row cleaners. The objectives of this study were (1) to determine the effect of different rolling directions relative to cotton planting direction on cotton stand, emergence rate, and yield, and (2) to evaluate different commercially available and custom-designed row-cleaner attachments on cotton stand, emergence rate, and yield for no-till cotton.

MATERIALS AND METHODS

Two experimental sites were chosen for this study: the E.V. Smith Research and Extension Center (EVS) at Milstead (central Alabama) and the Tennessee Valley Research and Extension Center (TVS) at Belle Mina (northern Alabama) to account for different soils and climatic conditions. Cereal rye was planted at both locations in the fall of 2005, 2006, and 2007 using a grain drill with row spacing of 19 cm. At the EVS, rye was rolled/crimped in the spring on 18 April 2006, 11 April 2007, and 17 April 2008; at the TVS, rye was rolled/crimped on 20 April 2006, 19 April 2007, and 24 April 2008 at the early milk growth stage (Zadoks scale: #73; Zadoks et al., 1974), a desirable period for termination that normally produces an optimum level of biomass (Nelson et al., 1995). Rolling/crimping was performed using an experimental three-section, 4.1-m wide roller (Bigham Brothers, Lubbock, TX) with long, straight crimping bars (Fig. 1). The day before terminating the rye cover crop, biomass (0.25-m^2 sample per plot) and plant heights (8 readings per plot) were measured. Following rolling, the cover crop was sprayed with herbicide (glyphosate) at a rate of 1.64 L (ai) per hectare to ensure complete termination.

The experiment consisted of a strip-plot design with four replications for each treatment (Fig. 2). Four different treatments for rolling direction (main effects; horizontal strips) were used with respect to cotton planting direction: (1) parallel, (2) perpendicular, (3) diagonal (45°), and (4) no roller (standing rye). For subplots (vertical strips) in this experiment, two different commercially available row cleaner attachments were used (Fig. 3): (a) Yetter^{TM} row cleaner (Yetter Farm Equipment, Colchester, IL), (b) Dawn^{TM}) row cleaner with coulter (Dawn Equipment Company, Sycamore, IL), and (c) Dawn row cleaner with a custom residue pusher/residue manager (Kornecki et al., 2014). Results were compared to (d) no row cleaner.

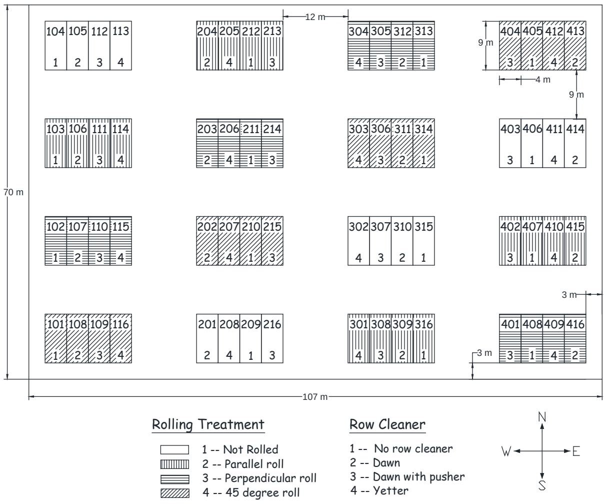

Figure 2. Experimental layout: strip-plot design with rolling patterns as horizontal treatments and row cleaners as vertical treatments with four replications for each treatment at each location.

Figure 3. Row cleaners: (a) Dawn, (b) Yetter, (c) Dawn with an attachment (custom residue pusher), (d) No row cleaner.

Cotton (*Gossypium hirsutum* L.) Stoneville 5242BR variety was planted at the EVS on 3 May 2006, 22 May 2007, and 22 May 2008; at the TVS, cotton was planted 16 May 2006, 8 May 2007, and 20 May 2008. At both locations, a 4-row John Deere Max Emerge Plus vacuum planter was used to plant the cotton. At planting, soil moisture conditions were adequate for planting (approximately 3 wks after rolling). During the planting operation, two commercially available row cleaners and one custom residue pusher were evaluated. The amount of residue that accumulated on row cleaners and time required to remove residue were recorded for each plot. The time to remove residue from the planting units was recorded (in seconds) using a battery operated digital stopwatch. The residue that was removed from the row cleaners was collected in a paper bag, labeled, and air dried for dry biomass utilizing a forced air-drying chamber for 72 h.

