EFFECTS OF A CUSTOM COVER CROP RESIDUE MANAGER IN A NO-TILL COTTON SYSTEM

T. S. Kornecki, S. A. Prior, H. A. Torbert

ABSTRACT. *Cover crops are an important part of no-till conservation agriculture, and these crops must produce optimum biomass amounts to effectively protect the soil surface from erosion and runoff, conserve soil water, and provide a physical barrier against weeds. Because of the large amount of residue produced by cover crops, the residue must be managed appropriately to minimize planting problems for producers. A study was conducted at the E.V. Smith Research and Extension Center (EVS) in central Alabama to determine the effects of commercially available DAWN® row cleaners and different experimental residue managers on cotton (*Gossypium hirsutum *L.) stand, emergence rate, and seed cotton yield. Experimental residue managers consisted of two different ski-like devices (jointed and rigid) to press down the residue on each side of the planting path. Each type of pressing device was equipped with a V-shape divider or two different residue pushers to divide or to push down the residue. A randomized complete block design with four replications was used and results represent three growing seasons (2012, 2013, and 2014). Rye (*Secale cereale *L.) was the selected cover crop since it is popular among Alabama producers. Standing rye (without rolling down) was chosen to study treatment effects of the different residue managers. Rye was chemically terminated using Roundup (glyphosate), and after complete rye desiccation, cotton was planted directly into standing rye residue cover. During cotton planting, cover crop residue accumulation on the no till planter and the time required to clean residue from planting units were measured. In three growing seasons, treatments did not affect cotton yield: however, differing weather and residue amounts did affect cotton yield. Cotton population was affected by residue manager treatments in 2012, but not in 2013 or 2014. Significant population differences were observed between the three growing seasons, and cotton stand was significantly lower in 2013 due to large amounts of cover crop residue. The highest cotton population was observed in 2014 due to optimum soil moisture. In three growing seasons, residue management treatments affected residue amounts on planting units. The highest residue accumulation was observed with the V-type divider where rye was pulled because of winding weeds (hairy vetch) interlocking with stalks. The second largest residue accumulation was observed with the standard DAWN® row cleaners with coulters; this was due to rye residue wrapping around the rotating row cleaning wheels which required significantly more time for cleaning compared to the other residue managers. Compared to the commercially available standard DAWN® row cleaner, the custom residue managers performed successfully, especially in standing cover crops that had not lodged in different directions.*

Keywords. *Conservation system, Cotton population, Row cleaner, Rye cover crop, Seed cotton.*

Utilization of cover crops in no-till systems has steadily increased, and effective management of cover crop residue is necessary to successfully and efficiently plant cash crops into residue without seeding skips or residue accumulation on planting units. Because planting cash crops into residue cover is the most important operation in conservation systems, it must provide the best possible soil environment for optimum seed germination, emergence, and growth. Winter cover crops are an integral part of conservation tillage systems. Major benefits of cover crops include weed suppression (allelopathy and mulch effect), 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 (McGregor and Mutchler, 1992; Kern and Johnson, 1993; Reeves, 1994; Raper et al., 2000a; Raper et al., 2000b, Kasper et al., 2001; Dinnes et al., 2002; Ashford and Reeves, 2003; Snapp et al., 2005).

Cereal rye is a commonly used winter cover crop in the Southeastern United States. To maximize benefits, rye must be terminated at the appropriate growth stage but in time for planting the cash crop. According to Ashford and Reeves (2003), an appropriate growth stage for rye termination that provides optimum levels of rye biomass is the soft dough stage. Most agricultural extension services recommend terminating the cover crop at least two weeks prior to planting the cash crop to prevent competition for valuable soil moisture and nutrients (Hargrove and Frye, 1987).

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The authors are **Ted S. Kornecki, ASABE Member,** Agricultural Engineer, **Stephen A. Prior,** Plant Physiologist, and **H. Allen Torbert,** Soil Scientist, USDA-ARS, National Soil Dynamics Laboratory, Auburn, Alabama. **Corresponding author:** Ted S. Kornecki, 411 South Donahue Drive, Auburn, AL 36832; phone: 334-887-8596; e-mail: ted.kornecki@ars.usda.gov.

Large amounts of cover crop residue can create problems with any spring tillage practice that must be conducted prior to planting operations. Thus, cover crops must be managed appropriately to prevent planting problems. The most common problem is "hair-pinning," where residue is pushed into the soil rather than being cleanly sheared. "Hair-pinning" creates a condition where the seeds lack good seed-soil contact, resulting in skips that negatively impact crop emergence and populations. Another major problem is the accumulation of cover crop residue on planting units, which can lead to frequent stops for equipment cleaning that increases overall operation time.

