EFFECTS OF DIFFERENT RESIDUE MANAGEMENT METHODS ON COTTON ESTABLISHMENT AND YIELD IN A NO-TILL SYSTEM

T. S. Kornecki, F. J. Arriaga, A. J. Price, K. S. Balkcom

ABSTRACT. *A field experiment was conducted in 2007, 2008, and 2009 in central Alabama to evaluate the effects of cover crop mechanical termination, strip tillage width, and row cleaners attached either to the tillage implement or planting units, on cotton population and yield. Treatments included roller (present or absent), in-row subsoiler (wide and narrow strips), and row-cleaners attached either to subsoiler, planter, or both. Rye was terminated with glyphosate (both rolled and non-rolled rye) in mid-April, and tillage treatments were applied; cotton was planted three weeks after tillage. In 2007, generally higher cotton stands were associated with rolled rye residue (137,134 plants/ha) vs. non-rolled rye (115,641 plants/ha). On average, significantly higher cotton seed yield was found for rolled rye (4,540 kg/ha compared to non-rolled rye (4,332 kg/ha). Examining specific treatments, the highest cotton seed yield (4,933 kg/ha) was associated with rolled rye under narrow strip tillage with row cleaners attached to both subsoiler and planter. The lowest cotton yield (3,913 kg/ha) was associated with non-rolled residue, under narrow strip tillage with row cleaners present on both subsoiler and planter. In 2008, no difference was found in cotton stand for rolled (108,375 plants/ha) and non-rolled rye (107,719 plants/ha). Cotton seed yield was higher in 2008 than in 2007 due to a severe drought in Alabama during 2007. In 2008, slightly higher cotton yield was reported for non-rolled rye (5,658 kg/ha) vs. rolled rye (5,419 kg/ha). The non-rolled rye, narrow strip subsoiling, and row cleaners on subsoiler generated the highest cotton yield (5,812 kg/ha) compared with the lowest (5,171 kg/ha) by rolled rye, narrow strip, and row cleaners on the planter. In 2009, cotton stand for rolled rye was higher (115,036 plants/ha) compared to non-rolled rye residue (65,894 plants/ha). In 2009, the cotton yield was substantially reduced by flooding of the experimental area. Because of the excess water, the cotton yield was lower (2,672 kg/ha) compared to 2007 and 2008 growing seasons. Soil strength measurements taken in fall 2009 showed significantly lower cone index values with rolled vs. non-rolled rye from 0 to 15-cm depth, with trends reversed after 20 cm. Cone index values at all depths, however, were below the 2-MPa threshold that indicates restrictive conditions for root growth. In all three growing seasons, the width of the tillage strip and the location of row cleaners (planter/subsoiler) did not affect cotton stand and seed cotton yield.*

Keywords. *Conservation agriculture, Cover crops, Roller/crimper, Row cleaners, Subsoiling.*

Conservation agriculture systems that include cover crops producing high amounts of biomass provide many benefits, such as improving soil properties, increasing soil organic carbon, decreasing detrimental soil erosion by providing a residue barrier against rainfall energy, providing a physical barrier for weed suppression, reducing runoff, increasing infiltration, and lessening the impact of soil compaction (McGregor and Mutchler, 1992; Kern and Johnson, 1993; Reeves, 1994; Raper et al., 2000; Kasper et al., 2001; Ashford and Reeves, 2003; Snapp et al., 2005). These benefits make agricultural production more sustainable by protecting our soil resource. Large amounts of cover crop residue, however, can create problems with any tillage practice that must be conducted in the spring, prior to planting operations. Thus, cover crops must be managed appropriately to prevent planting problems such as "hair pinning" and residue accumulation on planting units. "Hair pinning" is a condition when residue is pushed into the soil rather than being cleanly sheared and prevents good seed-soil contact. As a result, skips in planted rows of the cash crop can occur, impacting negatively crop emergence and yield (Kornecki et al., 2009). Rye (*Secale cereale* L.) is a commonly used winter cover crop in the Southeastern United States. To maximize benefits from rye, the cover must be terminated at the appropriate growth stage and with sufficient lead time to allow soil water recharge before planting a cash crop, such as cotton (*Gossypium hirsutum* L.). An appropriate growth stage for rye termination is soft dough, a maturity stage that provides optimum levels of rye biomass (Nelson et al., 1995). Most agricultural extension

Submitted for review in September 2011 as manuscript number PM 9398; approved for publication by the Power & Machinery Division of ASABE in August 2012.