To evaluate cotton stand, the number of emerged plants was counted at four random locations along the two middle rows in each four-row plot using a 1.5-m ruler. Cotton population (plants ha^{-1}) in each plot was calculated using number of plants per 6.0-m distance and the row spacing. This measurement was performed several times during the plant emergence period (dates for both locations in Table 1), until no change in number of emerged plants occurred. The Emergence Rate Index (ERI) is a dimensionless index that evaluates how fast plants emerged from the ground: the larger the number, the faster the emergence of plants. ERI was calculated using the following equation (Erbach, 1982):

$$ERI = \sum \frac{\left[\left(\frac{\frac{Seed\ number}{6.0\ meter}}{Population\ target}\right) * 100\right] - \left[\left(\frac{\frac{Previous\ seed\ number}{6.0\ meter}}{Population\ target}\right) * 100\right]}{\{Number\ of\ days\ after\ planting\}}$$

Table 1. Dates for cotton population measurements to establish a dimensionless Emergence Rate Index (ERI) at the EVS and TVS during three growing seasons

EVS			TVS		
2006	**2007**	**2008**	**2006**	**2007**	**2008**
5/18/2006	6/1/2007	5/29/2008	5/26/2006	5/16/2007	5/29/2008
5/26/2006	6/5/2007	6/3/2008	6/1/2006	5/21/2007	6/2/2008
6/2/2006	6/8/2007	6/5/2008	6/6/2006	5/24/2007	6/5/2008
6/8/2006	6/12/2007	6/9/2008	6/10/2006	5/29/2007	6/5/2008
	6/18/2007	6/12/2008		5/31/2007	6/9/2008
		6/16/2008		6/4/2007	6/12/2008
		6/19/2008			6/16/2008

Cotton was harvested in fall of each year using a two-row John Deere 9920 cotton picker. The two middle rows from each four-row plot were harvested and bagged in the field. Bags were then weighed to determine the seed cotton yield. Data were analyzed using linear mixed models and procedures in SAS PROC GLIMMIX (SAS Institute, 2013). Least significant difference (LSD) method was employed for mean separation. All tests were conducted at a significance level of $p \leq 0.10$. Initially, year and location were treated as fixed effects to determine their respective effect on the results with the analysis of variance using a generalized linear mixed model. This initial analysis determined if data can be averaged over years, locations, or both for further analyses. Row cleaner residue and collection time data were analyzed using Yetter row cleaner, Dawn row cleaner with coulter, and Dawn with a custom residue pusher/residue manager without comparing to no row cleaner as there was no residue accumulation (no row cleaners).

RESULTS AND DISCUSSION

Preliminary results indicated that based on F-values, year had a stronger effect compared to location for all dependent variables except for biomass production for which interactions between years and locations were stronger (higher F-values and their respective probabilities, Table 2). There were significant interactions between Year and Location for all dependent variables. The reason for these differences among years and significant interactions between years and locations was differences in weather conditions, that is, precipitation and temperature in each growing season and at each location. To establish the treatment effects for dependent variables, and to account for differences among the years, all dependent variables data were analyzed again separately by each year but combined over the locations. In addition, to determine the overall treatment effects for dependent variables, data were combined over 3 yrs and two locations and analyzed. These data were tabulated as "across 2006-2008" for relevant comparisons.

Cover Crop Production. Averaged over locations, rye biomass in 2006 was lower (5,832 kg ha^{-1}, plant height 157 cm) compared to higher biomass production of 6,891 kg ha^{-1}, and 7,056 kg ha^{-1}, in 2007 and 2008, respectively ($p < 0.0001$) with an average plant height of 159 cm. Across three growing seasons, the average dry cereal rye biomass production at the TVS was significantly higher, producing 7,289 kg ha^{-1} compared to 5,898 kg ha^{-1} at the EVS, ($p < 0.0001$). In 2006 and 2007 at the EVS, rye production was similar (6,363 kg ha^{-1}), but for 2008 growing season, rye was planted late in fall (15 November 2007) and wet weather in January and February (213 mm, Fig. 4) and cool temperatures in March (lowest temperature -3°C) negatively affected rye growth generating only 4,966 kg ha^{-1}. At the TVS in 2006, the rye cover crop biomass was the lowest (5,301 kg ha^{-1}) due to dry weather in February and March of 2006 (100-mm rainfall, AWIS, 2014) compared to higher rye biomass in 2007 (7,419 kg ha^{-1}) and the highest in 2008 (9,146 kg ha^{-1}).

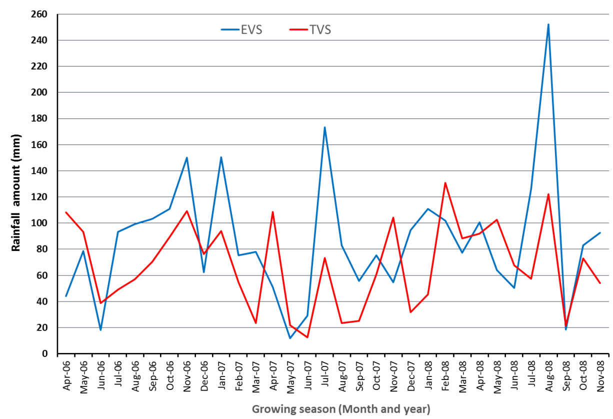

Figure 4. Monthly rainfall amounts (mm) at EVS and TVS locations during three growing seasons (2006-2008) for cotton; rainfall data from AWIS (2014).