There are several commercially available row cleaners, however, these row cleaners do not perform satisfactorily when planting into standing cover crops. With rotating cleaning wheels, residue wrapping will likely occur, especially when cover crops are lodged in different directions. This is a common problem in the Southeast where cereal rye is a widely used cover crop. A custom-made residue manager that attaches to planting units was developed to press the residue against the soil surface to allow more effective residue cutting and less wrapping (compared to the commercial DAWN® row cleaners manufactured by DAWN®, Sycamore, Ill.).

In no-till planting, use of commercially available row cleaners and coulters to manage cover crop residues is mostly associated with cover crops that have been flattened using roller/crimper technology (Derpsch et al., 1991). However, when cover crop residue amounts are low, no-till planting might be successfully accomplished using a different cover crop management technology. Kornecki et al. (2014) developed a residue manager as an alternative method that is capable of managing both rolled and unrolled (standing) cover crops of different densities and heights. This device could be utilized by producers who are using cover crops but do not have available rollers/crimpers.

The current research utilized custom devices to manage a standing rye cover crop (without rolling) in a Southeast no-till cotton system. The objective of this study was to evaluate the effects of residue managers on cotton emergence and yield, residue amounts accumulated on the planter during planting, and time required to clean planting units.

Materials and Methods

A replicated field experiment was initiated in 2012 in central Alabama (E.V. Smith Research Station) to evaluate the performance of custom-made residue managers for use in standing rye (without rolling/crimping) during cotton planting. The experiment was a randomized complete block design with four replications (fig. 1). Cereal rye cover crops (Wrens Abruzzi variety) were planted 4 November 2011 (2012 growing season), 23 October 2012 (2013 growing season), and 8 November 2013 (2014 growing season). The day before terminating the rye cover crop,

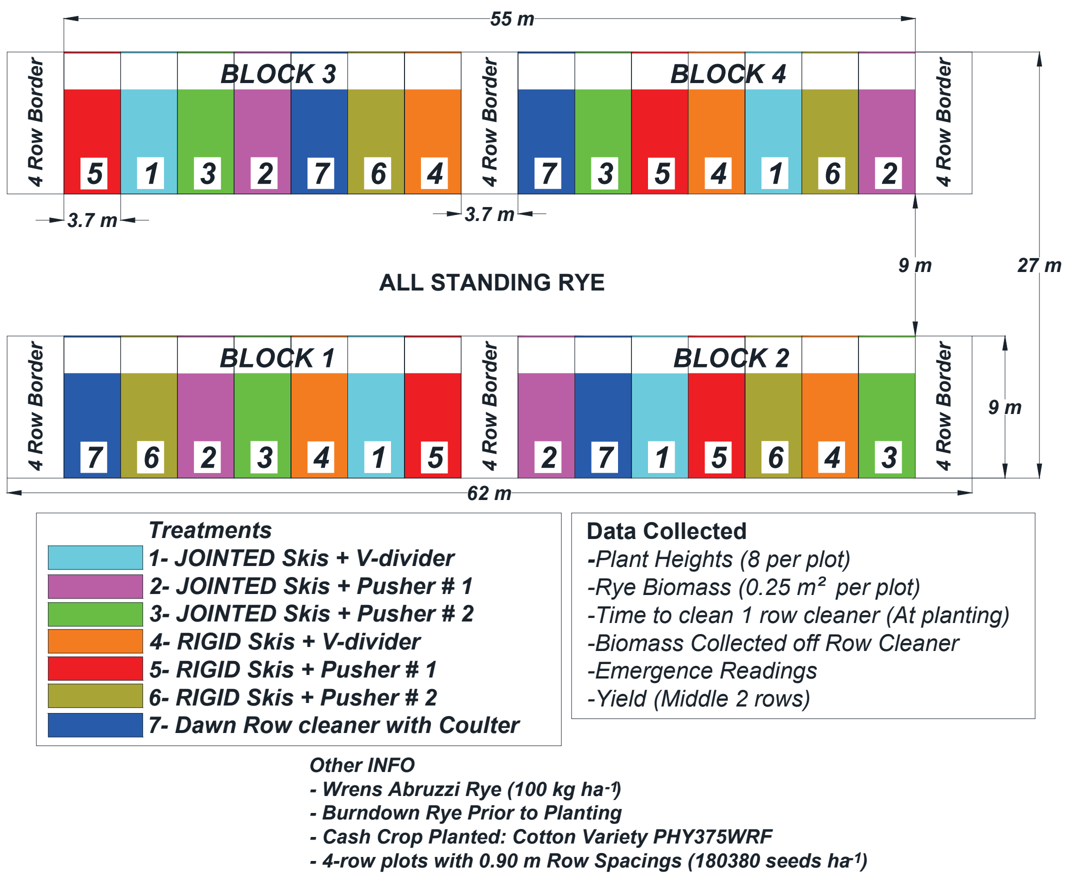

Figure 1. Experimental layout: Randomized complete block design with four (blocks) replications.