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

The authors are **Ted S. Kornecki, ASABE Member,** Research Agricultural Engineer, **Francisco J. Arriaga, ASABE Member,** Soil Scientist, **Andrew J. Price,** Plant Physiologist, and **Kipling S. Balkcom,** Research Agronomist, USDA, ARS, National Soil Dynamics Laboratory, Auburn, Alabama. **Corresponding author:** Ted S. Kornecki, USDA, ARS, National Soil Dynamics Laboratory, 411 South Donahue Drive, Auburn, AL 36832; phone: 334-844-4741; e-mail: ted.kornecki@ars.usda.gov.

services recommend terminating cover crops at least two weeks prior to planting. This is important to prevent the cover crop from competing for valuable soil moisture and nutrients with the cash crop (Hargrove and Frye, 1987). Because of multiple proven benefits, many cotton producers in the Southeast, including Alabama, have already adopted or are transitioning to some form of conservation tillage. The transition process involves purchasing no-till equipment which is the single most expensive element in a no-till system.

Because of substantial cost which is involved with the purchase of cover crop roller/crimpers and no-till planters, and to avoid unnecessary financial risks, producers are reluctant to spend tens of thousands of dollars on this equipment. Further, a lack of experience managing high residue cover crops and finding the best solution for particular farm settings, creates resistance to adopt high residue cover crops. In this experiment simulating a transitioning process from conventional to a no-till system, a producer might first utilize his conventional tillage and planting equipment while modifying existing equipment with relatively inexpensive add-on attachment tools, such as row cleaners, to help manage large amounts of residue. Experienced no-till cotton producers who have been farming using cover crops already possess knowledge in establishing proper plant stands in high residue no-till systems utilizing several residue management techniques. However, there are no field-scale research results concerning the optimal choice of equipment and tools available that maximize the benefits of high-residue covers. In addition, for producers making a transition to a conservation-tillage system who may utilize their existing tillage equipment, such as wide strip tillage and/or residue management attachments on the tillage unit, may also utilize conventional planters without row-cleaners. Therefore, the objectives for this three-year study were to evaluate the effects of cover crop rolling and its effects on cotton establishment, and yield to specifically determine:

- the effects of strip tillage width,
- the advantages/disadvantages of moving residue with row cleaner attachments located either on an in-row subsoiler, a planter, or both, and
- interactions of these equipment combinations.

Methods and Materials

The experiment was conducted at the E.V. Smith Research and Extension Center (EVS) near Milstead (central Alabama) on a Compass loamy sand soil (thermic Plinthic Paleudults) between 2006 and 2009. Before starting this experiment in fall of 2006 the whole experimental area was disked, subsoiled, and surface conditioned to alleviate any compacted layer in the soil profile and to provide acceptable uniformity of the soil layer down to a depth of 30 cm before seeding the cover crop. Rye cover crop (Elbon variety) was planted 25 October 2006, 30 October 2007, and 30 October 2008 at a rate of 100 kg ha^{-1} using a Great Plains grain drill with row spacing set to 19 cm. To roll/crimp rye cover crop, a 4.1-m wide, three-section straight bar roller/crimper fabricated by Bigham Brothers, Inc. (Lubbock, Tex.) was utilized with an operating speed of 6.4 km/h (fig. 1). Each section of the straight bar roller contained a 36-cm diameter steel drum mounted to the roller's frame by two flange bearings. Seven steel crimping bars equally spaced around the perimeter were attached to the drums. Each crimping bar measured 76 mm in height and 6 mm in thickness. Before rolling treatment application, the height and the biomass of rye were measured. The height was measured at ten randomly chosen locations throughout the plot using a custom-made scale rod and averaged for each plot. Biomass was collected from two different locations in each plot using a 0.25-m^2 area (0.5 m × 0.5 m) frame. The collected rye biomass was oven dried for 72 h at 55°C using an electric oven (Model No. SC-350, Grieve Corporation, Round Lake, Ill.). Rolling treatments with direction parallel to both rye rows and cotton planting direction were carried out on 11 April 2007, 17 April 2008, and 22 April 2009 when rye was at the soft dough growth stage, which was a desirable growth stage for mechanical rye termination (Nelson et al., 1995). Glyphosate (Roundup™) was applied by spraying at the rate of 1.12 kg/ha (1.61 L/ha) (active ingredient) to all cover crop treatments on the same days as the rolling operation was conducted.