Table 2. ANOVA F-values and probabilities (Pr > F) from SAS GLIMMIX procedure for all dependent variables with respect to year, location, and year x location interactions

Source	DF	Cover crop		Cotton cash crop dependent variables						Cover crop accumulated on planter			
		Biomass		Stand		ERI		Yield		Residue		Time to clean	
		F Value	Pr > F	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
Year	2	29.37	<.0001	99.20	<.0001	803.06	<.0001	1112.9	<.0001	5.76	0.0037	205.10	<.0001
Loc	1	36.31	<.0001	7.82	0.0682	3.39	0.1630	17.56	0.0248	2.42	0.2177	0.01	0.9479
Year*Loc	2	115.78	<.0001	55.60	<.0001	13.68	<.0001	142.00	<.0001	15.49	<.0001	16.76	<.0001

Cotton Population. *Effect of Rolling Direction and Row Cleaners on Cotton Population.* In each growing season, rolling directions and row-cleaner treatments affected cotton population ($p < 0.0001$, Table 3). In 2006, significantly higher cotton population was associated with non-rolled rye residue and parallel rolling direction, compared with lower population for diagonal direction, and the lowest population for perpendicular rolling direction. For row-cleaner treatments, significantly higher cotton population was observed for Yetter row cleaner, compared to lower population for Dawn with pusher. Dawn had lower cotton population than Dawn with pusher and the lowest population was found for no row-cleaner treatment (47% lower than for Yetter row cleaner).

In 2007, higher cotton population was found with the parallel rolling direction, compared with lower population for non-rolled residue, and the lowest cotton population was associated with 45 and 90° rolling patterns. Cotton population with respect to row cleaners was higher for Dawn with pusher and Yetter row cleaners compared to lower population for Dawn and the lowest population was due to no row-cleaner treatment.

In 2008, cotton population was higher for parallel rolling and no-rolled treatments compared with lower cotton population for 45° and the lowest for 90° rolling directions (37% lower than for parallel rolling treatment). Significantly higher cotton population with respect to row cleaners was observed for Yetter, Dawn with pusher, and Dawn row cleaners without differences among these treatments. The lowest cotton population was associated with no row cleaner and was 25% lower than for Yetter row cleaner.

Overall, data across 2006-2008 indicate that the higher cotton population was associated with parallel rolling direction and non-rolled residue without significant difference between these treatments compared to a lower population for 45° and the lowest for 90° rolling direction. For row cleaners, the highest cotton population was found for Yetter and Dawn with pusher, without differences between these treatments, followed by lower population for Dawn and the lowest for no row cleaner.

Combined Treatment Effect on Cotton Population. No interactions between rolling directions and row-cleaner treatments with respect to cotton population occurred in 2006 ($p = 0.1081$). In contrast, significant interactions were found between rolling direction and row-cleaner treatments during 2007 ($p = 0.0100$) and 2008 growing seasons ($p = 0.0161$, Table 4). Likewise, significant interactions between rolling directions and row cleaners for cotton population were also found across 2006-2008 ($p = 0.0001$, Table 4).

Table 3. Cotton population (thousands of plants ha^{-1}) with respect to rolling direction and row-cleaner treatments during three growing seasons. Last column shows cotton population across all locations and growing seasons

Treatment description		Growing season 2006	Growing season 2007	Growing season 2008	2006 - 2008
Rolling direction treatment	No-rolled	97.3 a[z]	110.6 b	102.2 a	103.4 a
	Parallel	93.9 a	117.3 a	112.6 a	107.9 a
	90°	62.3 c	96.0 c	70.6 c	76.3 c
	45°	68.9 b	102.2 c	86.7 b	85.9 b
	p-Value	<0.0001	<0.0001	<0.0001	<0.0001
Row-cleaner treatment	No row cleaner	51.9 d	75.1 c	76.2 b	67.7 c
	Dawn	82.5 c	114.3 b	97.3 a	98.0 b
	Dawn with pusher	90.0 b	121.3 a	97.3 a	102.9 a
	Yetter	98.0 a	115.4 ab	101.2 a	104.8 a
	p-Value	<0.0001	<0.0001	<0.0001	<0.0001
Rolling direction x Row cleaner: *p*-Value		0.1081	0.0100	0.0161	0.0001

[z] Comparisons between means are valid only within each column. Treatment means are compared for each year using LSD procedure. Treatment means followed by the same letter are not statistically different ($p \leq 0.10$).

Based on these interactions, higher cotton population in 2007 and 2008 was associated with the combination of non-rolled rye and all three tested row cleaners. Similar results were obtained for parallel rolling direction, where all tested row-cleaner types showed significantly higher cotton yield compared to no row-cleaner treatment (Table 4). Cotton population was consistently lower with no row cleaner in 2007 and 2008 growing seasons.