biomass (sample from 0.25 m^2 per each plot) and plant height (8 readings perplot) were assessed. The cereal rye was terminated chemically with glyphosate (1.75 L ha^{-1}) and ignite (Glufosinate; 1.75 L ha^{-1}) on 3 April 2012, 23 April 2013, and 24 April 2014 at the early milk growth stage, approximately three weeks before cotton planting. Cotton was planted on 25 April 2012, 8 May 2013, and 20 May 2014 utilizing a John Deere Vacuum no-till drill (MaxEmerge 1700, Moline, Ill.) pulled by a John Deere 6410 77 KW four-wheel drive tractor (operating at 4.8 km h^{-1}). During planting operations, residue mass that accumulated on row cleaners and cleaning time for rye residue removal were recorded for each treatment. After visible seedling emergence, cotton stand was evaluated twice per week (4 counts per each plot along a 1.52 m row length) until no changes in stand were detected. Cotton population in each plot was calculated using number of plants at 6.08 m distance and the row spacing. To compare plant emergence rates for a particular treatment, an emergence rate index (ERI) was calculated using the procedure described by Erbach (1982). The ERI is a dimensionless entity that evaluates how fast cotton seeds are emerging after the first sign of their emergence. Higher ERI values represent faster cotton emergence while lower values indicate slower emergence. Cotton was harvested 10 October 2012, 5 November 2013, and 9 October 2014. Seed cotton yield was measured (collected and weighted) while harvesting cotton using a 2-row John Deere cotton picker.

Data for rye height and biomass, cotton stand, cotton ERI, cotton yield, residue amounts accumulated on planting units, and time required to clean residue from planting were subjected to analysis of variance. Treatment means were separated using the ANOVA GLM procedure, and Fisher's protected Least Significant Differences (LSD) test at the 10% probability level (SAS, 2009). Data from the 2012, 2013, and 2014 growing seasons are presented.

In both growing seasons, the following rolling/planting treatments were applied at 4.8 km h^{-1} operating speed:

- Treatment #1 – Residue manager with jointed skis and V-shape divider (figs. 2a and 3a)
- Treatment #2 – Residue manager with jointed skis and pusher type 1 (figs. 2a and 3b)
- Treatment #3 – Residue manager with jointed skis and pusher type 2 (figs. 2a and 3c)

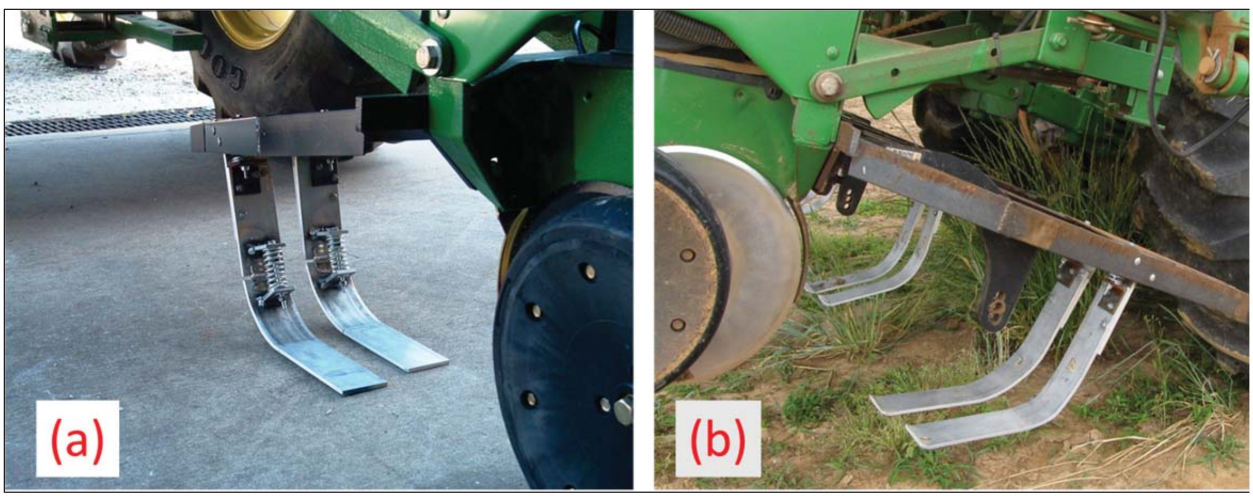

Figure 2. Custom made prototype residue managers: (a) Jointed skis preloaded by sets of springs at the joint line to maintain downward pressure against residue on the soil surface and spaced to accommodate a coulter, (b). Rigid double pressing ski with spacing for a coulter.