The cotton variety planted in all three growing seasons was Stoneville 5242BR. Cotton was planted on 9 May 2007, 22 May 2008, and 21 May 2009 using a 4-row John Deere Vacuum Max planter (with row spacing of 101 cm) (Moline, Ill.) directly into rye residue.

Cotton was harvested 24 September 2007, 13 October 2008, and 9 October 2009, with a two-row John Deere 9920 cotton picker (Moline, Ill.). The two middle rows from each 4-row plot were harvested and bagged in the field. Bags were then weighed in order to determine the cotton yield. The cotton yield is referred as the harvested seed cotton, i.e., locks of cotton containing the seed and the fiber still attached. The experiment was a randomized complete block (RCB) design with four blocks for each rolling treatment (rolled vs. non-rolled). Each block contained eight equal-sized experimental units seeded with the rye cover crop. The randomized complete block design was chosen in this study due to the gradual slope of the experimental area which could result in varying soil moisture conditions. The ground surface had minor depressions (up to 50 mm) either from previous fall harvest, cover crop planting, or fertilizer application, where higher soil moisture within experimental area made soil more susceptible for equipment tires to create depressions. Such field conditions were considered normal for typical farming operations in Alabama. A total of 64 plots (experimental units) were utilized. Each plot was 9.2 m long and 4.1 m wide allowing four rows of cotton to be planted in one run.

The experiment was a split plot design with a factorial arrangement, with rye cover crop planted on the whole plot and divided into two split parts: rye rolled using roller crimper and non-rolled (standing rye). The overall factorial

Figure 1. Three-section straight bar roller/crimper for terminating rye cover crop.

treatment arrangement with four replications consisted of three equipment levels:

1. Roller/crimper (fig. 1) absent or present, for rolled and non-rolled rye residue.
2. Two levels of non-inversion strip tillage: Narrow strip for minimum soil disturbance and wide strip for maximum soil disturbance, both with and without row cleaners attached to the tillage unit. Figure 2 depicts the narrow strip tillage KMC tillage implement with straight shanks, whereas figure 3 depicts wide strip tillage.
3. No-till planter with or without row cleaners: Figure 4 shows the John Deere 1700 planter (vacuum planter Max Emerge Plus), with and without row cleaners. The row cleaners selected for this experiment were depth adjustable DAWN^{TM} with cast-iron spiked wheels with a coulter mounted out front.

Main plots consisted of rolled and non-rolled rye (four blocks) with eight subplots (treatments) which were randomly assigned to main plots. The eight treatment arrangements are presented in table 1.

Data were analyzed using the analysis of variance, ANOVA, General Linear Model (GLM) procedure. To separate treatment effects, the Fisher's protected least significant difference (LSD) procedure (SAS, 2009) was used. Significance of differences among treatments was determined at P-value < 0.10 level. Where interactions between treatments by years occurred, data were analyzed separately, and where no interactions were present, data were combined using SAS (2009) ANOVA Analyst's linear model. Treatments were considered fixed effects and year was considered a random effect (Gomez and Gomez, 1984).

Figure 2. Narrow strip subsoiler without row cleaners and with row-cleaners. Red arrow points to the row cleaners' location.