In 2007, for perpendicular rolling direction the Dawn with pusher, Yetter and Dawn row cleaners generated higher cotton populations compared to lower cotton population for no row cleaner. In 2008, the highest cotton population for perpendicular rolling pattern was obtained with Yetter compared with lower population for Dawn without and with pusher. In 2007 and 2008, the lowest population was associated with perpendicular rolling directions and no row cleaner. For diagonal rolling direction in 2007 and 2008, all tested row cleaners performed similarly without significant differences in cotton population among them, compared to significantly lower cotton population for no row-cleaner treatment. Overall, results across 2006-2008 indicate that significantly higher cotton population was associated with non-rolled and parallel rolling directions equipped with Dawn, Dawn with pusher, and Yetter row cleaners compared to perpendicular and diagonal rolling directions with the same row cleaners. This can be explained by the fact that parallel and no-rolled residue did not interfere with the planter allowing it to cut residue along rows of cover crop. In perpendicular and diagonal systems, coulters could not cut successfully residue that was rolled at 90 and 45°. These rolling directions are not recommended especially when biomass production is greater; the coulter cannot cut through the residue and creates hair pinning. According to the results, not using row cleaners in a no-till system is not recommended for optimum planting of cotton into the rye residue.

Cotton Emergence Rate Index (ERI). *Effect of Rolling Direction and Row Cleaners on ERI.* In each growing season, rolling direction and row-cleaner treatments had a significant effect on cotton emergence ($p < 0.0001$, Table 5).

Table 4. Combined treatment effect on cotton population (thousands of plants ha^{-1}) during three growing seasons. Last column shows cotton population across all locations and growing seasons

Treatment combination		Growing Season			
Rolling Direction	Row cleaner	2006	2007	2008	2006-2008
Non-rolled	No row cleaner	64.2	88.6 f[z]	84.4 ef	79.0 de
	Dawn	102.5	118.3 abc	110.4 ab	110.4 a
	Dawn with pusher	110.8	120.1 abc	113.2 ab	114.7 a
	Yetter	111.6	115.4 bcd	100.7 bcd	109.3 a
Parallel	No row cleaner	71.0	96.9 ef	103.9 bc	90.6 bc
	Dawn	102.7	119.9 abc	117.5 a	113.4 a
	Dawn with pusher	97.5	129.0 a	115.4 a	114.0 a
	Yetter	104.3	123.3 ab	113.4 ab	113.7 a
Perpendicular	No row cleaner	34.9	47.6 h	49.7 h	44.1 g
	Dawn	54.9	104.5 de	73.1 fg	77.5 e
	Dawn with pusher	72.3	116.7 abcd	69.6 g	86.2 cd
	Yetter	87.2	115.2 bcd	90.0 cde	97.5 b
Diagonal	No row cleaner	37.3	67.2 g	67.0 g	57.2 f
	Dawn	70.0	114.4 bcd	88.2 de	90.9 bc
	Dawn with pusher	79.5	119.7 abc	91.0 cde	96.7 b
	Yetter	88.8	107.6 cde	100.5 bcd	99.0 b
p-Value		0.1081	0.0100	0.0161	0.0001

[z] **Comparisons between means are valid only within each column. Treatment means are compared for each year using LSD procedure. Treatment means followed by the same letter are not statistically different ($p \leq 0.10$).**

ERI values in 2006 were lower compared to 2007 and 2008 growing seasons. Because the amounts of cereal rye biomass production in 2006 (combined over locations) was 5,832 kg ha^{-1}, which was the average biomass production level in Alabama (Reiter et al., 2008), the only reason for slow emergence was the inclement weather conditions after planting (i.e., insufficient soil moisture and higher temperatures). At EVS, the rainfall amount during June of 2006 was only 18 mm with an average maximum air temperature of 34° C. Similarly, at TVS, the rainfall amount was 38 mm in June with average maximum temperature of 31° C (AWIS, 2014).

In 2006, a higher ERI was observed for non-rolled and parallel rolling directions compared to significantly lower ERI for 90 and 45° treatments. With respect to row cleaners, the highest ERI was associated with Yetter compared to lower ERI for Dawn with pusher and Dawn, and the lowest for no row cleaner. In 2006, 2007, and 2008, and across 2006-2008, significantly higher ERI was observed for non-rolled residue and for parallel rolling direction compared with a lower ERI for 45° direction and the lowest ERI for 90° rolling direction. The reason for the lower ERI was the residue interference on the soil surface that was not completely cut (visual observations) and created hair pinning where residue prevented contact of seed with the soil. In 2007, the Dawn with pusher generated the higher ERI compared with Dawn, although no difference in ERI was found between these treatments and Yetter. In 2008 and across 2006-2008, the highest ERI was associated with Yetter followed by lower ERIs for Dawn and Dawn with pusher, and the lowest for no row cleaner (Table 5). Based on these results, having a row cleaner in a no-till system is essential for unhindered cotton emergence.