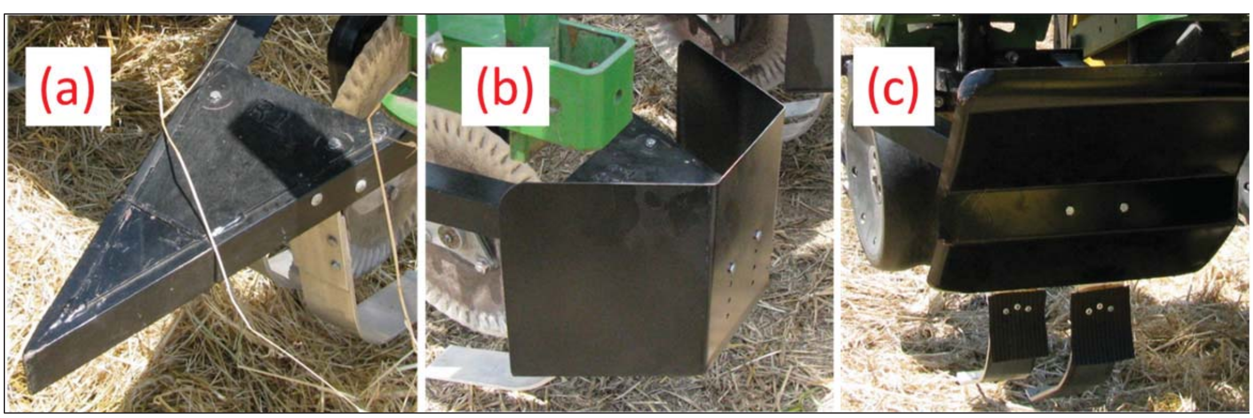

Figure 3. Custom made prototype of cover crop splitters (dividers) and guards (pushers): (a) V-shape divider, (b) Solid shield type pusher (pusher #1), (c) Bulldozer type pusher (pusher #2). These three types are mounted on a frame that accommodates both rigid and jointed residue pressing skis.

- Treatment #4 – Residue manager with rigid skis and V-shape divider (figs. 2b and 3a)
- Treatment #5 – Residue manager with rigid skis and pusher type 1 (figs. 2b and 3b)
- Treatment #6 – Residue manager with rigid skis and pusher type 2 (figs. 2b and 3c)
- Treatment #7 – Standard DAWN® row cleaner and coulter (fig. 4)

Treatments #1 to #6 are custom developed prototypes of two residue managers [jointed (fig. 2a) and rigid (fig. 2b) skis] with different cover crop pushers, dividers (fig. 3) for deflecting, and for dividing (splitting) standing cover crops in the center of planting path. To accommodate a standard coulter for cutting residue on the soil surface, both skis were spaced 6 cm apart. The rigid skis are preloaded at pivot points with torsion springs to push the residue down against the soil surface. The jointed skis are also preloaded by torsion springs at pivot points, but they have an additional pivot point (at the bend, fig. 2a) with a compression spring that causes the ski to always lay flat against the soil surface. A full description of the residue manager system is described by Kornecki et al. (2014). These devices were developed and fabricated at the USDA-ARS, National Soil Dynamics Laboratory in Auburn, Alabama. Treatment #7 is a row-cleaner and is used in the southeastern United States as a standard row cleaner setup (fig. 4).

RESULTS

Statistical analysis showed that significant differences in rye biomass, cotton yield, cotton stand, ERI, residue accumulated on planting units, and time required to clean residue from planting units were significant in all study years. Across all growing seasons, treatments had a significant effect on residue amounts accumulated on planting units and time required to clean planting units (P-value < 0.0001).

CEREAL RYE COVER CROP PRODUCTION

There were significant differences in rye cover crop height and biomass production among the three growing seasons (P < 0.0001). In 2012, the average rye height reached 172 cm which was lower than in 2013 (179 cm) and 2014 (182 cm). Cereal rye generated 7854 kg ha^{-1} of biomass (dry basis) in 2012 compared to significantly higher biomass produced in 2013 (10601 kg ha^{-1}) and 2014 (8333 kg ha^{-1}).

COTTON EMERGENCE RATE INDEX (ERI)

There was a significant difference in cotton ERI among the 2012, 2013, and 2014 growing seasons (P-value < 0.0001, table 1). Averaged across residue management treatments, ERI values were 5.2, 1.9, and 10.8 for 2012, 2013, and 2014, respectively. During the 28 day cotton

Figure 4. Commercially available DAWN® row cleaner with fluted coulter and spoked row cleaning wheels behind the coulter.

Table 1. Cotton Emergence Rate Index (ERI) in 2012, 2013, and 2014 growing seasons.