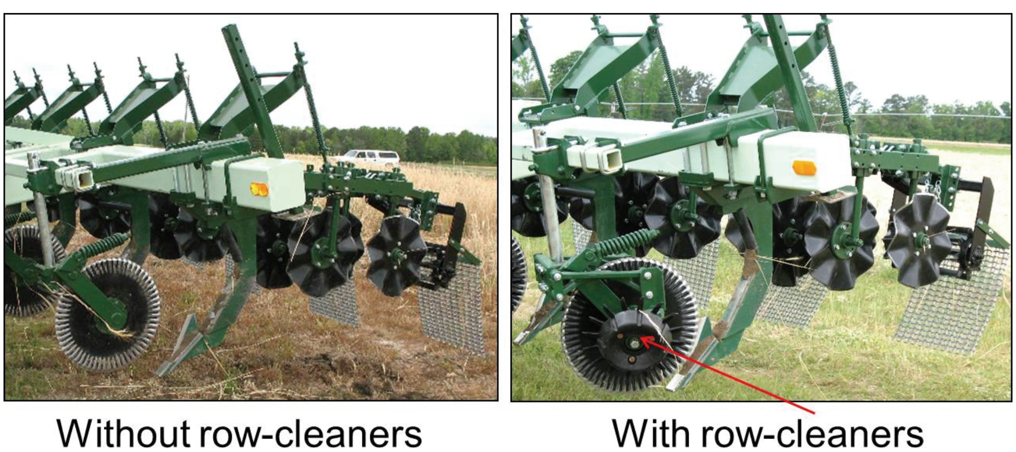

Figure 3. Wide strip subsoiler without row cleaners and with row-cleaners. Red arrow points to the row cleaners' location.

Table 1. Treatment arrangements assigned to rolled and non-rolled residue (standing rye).

Treatment No.	Treatment Description
1	Wide strip, with row cleaners attached to both subsoiler and the planter
2	Wide strip, with row cleaners attached only to the subsoiler
3	Wide strip, with row-cleaners attached only to the planter
4	Wide strip, with no row cleaners attached to either implement
5	Narrow strip, with row cleaners attached to both subsoiler and the planter
6	Narrow strip, with row cleaners attached only to the subsoiler
7	Narrow strip, with row-cleaners attached only to the planter
8	Narrow strip, with no row cleaners attached to either implement

To determine soil strength differences after 3 years of the experiment, penetrometer data (soil cone index) were obtained after cotton harvest in fall of 2009 utilizing a mobile penetrometer tractor unit (Raper et al., 1999) to 50-cm depth with data recorded at 5-cm increments. Standardized by the American Society of Agricultural Engineers (ASAE), stainless steel cone tips with the base area of 129 mm^2 were utilized in the experiment (*ASAE Standards,* 2004b). Cone index data were obtained according to the procedure described in ASAE standards (*ASAE Standards,* 2004a). Soil strength measurements were obtained from each plot (two per plot) from a non-trafficked area using three stainless rods with cone tips spaced 19 cm apart providing measurements over a 38-cm width. Soil samples were obtained using a soil probe to a depth of 30 cm to determine the associated gravimetric soil water content. Three soil samples were taken per plot. Each soil sample was divided equally for two depths 0 to 15 cm and 15 to 30 cm. The three samples from each depth were combined to make a composite sample.

Results and Discussion

In all statistical analyses, BLOCK variable for biomass, height, cotton stand, and cotton yield was significant (P-value <0.0001), indicating significant variability among the blocks, therefore justifying the RCB design and blocking of treatments. To explain results relating to both cover crop production and cotton stand and yield in each growing season, precipitation data for the EV Smith Research Station during 1 April to 15 October in 2007, 2008, and 2009 are presented in figure 5. The different weather patterns in each year most likely influenced rye biomass production and cotton yield.

Rye Cover Crop

There were significant differences in rye biomass production among three growing seasons (years) with corresponding P-value <0.0001. Similarly, significant differences in plant height occurred among the years (P-Value <0.0001), therefore data for rye biomass and height were analyzed separately for each year. In addition there were significant differences among blocks with respect to both rye biomass (P-value = 0.0205) and plant height (P-value = 0.0021), indicating that blocking of treatments in this experiment was necessary. Results for rye cover crop production and rye height are displayed in table 2.