Combined Treatment Effect on the ERI. In each growing season there were significant interactions between rolling directions and row-cleaner treatments (p = 0.0024 in 2006, p = 0.0318 in 2007, and p = 0.0007 in 2008; the last row of Table 6). These significant interactions also were present across growing seasons and locations, as ERI was affected by rolling direction treatments and by row-cleaner treatments (p = 0.0002, the last column of Table 6). Data in each growing season and across 2006-2008 have shown that consistently lower ERI was obtained for no row-cleaner treatments for all rolling direction treatments. The ERI for non-rolled rye and parallel rolling directions with all tested row cleaners was significantly higher compared with perpendicular and diagonal rolling directions. From these results, it appears that parallel rolling direction effectively minimized hair pinning, especially when cover crop biomass is high and poor seed-soil contact resulting from residue laying across the furrow is more likely to occur with perpendicular and diagonal rolling directions. An exception was, however, in 2007 using the Dawn with pusher where perpendicular and diagonal patterns of the cotton stands were as good as with parallel rolling direction. Despite these higher ERI values in 2007, however, perpendicular and diagonal rolling directions are not recommended due to incomplete cutting of rye residue by coulters through the planting path.

Table 5. Cotton Emergence Rate Index (dimensionless) with respect to rolling direction and row-cleaner treatments during three growing seasons. Last column shows ERI across all locations and growing seasons

Treatment description		Growing season 2006	2007	2008	2006 - 2008
Rolling direction treatment	No-rolled	4.4 a[z]	9.4 a	7.5 a	7.1 a
	Parallel	4.2 a	9.9 a	8.2 a	7.4 a
	90°	2.8 b	7.8 c	4.7 c	5.1 c
	45°	3.1 b	8.7 b	6.1 b	5.9 b
	p-Value	<0.0001	<0.0001	<0.0001	<0.0001
Row-cleaner treatment	No row cleaner	2.2 d	6.0 c	5.0 c	4.4 c
	Dawn	3.7 c	9.7 b	7.0 b	6.8 b
	Dawn with pusher	4.0 b	10.3 a	6.8 b	7.0 b
	Yetter	4.6 a	9.8 ab	7.7 a	7.3 a
	p-Value	<0.0001	<0.0001	<0.0001	<0.0001

[z] Comparisons between means are valid only within each column. Treatment means are compared for each year using LSD procedure. Treatment means followed by the same letter are not statistically different ($p \leq 0.10$).

Overall, for non-rolled residue and parallel rolling with a presence of any of the tested row cleaners, the ERI was higher (7.6-8.0) compared to lower ERI for no row cleaner (5.4-6.0). For diagonal and perpendicular rolling directions with all tested row cleaners, the ERI was lower (5.4-6.9) and much lower for no row cleaner (2.6-3.8), respectively.

Examining the relationship between cotton stand and ERI, regression analysis has shown that across three growing seasons, cotton stand was highly correlated with ERI ($R^2 = 0.99$) indicating that cotton population was higher with faster emergence of plants. On the other hand, rye biomass residue (Table 7) had virtually no correlation with cotton population ($R^2 = 0.005$, Table 4) and ERI ($R^2 = 0.02$, Table 6) suggesting that amount of biomass was not the main factor affecting cotton population and ERI, but rather how the residue was managed on the field during the cotton planting operation.

Seed Cotton Yield. Cotton yield among three growing seasons was significantly different (Pr < F < 0.0001, Table 8), with the lowest yield obtained in 2006 (1,824 kg ha^{-1}), a higher yield in 2007 (2,040 kg ha^{-1}), and the highest in 2008 (3,986 kg ha^{-1}). The main reason for these differences was the different weather conditions in each year and at each location. The rainfall amounts at each location influenced cotton growth (Fig. 4, AWIS, 2014). In 2007, TVS had unusually dry weather from May to September with rainfall amount of 156 mm. During the same period, the EVS received 353 mm of rainfall. In 2008, seed cotton yield was higher compared to previous growing seasons, and most likely associated with higher rainfall amounts during the 2008 growing season. EVS received 511 mm, whereas TVS received 371 mm during May and September (AWIS, 2014).