Treatment Number	Treatment	Growing Season[a] 2012	2013	2014
Treatment #1	Residue manager with jointed skis and V-shape divider	5.0bc	2.1	11.4
Treatment #2	Residue manager with jointed skis and type 1 pusher	4.5c	3.3	10.1
Treatment #3	Residue manager with jointed skis and type 2 pusher	5.3ab	1.2	10.5
Treatment #4	Residue manager with rigid skis and V-shape divider	5.2b	2.6	10.7
Treatment #5	Residue manager with rigid skis and type 1 pusher	5.2b	1.1	10.3
Treatment #6	Residue manager with rigid skis and type 2 pusher	5.0bc	1.7	10.9
Treatment #7	Standard DAWN® row cleaner and coulter	5.9a	1.4	11.5
Average	ERI value averaged across treatments (P-value <0.0001, LSD = 0.40) for year comparison.	5.2 B	1.9 C	10.8 A
Statistics for each year	P-value	0.0632	0.1496	0.2275

[a] Different lower case letters signify significant differences among residue manager treatments within each growing season. Different upper case letters in the same row indicate significant differences among three growing seasons.

stand counting period in 2012, there were 7 rainfall events (total of 176 mm of rainfall) that could have slowed plant emergence due to excess soil moisture. For the 2013 growing season, the very low ERI appears to be associated with an unusually large amount of rye residue on the soil surface (>10 tones ha^{-1}) that inhibited and delayed cotton emergence. This was coupled with "hair pinning" conditions from lodged residue that is commonly associated with large cover crop biomass production. In addition, there was only 11 mm of rainfall during the first 26 days of emergence counts, and lack of adequate soil moisture from rainfall likely delayed cotton emergence.

The high ERI (averaged across treatments) recorded in 2014 was most likely associated with adequate soil moisture from three rainfall events (85 mm total rainfall) that occurred one week before planting cotton. Furthermore, there were 14 rainfall events (beginning within a week after planting) during a 34 day period (total of 124 mm of rainfall) that provided optimum soil moisture during the stand count period. Residue management treatments influenced ERI in 2012 (P-value =0.0632; table 1) but not in 2013 (P-value = 0.1496) or 2014 (P-value = 0.22750). In 2012, the high ERI associated with the DAWN® treatment (ERI= 5.9) was not significantly different from treatment 3 (residue manager with jointed skis and pusher type 2; ERI=5.3). No significant differences in ERI were observed among residue managers with rigid skis equipped with the V-divider, pusher type 1, or type 2 (ERI values between 5.2 and 5.0). The lowest ERI (4.5) was observed with the residue manager equipped with jointed skis and pusher type 1. A study conducted by Kornecki et al. (2009) with various row cleaners for rolled rye residue found average ERI values that were higher than those of this study in 2012 and 2013 for standing rye. It is important to note that the faster emergence reported in that study was also associated with residue amounts that were between 21 to 45% lower than those reported in the current study.

COTTON POPULATION

Average cotton population in 2012 was 94190 plants ha^{-1} compared to a lower cotton population of 42921 plants ha^{-1} in 2013, and the highest population of 139090 plants ha^{-1} in 2014. Compared to 2012, the cotton population in 2013 was significantly reduced (45%) most likely due to large amounts of rye residue on the soil surface (35% higher in 2013). The cotton stand reduction was most likely associated with large amounts of lodged rye residue (creating hair pinning conditions) that did not allow cotton seeds to have adequate soil contact needed for successful emergence and growth. Residue manager treatments influenced cotton populations in 2012 (P=0.0409) but not in 2013 (P-value =0.1519) or 2014 (P-value =0.2558). In 2012, the high cotton stand for the DAWN® row cleaner was not significantly different from the jointed design with pusher type 2 and the rigid design with pusher type 1. In 2013, the trend was for pusher type 1 with jointed skis to have a numerically higher cotton population (71309 plants ha^{-1}) while the pusher type 2 and jointed skis had the lowest (25115 plants ha^{-1}). Examining the cotton emergence data in 2013, there was substantial variability within replications for a particular treatment. The coefficient of variation was unusually large (60%), diminishing detection of differences among treatments. This large variability was associated with flooding of several experimental plots after emergence which caused a rapid decrease in plant number in flooded plots (i.e., one order of magnitude lower than the non-flooded plots). In 2013, rainfall was 180 and 164 mm in June and July, respectively. In 2014, rainfall was 107 mm in June and 89 mm in July.

In 2014, higher cotton population was most likely associated with less lodged rye residue and an optimum soil moisture before and after planting. Four days before planting cotton, the site received three rainfall events with total of 97 mm of rain, and one week after planting there were eight rainfall events with total rain of 98 mm. Cotton population ranged from 130,000 (treatment #2) to 147,000 (treatment #1) plants ha^{-1} (table 2).