Average rye cover crop dry biomass in 2007 was 5902 kg/ha and the average plant height was 163.4 cm. In 2008 the average biomass was significantly reduced (44% less) and produced only 3319 kg/ha with average height of 123.2 cm. The main reason for this lower biomass production in 2008 was the water deficit that occurred in the summer of 2007 and continued throughout fall and winter and early spring of 2008. Because rye was planted in November of 2007 when conditions were still under severe drought, it was subjected to moisture deficit, consequently affecting rye growth. Late spring and summer through the fall of 2007 was the worst drought on record in Alabama. In 2009 the biomass production (5715 kg/ha) was similar as in 2007 with slightly lower average rye height of 141.5 cm compared to 2007.

Table 2. Rye cover crop production results during 2007, 2008, and 2009 growing seasons.

Year	Rye Dry Biomass Production (kg/ha)	Rye Height (cm)
2007	5902 a	163.4 a
2008	3319 b	123.2 c
2009	5715 a	141.5 b
LSD[a]	270	1.8

[a] LSD values at α = 0.1 level of significance. Values followed by the same letter are not significantly different and comparisons are valid only within columns.

Figure 4. Planting unit Max Emergence Plus without and with row cleaners. Red arrow points to the row cleaners' location.

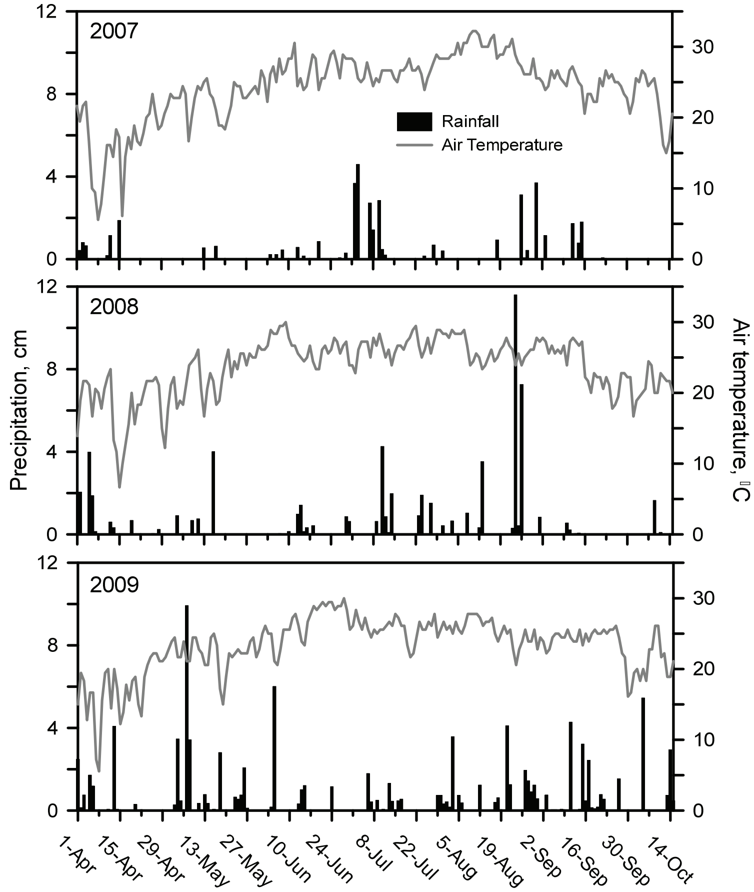

Figure 5. Precipitation amounts for the 2007, 2008, and 2009 growing seasons from 1 April to 14 October at the E.V. Smith Research Station.

COTTON STAND

Because YEAR and YEAR*ROLLER variables for cotton stand were significant (P-value < 0.0001), stand data for each year were analyzed separately. In three growing seasons the final cotton stand was significantly different [LSD = 7323 plants/ha at 10% significance level (α = 0.10)]. The overall mean of the cotton final stand for 2007 was the highest at 126,387 plants/ha, for 2008 the cotton stand was lower than in 2007 (108,047 plants/ha), and the lowest cotton stand was calculated for 2009 (90,465 plants/ha). Across the three growing seasons the cotton stand was significantly higher (120,182 plants/ha) with rolled rye compared to standing, non-rolled rye residue (96,418 plants/ha; LSD = 5979 plants/ha). Across the years, no significant differences were detected in cotton stand with respect to wide strip (110,882 plants/ha) and narrow strip (105,718 plants/ha) with P-value = 0.1413.