In each growing season and across the years, rolling directions did not have any effects on seed cotton yield (p values 0.1160-0.7636, Table 8). Likewise, in 2006 and 2007, seed cotton yield was not affected by row cleaners. In contrast, in 2008 and across three growing seasons, row-cleaner treatments affected seed cotton yield. Higher cotton yield was observed for all row cleaners without differences among these treatments, compared with significantly lower cotton yield for no row-cleaner

Table 6. Cotton ERI with respect to combined effects between rolling direction and row-cleaner treatments during three growing seasons combined over locations. Last column shows ERI across all locations and growing seasons

Treatment combination		Growing Season			
Rolling Direction	**Row cleaner**	**2006**	**2007**	**2008**	**2006-2008**
Non-rolled	No row cleaner	2.7 ef[z]	7.3 f	5.6 ed	5.4 e
	Dawn	4.7 ab	9.7 bcde	8.4 a	7.6 a
	Dawn with pusher	5.1 a	10.4 abc	8.2 a	7.9 a
	Yetter	5.2 a	10.1 bcd	7.8 ab	7.7 a
Parallel	No row cleaner	3.1 de	7.4 f	7.5 ab	6.0 cd
	Dawn	4.8 a	10.4 abc	8.3 a	7.8 a
	Dawn with pusher	4.2 bc	11.2 a	8.4 a	7.9 a
	Yetter	4.8 a	10.6 ab	8.6 a	8.0 a
Perpendicular	No row cleaner	1.4 g	3.6 h	2.7 g	2.6 g
	Dawn	2.5 f	8.8 e	5.0 ef	5.4 de
	Dawn with pusher	3.2 de	9.4 cde	4.5 ef	5.7 de
	Yetter	4.2 c	9.5 cde	6.7 bcd	6.8 b
Diagonal	No row cleaner	1.7 g	5.5 g	4.1 f	3.8 f
	Dawn	3.1 de	9.9 bcd	6.4 cd	6.5 bc
	Dawn with pusher	3.5 d	10.1 abcd	6.2 d	6.6 bc
	Yetter	4.1 c	9.2 de	7.5 abc	6.9 b
Rolling direction x Row cleaner: *p*-Value		0.024	0.0318	0.0007	0.0002

[z] **Comparisons between means are valid only within each column. Treatment means are compared for each year using LSD procedure. Treatment means followed by the same letter are not statistically different ($p \leq 0.10$).**

treatment. In addition, there were significant interactions between rolling directions and row-cleaner treatments in 2008 (p=0.0176) and across the years (p=0.0237, Table 8). For non-rolled residue and parallel rolling directions, no significant differences in cotton yield were detected for all row-cleaner treatments. In contrast, for perpendicular rolling direction, cotton yield for no row cleaner was significantly lower compared to other row-cleaners. Likewise, for diagonal rolling direction, cotton yield was lower for no row cleaner but not significantly different from Yetter. Higher cotton yield for diagonal direction was for Dawn and Dawn with pusher but not different compared with Yetter. Across three growing seasons and locations, correlation coefficient between cotton population (Table 4) and cotton yield (Table 7) was R = 0.75 (R^2 = 0.56). Similar results were obtained from regression analysis between the ERI (Table 6) and yield (Table 7), where R^2 = 0.57. Data suggest that with increased cotton population and ERI, seed cotton yield was also increased to some extent. In contrast, examining the relationship between cover crop biomass and seed cotton yield (Table 7), there was weak correlation between these variables (R^2 = 0.12) indicating that amount of rye of residue generated did not have a strong effect on the seed cotton yield.

Mass of Residue Collected from Row Cleaners. There were significant differences in amounts of residue accumulated on row cleaners among years (p < 0.0001). In each growing season, significant differences in the amount of rye residue accumulated on row cleaners occurred among rolling directions and among row cleaners (Table 9). In each growing season, the highest residue accumulation was measured for non-rolled rye (116.9 kg ha^{-1}) compared to significantly lower (8% for parallel rolling directions and 0.4% for 45 and 90° patterns). Significantly higher residue accumulation on row cleaners with respect to row-cleaner treatments for each year and across three growing seasons was associated with Dawn compared to Dawn with the pusher and Yetter row cleaners. Across three growing seasons, Dawn accumulated 34% more residue compared to Dawn with pusher and 49% more compared to Yetter row cleaner. Data suggest that most accumulation on Dawn was due to rotation of row-cleaner spoked wheels on which residue wrapping occurred.

Table 7. Seed cotton yield with respect to combined effects between rolling direction and row-cleaner treatments for 2008 and across locations and years

Treatment combination		Growing Season			
Rolling Direction	Row cleaner	Cereal Rye biomass		Seed Cotton Yield	
		2008	2006-2008	2008	2006-2008
Non-rolled	No row cleaner	6499	6528	3973 ab[z]	2606 ab
	Dawn	6798	6439	4103 ab	2611 ab
	Dawn with pusher	7167	6726	4064 ab	2615 ab
	Yetter	7466	6638	3936 ab	2599 ab
0° (Parallel)	No row cleaner	7991	7069	4178 abs	2751 a
	Dawn	6848	6442	4285 a	2713 a
	Dawn with pusher	7323	6870	4196 ab	2641 ab
	Yetter	6179	6244	4260 a	2708 a
90° (Perpendicular)	No row cleaner	6617	6449	3067 c	2277 c
	Dawn	7760	7075	3918 ab	2611 ab
	Dawn with pusher	6499	6131	3791 b	2548 ab
	Yetter	7642	6758	4123 ab	2720 a
45° (Diagonal)	No row cleaner	7117	6327	3302 c	2363 bc
	Dawn	6819	6415	4059 ab	2697 a
	Dawn with pusher	7235	6644	4278 a	2770 a
	Yetter	6936	6733	4246 ab	2639 ab
p-Value		0.3755	0.1479	0.024	0.0318

[z]Comparisons between means are valid only within each column. Treatment means are compared for each year using LSD procedure. Treatment means followed by the same letter are not statistically different ($p \leq 0.10$).