COTTON YIELD

Seed cotton yields for treatments in the three growing seasons are shown in table 3. The seed cotton yield averaged over residue management treatments was 4003 kg ha^{-1} in 2012, which was significantly higher than 2013 (2260 kg ha^{-1}) and 2014 (3637 kg ha^{-1}; P <0.0001). The main reason for the significant yield reduction in 2013 was most likely due to the large amount of rye residue on the soil surface (35% more biomass generated than in 2012, and 27% more biomass generated than in 2014). This large amount of rye residue likely prevented good seed to soil contact. In all growing seasons, the individual residue management treatments did not significantly affect seed

Table 2. Cotton population in 2012, 2013, and 2014 growing seasons (plants ha^{-1}).

Treatment Number	Treatment	Growing Season[a] 2012	2013	2014
Treatment #1	Residue manager with jointed skis and V-shape divider	91099bc	47614	147066
Treatment #2	Residue manager with jointed skis and type 1 pusher	83194c	71309	130098
Treatment #3	Residue manager with jointed skis and type 2 pusher	98162ab	25115	134882
Treatment #4	Residue manager with rigid skis and V-shape divider	94799b	60321	139853
Treatment #5	Residue manager with rigid skis and type 1 pusher	96705ab	27993	134359
Treatment #6	Residue manager with rigid skis and type 2 pusher	90370bc	35430	141871
Treatment #7	Standard DAWN® row cleaner and coulter	105002a	32665	145496
Average	Cotton population averaged across treatments (P-value <0.0001, LSD = 7508 plants ha^{-1}) for year comparison.	94190 B	42921 C	139090 A
Statistics for each year	P-value	0.0409	0.1519	0.2558

[a] Different lower case letters signify significant differences among residue manager treatments within each growing season. Different upper case letters in the same row indicate significant differences among each growing season.

Table 3. Seed cotton yield in 2012, 2013, and 2014 growing seasons (kg ha^{-1}).

Treatment Number	Treatment	Growing Season		
		2012	2013	2014
Treatment #1	Residue manager with jointed skis and V-shape divider	3908	2058	3557
Treatment #2	Residue manager with jointed skis and type 1 pusher	4230	3197	3563
Treatment #3	Residue manager with jointed skis and type 2 pusher	3835	1898	3689
Treatment #4	Residue manager with rigid skis and V-shape divider	3826	2170	3747
Treatment #5	Residue manager with rigid skis and type 1 pusher	3853	1837	3669
Treatment #6	Residue manager with rigid skis and type 2 pusher	4184	2132	3679
Treatment #7	Standard DAWN® row cleaner and coulter	4184	2529	3553
Average	Seed cotton yield averaged across treatemnts (P-value <0.0001, LSD 242 kg ha^{-1}) for year comparison.	4003 A[a]	2260 C	3637 B
Statistics for each year	P-value	0.6963	0.2611	0.8133

[a] Different upper case letters in the same row indicate significant differences among each growing season.

cotton yield. However for 2013, treatment #2 (residue manager with jointed skis and type 1 pusher) generated a numerically higher seed cotton yield (3197 kg ha^{-1}) compared to other treatments where yields ranged between 1837 kg ha^{-1} and 2529 kg ha^{-1}. In 2014, cotton yield (3637 kg ha-1) did not correspond with plant population which was the highest of all growing seasons. Cotton plant population is not always proportionally related to yield. Many factors may arise during a growing season that could negatively impact yield. The main reason for the lower 2014 yield (vs. 2012) may be water deficiency and higher temperatures that negatively impacted cotton flowering and boll development (60 to 80 days after planting, Ritchie et al., 2004). Examining the weather (July, August, September, and October), 2014 had the highest average temperature of 30.4 °C and lowest rainfall of 227 mm compared to 29.7 °C with 308 mm of rainfall in 2012 and 28.7 °C with 352 mm of rainfall in 2013 (AWIS, 2014).

Residue Accumulation on Planting Units

There were significant differences among the three growing seasons for the amount of residue accumulated on planting units (P-value = 0.0084). Rye residue accumulation amounts (averaged over treatments) were 20.37, 20.54, and 59.04 kg ha^{-1} for 2012, 2013, and 2014, respectively (table 4). Across all growing seasons, residue manager treatments significantly affected the amount of residue on planting units (P-value <0.0001, LSD=35.3 kg ha^{-1}). The highest residue accumulation was treatment #4 (residue manager with rigid skis and V-shape divider; 104.94 kg ha^{-1}) followed by treatment #1 with 93.07 kg ha^{-1} of residue accumulation (residue manager with jointed skis and V-shape divider), but these were not statistically different from each other across all three growing seasons (table 4). The main reason for this high residue accumulation was the presence of winding weeds. However, the presence of weeds was higher (based on visual observation) in 2014 compared to the 2012 and 2013 growing seasons, The high residue accumulation on the planter in 2014 was caused by self-seeded hairy vetch that had climbed and interlocked with lodged rye residue in different directions. Lodged rye (instead of standing) allowed for weeds to climb easily on the rye residue. Because of this interlocking effect intensified with the lodged rye residue, the V-shaped divider was unable to push between individual rye stalks; the results were that both weeds and rye were pulled out of the ground and accumulated on planting units. The third highest rye residue accumulation (31.07 kg ha^{-1}) on planting units was generated by treatment #7 (standard DAWN® row cleaner and coulter). This accumulation was related to residue wrapping around the rotating row cleaners. Examination of rye residue accumulation in each growing season (table 4) showed that the highest rye residue accumulation in 2012 was for the jointed skis with V-shape divider (42.50 kg ha^{-1}) and for the rigid skis with V-shape divider (72.36 kg ha^{-1}).