2007

Significantly higher overall cotton stand was found for rolled rye residue (137,134 plants/ha) compared to non-rolled residue (115,641 plants/ha), P-value = 0.0014. However, there was no difference in cotton stand between wide strip tillage (127,951 plants/ha) and narrow strip tillage (124,823 plants/ha) among all treatments (P-value = 0.7967). Similarly, no significant differences among the row cleaner treatments were observed (P-value = 0.2996)

2008

Compared to 2007, cotton stand was lower in 2008. No significant differences in cotton stand were observed between rolled and non-rolled rye residue (P-value = 0.8348). The average stand for rolled residue was 108,375 plants/ha and was slightly lower for non-rolled residue (107,719 plants/ha). Similarly, no significant differences were found between wide and narrow strip tillage treatments (108,829 plants/ha vs. 107,265 plants/ha, P-value = 0.5831). Also, no significant differences in cotton stand are reported among all treatments (P-value = 0.9347)

2009

Compared to 2007 and 2008, cotton stand was significantly lower in 2009. In 2009, significant differences in cotton stand were observed between rolled (115,036 plants/ha) and non-rolled rye residue (65,894 plants/ha; P-value < 0.0001). However, no significant differences were found between wide and narrow strip tillage treatments (96,671 plants/ha vs. 84,259 plants/ha; P-value = 0.7304). Similar to previous growing seasons, no significant differences in cotton stand were found between the row cleaner treatments (P-value = 0.5612).

YIELD OF SEED COTTON

Because the YEAR variable with respect to cotton yield was significant (P-value < 0.0001), cotton yields for each year were analyzed separately. The severe drought conditions in Alabama during the 2007 growing season (late spring, summer, and fall) negatively affected cotton yield. Even though cotton stand was higher in 2007 than 2008, it generated lower cotton yield due to drought conditions. In 2007, the overall average seed cotton yield was 4436 kg/ha, which was significantly lower (20% less) than the cotton yield in 2008, 5,539 kg/ha. In 2009 the yield was the lowest (2,672 kg/ha), and it was only 60% compared to 2007 and 48% compared to 2008 (LSD = 126 kg/ha). The main reason for this drop in yield was flooding conditions of the experimental plots soon after cotton planting during May and June of 2009. Across rolling treatments (rolled vs. standing rye), rolling rye residue generated higher yield (4,332 kg/ha) compared to non-rolled rye (4,100 kg/ha). There was no significant difference (P-value = 0.1131) between cotton yield with respect to wide-strip (4265 kg/ha) and narrow-strip tillage (4,166 kg/ha) during all growing seasons.

2007

In 2007, significantly higher seed cotton yield was associated with the rolled rye residue (4540 kg/ha) compared to non-rolled rye (4,332 kg/ha; P-value = 0.0990). Results suggest that rolled residue helped to preserve soil moisture even during drought conditions. Also, no significant difference was found between average seed cotton yield for wide strip tillage (4,509 kg/ha) vs. narrow strip tillage (4,362 kg/ha; P-value = 0.3984). Significant differences in cotton yield were observed for different row cleaner treatments (P-value = 0.0718). Results for each treatment combination are presented in table 3.

From table 3, the highest cotton yield of 4,933 kg/ha was found with Treatment 5 (rolled rye residue, narrow width subsoiler and row cleaners attached to both the subsoiler and the planter). No significant differences observed among this treatment and treatments 2, 3, and 1 (for non-rolled residue), and treatments 6, 3, 4, 1, 7, 8 (for rolled rye residue). The lowest yield (3,903 kg/ha) was associated with treatment 4 (non-rolled rye, wide strip, and no row cleaners).

These results also indicate that row cleaners either on the planter or attached to the subsoiler or to both implements helped to produce significantly higher cotton yield compared to treatments where row cleaners were removed. The width of the strip (wide or narrow) did not have an effect on cotton seed yield.