For each year and across three growing seasons, there were significant interactions between rolling directions and row-cleaners treatments (Table 10). Except for 2006, in 2007, 2008, and across 2006-2008, the highest rye residue accumulation was observed for non-rolled rye and Dawn row-cleaner treatments. Overall, treatment combination of non-rolled rye and Dawn resulted in the highest residue accumulation (165.1 kg ha^{-1}) which was 31% and 57% higher compared to non-rolled rye for Dawn with pusher, and Yetter, respectively. For parallel, diagonal, and perpendicular rolling directions with all tested row cleaners, the rye residue accumulation was between 0.1% and 6% of that collected with the non-rolled and Dawn treatment combination. These results indicate that rolling the cover crop against the soil surface, regardless of rolling direction, significantly minimized residue accumulation on row cleaners compared to standing (non-rolled cover crop).

Table 8. Seed cotton yield with respect to rolling directions and row-cleaner type during three growing seasons. Last column shows seed cotton yield across all locations and growing seasons

Treatment description		Growing season			
		2006	2007	2008	2006 - 2008
Rolling direction treatment	No-rolled	1858	1946	4019	2608
	Parallel	1864	2016	4230	2703
	90°	1783	2109	3725	2539
	45°	1792	2089	3971	2617
	p-Value	0.5170	0.7636	0.1160	0.6726
Row-cleaner treatment	No row cleaner	1805	2064	3630 b[z]	2499 b[z]
	Dawn	1798	2084	4091 a	2658 a
	Dawn with pusher	1828	2022	4082 a	2644 a
	Yetter	1867	1991	4141 a	2666 a
	p-Value	0.7482	0.6351	<0.0001	0.0129
Rolling direction x Row cleaner: *p*-Value		0.3879	0.3472	0.0176	0.0237
Average cotton yield: *p*-Value		1824 C[y]	2040 B	3986 A	<0.0001

[z] Comparisons between means are valid only within each column.

[y] Comparisons between means (years) are valid only within last row. Treatment means are compared for each year using LSD procedure. Treatment means followed by the same lower-case letter are not statistically different at each column ($p \le 0.10$). Treatment means followed by the same upper-case letter are not statistically different last row.

Table 9. Mass (kg ha^{-1}) of accumulated residue on row cleaners with respect to rolling direction during three growing seasons and across all years and locations

Treatment description		Growing season			2006 -2008
		2006	2007	2008	
Rolling direction treatment	No-rolled	146.7 a[z]	61.5 a	142.5 a	116.9 a
	Parallel	20.4 b	5.0 b	2.3 b	9.2 b
	90°	1.2 b	0.4 b	0.0 b	0.5 b
	45°	1.4 b	0.0 b	0.0 b	0.5 b
	p-Value	<0.0001	<0.0001	<0.0001	<0.0001
Row-cleaner treatment	Dawn	62.2 a	29.8 a	79.7 a	43.8 a
	Dawn with pusher	43.2 b	11.1 b	15.1 b	29.0 b
	Yetter	21.9 c	9.3 b	13.8 b	22.5 b
	p-Value	0.0026	0.0079	0.0021	0.0239
Rolling direction x Row cleaner: *p*-Value		<0.0001	0.0032	<0.0001	0.0001

[z] Comparisons between means are valid only within each column. Treatment means are compared for each year using LSD procedure. Treatment means followed by the same letter are not statistically different ($p \le 0.10$).

Table 10. Residue accumulated on planter (kg ha^{-1}) with respect to combination of rolling directions and row-cleaner treatments during three growing seasons

Treatment combination		Residue on planter (kg ha^{-1})			
Rolling Direction	Row cleaner	2006	2007	2008	2006-2008
Non-rolled	Dawn	76.6 c[z]	107.0 a	311.8 a	165.1 a
	Dawn with pusher	242.8 a	44.3 b	55.3 b	114.1 b
	Yetter	120.6 b	33.4 bc	60.5 b	71.5 c
0° (Parallel)	Dawn	9.5 d	11.9 cd	7.0 b	9.4 d
	Dawn with pusher	3.6 d	0.1 d	0.0 b	1.2 d
	Yetter	48.0 c	3.0 d	0.0 b	17.0 d
45° (Diagonal)	Dawn	0.7 d	0.0 d	0.0 b	0.2 d
	Dawn with pusher	1.8 d	0.0 d	0.0 b	0.6 d
	Yetter	1.8 d	0.0 d	0.0 b	0.6 d
90° (Perpendicular)	Dawn	0.6 d	0.4 d	0.0 b	0.4 d
	Dawn with pusher	0.5 d	0.0 d	0.0 b	0.2 d
	Yetter	2.4 d	0.8 d	0.0 b	1.1 d
p-Value		<0.0001	0.0032	<0.0001	0.0001

[z] Comparisons between means are valid only within each column. Treatment means are compared for each year using LSD procedure. Treatment means followed by the same letter are not statistically different ($p \leq 0.10$).