This high accumulation was due to actively growing weeds interlocked with standing rye that caused stalks and weeds to be pulled out of the soil. The third highest residue accumulation was found with the standard DAWN® row cleaner. Similar residue accumulation trends were observed in 2013. The highest residue accumulation was for the V-shape divider (jointed skis = 68.00 kg ha^{-1}; rigid skis = 43.13 kg ha^{-1}). In this same year, the third highest amount of rye residue accumulated (29.68 kg ha^{-1}) was observed

Table 4. Rye cover crop residue amount accumulated on the residue manager frame, and planting units (kg ha^{-1}).

Treatment Number	Treatment	Growing Season[a]			
		2012	2013	2014	3 Yr Average
Treatment #1	Residue manager with jointed skis and V-shape divider	42.50 ab	68.00 a	168.72 a	93.07 a
Treatment #2	Residue manager with jointed skis and type 1 pusher	1.17 c	0.00 c	2.57 b	1.25 b
Treatment #3	Residue manager with jointed skis and type 2 pusher	0.84 c	0.72 c	0.00 b	0.52 b
Treatment #4	Residue manager with rigid skis and V-shape divider	72.36 a	43.13 ab	199.33 a	104.94 a
Treatment #5	Residue manager with rigid skis and type 1 pusher	2.96 c	1.94 c	1.29 b	2.06 b
Treatment #6	Residue manager with rigid skis and type 2 pusher	0.00 c	0.30 c	0.63 b	0.31 b
Treatment #7	Standard DAWN® row cleaner and coulter	22.78 bc	29.68 bc	40.77 b	31.07 b
Average	Rye residue accumulated on planter averaged across treatemnts (P-value =0.0084, LSD 23 kg ha^{-1}) for year comparison.	20.37 B	20.54 B	59.04 A	N/A
Statistics for each year	P-value	0.0033	0.0042	0.0053	<0.0001
	LSD at α = 0.1	30.365	30.29	99.5	35.34

[a] Different lower case letters signify significant differences among residue manager treatments within each growing season. Different upper case letters in the same row indicate significant differences among each growing season.

with the standard DAWN® row cleaners. In both growing seasons, jointed and rigid residue managers with pusher types 1 and 2 did not collect significant amounts of rye residue (from 0.00 to 1.94 kg ha^{-1}). Similar to the first two growing seasons, the highest rye residue accumulation in 2014 was associated with treatments #4 (199.33 kg ha^{-1}) and #1 (168.7 kg ha^{-1}), but accumulated amounts were higher than those observed in 2012 and 2013. For treatment #7, the amount of residue accumulated was also higher (40.77 kg ha^{-1}) compared to 2012 and 2013. The main reason for increased amounts in 2014 was a larger weed infestation which caused more planting problems in standing rye versus rolled rye. Across all growing seasons, rigid or jointed skis equipped with pusher types 1 and 2 (treatments #2, #3, #5, and #6) consistently exhibited lower residue accumulation on planting units (from 0.31 to 2.06 kg ha^{-1}); this was an order of magnitude lower compared to treatments #1, #4, and #7. These findings suggest that rigid or jointed skis equipped with pusher types 1 and 2 are the preferred residue managers for planting into standing rye.

Time Required to Clean Residue from Planting Units

Significant differences existed among the three growing seasons with respect to time required to clean residue from planting units (P-value = 0.0699). The times (averaged over treatments) were 1.13, 1.94, and 1.48 h ha^{-1} for 2012, 2013, and 2014, respectively (table 5). Similarly, across all growing seasons, residue manager treatments affected the time required to clean residue accumulation from plant units (P-value < 0.0001, LSD = 0.88 h ha^{-1}). Across all growing seasons, treatment #7 (Standard DAWN® row cleaner and coulter) required significantly more time (5.5 h ha^{-1}, table 5) for cleaning planting units, followed by 2.4 h ha^{-1} for treatment #1 (residue manager with jointed skis and V-shape divider) and 1.7 h ha^{-1} for treatment #4 (residue manager with rigid skis and V-shape divider). The main reason for the higher time required for the DAWN row cleaners was that rye residue wrapped around the rotating spoked cleaning wheels close to the axle, and tightly accumulated on cleaning wheels. Because of this tight wrapping, more time was required for residue removal. In contrast, both jointed and rigid skis with pusher types 1 and 2 (treatments #2, #3, #5, and #6) exhibited significantly lower cleaning times (0.1 to 0.4 h ha^{-1}) due to minimal wrapping problems.