2008

Contrary to the cotton yield results in 2007, the overall seed cotton yield for non-rolled residue was significantly higher (5,658 kg/ha) compared to rolled residue, which produced lower cotton seed yield of 5419 kg/ha (P-value = 0.0448). Although this yield difference was significant, the reduced yield for rolled residue was only 4% lower than for non-rolled residue. A possible reason for this outcome was that with an unusually low rye biomass and low height in 2008, the benefits that cover crop should provide were reduced, and thus rolling did not contribute to improve growing conditions for cotton. The rye biomass in 2008 was 56% lower than that in 2007. Seed cotton yield results for each row cleaner treatment for rolled and non-rolled rye are presented in table 4.

As shown in table 4, the highest cotton yield of 5,812 kg/ha was associated with Treatment 6 (non-rolled rye residue, narrow width subsoiler and row cleaners attached only to the subsoiler). No significant differences were observed among this treatment and treatments 2, 4, 7, 3, 5, 1, and 8 (for non-rolled rye residue), and treatments 2, 8, and 1(for rolled rye residue). The lowest yield (5,171 kg/ha) was associated with treatment 7 (rolled rye, narrow strip, and row cleaners attached only to the planter). In 2008, the width of the strip tillage did not have any effect on the cotton seed yield (P-value = 0.2527). The average yield 5,580 and 5,497 kg/ha for the wide and narrow strips, respectively.

2009

Unlike the two previous growing seasons, the overall seed cotton yield averaged across all treatments was considerably lower (2,672 kg/ha). The main reason for this significant reduction was the partial flooding of the experimental area in which standing water remained for an

Table 3. Results for seed cotton yield (from the highest to the lowest yield) in 2007.

Treatment Number and Rye Rolling Treatment	Subsoiler Strip Type	Row Cleaners Attached to Implement	Seed Cotton Yield (kg/ha)[a]
Treatment 5, rolled	Narrow	Subsoiler & planter	4,933 a
Treatment 2, non-rolled	Wide	Subsoiler only	4,903 a
Treatment 3, non-rolled	Wide	Planter only	4,784 ab
Treatment 1, non-rolled	Wide	Subsoiler & planter	4,757 ab
Treatment 6, rolled	Narrow	Subsoiler only	4,750 ab
Treatment 3, rolled	Wide	Planter only	4,571 abc
Treatment 4, rolled	Wide	No row cleaners	4,534 abc
Treatment 1, rolled	Wide	Subsoiler & planter	4,523 abc
Treatment 7, rolled	Narrow	Planter only	4,482 abc
Treatment 8, rolled	Narrow	No row cleaners	4,425 abcd
Treatment 7, non-rolled	Narrow	Planter only	4,313 bcde
Treatment 6, non-rolled	Narrow	Subsoiler only	4,120 cde
Treatment 2, rolled	Wide	Subsoiler only	4,103 cde
Treatment 8, non-rolled	Narrow	No row cleaners	3,961 de
Treatment 5, non-rolled	Narrow	Subsoiler & planter	3,913 de
Treatment 4, non-rolled	Wide	No row cleaners	3,903 e

[a] Means with the same letters within the last column indicate no significant differences at $\alpha = 0.1$ (LSD = 520 kg/ha) among treatments.

Table 4. Results for seed cotton yield (from the highest to the lowest yield) in 2008.

Treatment Number and Rye Rolling Treatment	Subsoiler Strip Type	Row Cleaners Attached to Implement	Seed Cotton Yield (kg/ha)[a]
Treatment 6, non-rolled	Narrow	Subsoiler only	5,812 a
Treatment 2, non-rolled	Wide	Subsoiler only	5,776 a
Treatment 4, non-rolled	Wide	No row cleaners	5,740 ab
Treatment 7, non-rolled	Narrow	Planter only	5,694 ab
Treatment 2, rolled	Wide	Subsoiler only	5,691 ab
Treatment 3, non-rolled	Wide	Planter only	5,601 abc
Treatment 8, rolled	Narrow	No row cleaners	5,588 abcd
Treatment 5, non-rolled	Narrow	Subsoiler & planter	5,564 abcd
Treatment 1, non-rolled	Wide	Subsoiler & planter	5,564 abcd
Treatment 1, rolled	Wide	Subsoiler & planter	5,534 abcd
Treatment 8, non-rolled	Narrow	No row cleaners	5,516 abcd
Treatment 3, rolled	Wide	Planter only	5,416 bcde
Treatment 5, rolled	Narrow	Subsoiler & planter	5,361 cde
Treatment 4, rolled	Wide	No row cleaners	5,322 cde
Treatment 6, rolled	Narrow	Subsoiler only	5,271 de
Treatment 7, rolled	Narrow	Planter only	5,171 e