Time Required to Clean Residue Accumulated on Row Cleaners. Across three growing seasons and locations, there were significant interactions in cleaning time between rolling directions and row-cleaners for row cleaner residue removal time ($p <$ 0.0001). The time to clean residue was collected after the 9-m long plot, the cleaning time presented here is the relative time for non-rolled compared to parallel rolling direction for all row-cleaner treatments (data not shown). Across all growing seasons and locations, diagonal and perpendicular rolling directions with all tested row-cleaners exhibited the lowest cleaning time as residue accumulation was minimal. In contrast, the longest cleaning time was measured for non-rolled residue and Dawn, followed by Dawn with residue pusher and Yetter row cleaners. For parallel rolling direction, Dawn and Yetter had a similar time to clean residue compared to 50% lower time for Dawn with residue pusher. Non-rolled rye treatment with all tested row-cleaners contributed to the longest cleaning time, with cleaning time for parallel rolling direction being substantially lower. For the parallel direction, the Dawn with residue pusher needed 12%, Dawn needed 23%, and Yetter needed 34% of the time required to clean compared to the non-rolled rye treatment showing that the residue manager helped reduce cleaning time by half compared with Dawn and Yetter row cleaners. Based on these results, non-rolled cover crop required the longest time to clean residue from row cleaners. A no-till soybean producer who uses rye cover crop stated that the accumulation of residue on row-cleaners for non-rolled residue is still an ongoing problem especially wrapping residue tightly on the axles, which become even bigger problem with the presence of interlocking weeds (R. Hinton, personal communication, 9 May 2017). The tested residue manager needs to be redesigned by integrating a front deflector to redirect the residue towards the ground and away from the planter frame instead of the V-shape frame divider to minimize extracting residue with weeds from the ground and accumulation on the frame.

SUMMARY AND CONCLUSIONS

Across all growing seasons, non-rolled rye and the parallel rolling direction treatments under all tested row cleaners generated the highest cotton stand, exceeding 110,000 plants ha^{-1}. Cotton stand for perpendicular and diagonal rolling direction using row-cleaners was lower (77,000-99,000 plants ha^{-1}), and these patterns are not the preferred choice for rolling directions of cover crops. In contrast, use of no row-cleaners generated the lowest stand for all rolling direction treatments (44,000-79,000 plants ha^{-1}), with an exception of parallel rolling (91,000 plants ha^{-1}). Cotton stand was highly correlated with the ERI, as the fastest emergence was observed with the parallel rolling direction and with no-rolled rye, whereas the slowest emergence was observed with perpendicular and diagonal directions during all seasons and locations. Best combination for high ERI was non-rolled and the parallel rolling direction with all tested row cleaners. In contrast, an absence of row cleaner generated the lowest ERI, indicating that in conservation systems using cover crops, row cleaners are essential for optimum cotton emergence and stand. Seed cotton yield was different in each growing season and location. Significant changes in yield were dependent on different weather conditions at each location in the different growing seasons but row-cleaner treatments also had some effect. Across all growing seasons and locations, the largest mass of residue accumulation on row cleaners was reported for non-rolled rye residue and Dawn row cleaner compared to other rolling directions and row-cleaners, requiring extra time to clean row cleaners. The longest time required to clean residue accumulated on row cleaners was associated with non-rolled rye compared to other rolling patterns. Cleaning time was higher for Dawn as rye residue was wrapped around axles on the row cleaner. Based on the results in this study, the following recommendations of rolling direction and row cleaner are: (1) When rye produces large amounts of residue, the parallel rolling direction and commercial row cleaners such as Dawn or Yetter are recommended for optimum cotton establishment; (2) When rye is not rolled down, row cleaners are required, especially with custom designed spring-loaded pushers which press residue against the soil surface, so cotton can be planted into standing rye without interfering with rye residue while planting; (3) Regardless of height and the amount of residue produced by rye, perpendicular and diagonal rolling directions are not recommended even when row cleaners are used; (4) Utilizing row cleaners in high residue systems is essential, as conventional planters without row cleaners might negatively affect cotton population and yield; and (5) The parallel rolling direction minimized both accumulation of residue on row cleaners and the cleaning time required to clean residue from row cleaners.

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DISCLAIMER

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

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