Examination of individual growing seasons showed that the highest cleaning time in 2012 was associated with the standard DAWN® row cleaner (treatment #7; 3.5 h ha^{-1}) followed by treatment #4 (1.8 h ha^{-1}) and treatment #1 (1.0 h ha^{-1}). Jointed and rigid skis with pusher types 1 and 2 (treatment #2, #3, #5, and #6) required significantly less cleaning time (from 0.00 to 0.71 h ha^{-1}) than the standard DAWN® row cleaner and rigid skis with V-shape divider (treatment #4). In 2013, the higher cleaning time of 6.10 h ha^{-1} for the standard DAWN® row cleaner (treatment #7) was associated with greater amounts of rye residue compared to 2012. In addition, there was no significant difference in cleaning time between the standard DAWN® row cleaner (treatment #7) and the residue manager with jointed skis and V-shape divider (treatment #1). Similar to 2012, the time required to clean residue from pusher types 1 and 2 was significantly lower (0.00 to 0.45 h ha^{-1}) than treatments #1, #4 and #7. Cleaning times for the 2014 growing season were similar to 2013. Time required to clean the standard DAWN® row cleaner was 6.78 h ha^{-1} which was significantly longer than other treatments. No difference in cleaning time was observed between jointed and rigid skis with V-shape dividers (treatment #1 = 1.82 h ha^{-1}; treatment #4 =0.91 h ha^{-1}) and treatment #2 (0.5 h ha^{-1}). As observed in the two previous growing seasons, treatments #3, #5 and #6 (jointed and rigid skis with pusher types 1 and 2) required significantly less time to clean (0.00 to 0.23 h ha^{-1}).

Summary

From field testing during three growing seasons, residue manager treatments did not significantly affect seed cotton yield; however, different weather conditions (i.e., rainfall amounts) and amounts of residue did affect yield. Cotton population was affected by residue manager treatments in 2012, but not in the 2013 and 2014 growing seasons, however, significant differences in cotton populations were observed among the three growing seasons. The cotton population was significantly lower in 2013 due to the large amount of cover crop residue, while the higher population observed in 2014 was due to optimum soil moisture before and after cotton planting. In three growing seasons, the

Table 5. Time required to clean planting units and residue manager frame (h ha^{-1}).

Treatment	Growing Season[a]			
	2012	2013	2014	3 yr Average
Residue manager with jointed skis and V-shape divider	1.00 c	4.34 ab	1.82 b	2.39 b
Residue manager with jointed skis and type 1 pusher	0.71 cd	0.00 d	0.48 bc	0.40 c
Residue manager with jointed skis and type 2 pusher	0.46 cd	0.08 d	0.00 c	0.18 c
Residue manager with rigid skis and V-shape divider	1.80 b	2.51 bc	0.91 bc	1.74 b
Residue manager with rigid skis type 1 pusher	0.39 cd	0.45 cd	0.23 c	0.36 c
Residue manager with rigid skis type 2 pusher	0.00 d	0.13 d	0.16 c	0.09 c
Standard DAWN® row cleaner and coulter	3.50 a	6.10 a	6.78 a	5.46 a
Time required to clean planting units from rye residue averaged across treatemnts (P-value = 0.0699, LSD =0.57 h ha-1) for year comparison.	1.13 B	1.94 A	1.48 AB	N/A
P-value	<0.0001	0.0004	<0.0001	<0.0001
LSD at α = 0.1	0.75	2.1808	1.4016	0.88

[a] Different lower case letters signify significant differences among residue manager treatments within each growing season. Different upper case letters in the same row indicate significant differences among each growing season.

residue management treatments affected the amount of residue on planting units. Consistently higher residue accumulation was observed with the jointed and rigid skis with V-type divider due to winding weeds (hairy vetch) interlocking with standing rye, causing these residue managers to pull plants out of the soil. The second largest residue accumulation was observed with the standard DAWN® row cleaners where rotating row cleaning wheels caused rye wrapping and significantly increased cleaning time. Findings indicate that some of the custom residue managers performed as well or better than the commercially available DAWN® row cleaners. In three growing seasons, residue managers (both ski types) with pusher types 1 and 2 performed the best since these devices accumulated only minimal rye residue biomass and required the least cleaning time.

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