[a] Means with the same letters within the last column indicate no significant differences at $\alpha = 0.1$ (LSD = 327 kg/ha) among treatments.

extended period of time. In 2009, from rolling rye (11 April) to harvesting (9 October), the experimental site received 83 cm of rainfall, and from cotton planting (9 May) to harvest (9 October), the rainfall amount was 61 cm. Two major storm events occurred 7 and 8 May with cumulated rainfall of 14 cm, creating unfavorable planting conditions (fig. 5). Planting into rye residue was not done in ideal conditions since the rye was not completely dry due to rainfall, but considering that it was the recommended time for planting cotton and there was a wet weather forecast, planting was completed. Wet weather continued, and from 11 to 18 May the site received 5 cm of rain during five separate rainfall events. On 5 June, there was a single storm event which generated 6 cm of rainfall. Later in the season, several storm events occurred with 19 and 14 cm of rainfall falling during August and September, respectively. Finally, on 5 October (4 days before the harvest) more than 5 cm of rain fell on the site. Cotton yield obtained from rolled residue was significantly higher (3,035 kg/ha) compared to non-rolled rye residue (2,309 kg/ha; LSD = 203 kg/ha). There were no significant differences between wide-strip and narrow-strip tillage (2,705 and 2,639 kg/ha). Likewise no differences in average cotton yield among row-cleaner treatments were observed. There were significant differences (P-value = 0.002) in cotton yield among all treatments (table 5). Despite the excess precipitation during the growing season, there was a clear pattern that the rolled residue helped generate significantly higher cotton yield compared to non-rolled treatments.

Soil Strength

Penetration resistance was measured in the fall of 2009 after harvest to assess the cumulative effect of the treatments on soil strength. Row cleaners attached to either the subsoiler or planter had no significant effect (P-value = 0.8407) on soil strength. However, rolling the rye cover crop affected soil strength significantly. Since there was a significant ROLLER*DEPTH interaction, data were analyzed by depth (table 6). Soil strength, measured as cone index, was significantly lower from 0- to 15-cm depth when the rye was rolled compared to not-rolled. Rolling the rye cover crop clearly created favorable conditions for cotton growth since all rolled treatments had greater cotton yield regardless of row cleaner treatment in 2009 (table 5). Although cotton yields were lower in 2009 relative to 2007 and 2008 due to an unusually wet spring, rolling the cover crop enhanced soil conditions during the entire growing season in the region of the soil profile where most of the cotton roots would be present (0-15 cm) as evidenced by the lower cone index values. This difference in soil strength could be attributed to differences in soil moisture, however greater soil moisture values were observed with no-rolling when compared to rolled rye. Although these differences in soil moisture were significant (P-value < 0.0001), the actual numeric differences were small. Soil water content for non-rolled rye was significantly greater than rolled rye (13.7% vs. 13.1%, respectively; P-value = 0.0794) from the 0- to 15-cm depth. In the 15- to 30-cm depth, soil water content was 13.1 and 12.0% for non-rolled and rolled rye, respectively (P-value < 0.0001). Higher soil water content typically results in lower cone index values; however, this slightly higher soil moisture content was too small to have a detectable effect on penetration resistance.

Trends in soil strength changed deeper in the profile (25 to 45 cm), with statistically significant greater cone index values observed with rolled versus non-rolled rye (table 6). Cone index values only surpassed the 2.0-MPa threshold identified as restricting root growth (Taylor and Gardner, 1963) at the 50-cm depth. Therefore, soil strength conditions for cotton growth were probably favorable for the entire soil profile down to the 45-cm of depth. Cotton root growth was most likely not impaired by soil compaction given that strip-tillage was performed for all treatments.

Table 5. Results for seed cotton yield (from the highest to the lowest yield) in 2009.

Treatment Number and Rye Rolling Treatment	Subsoiler Strip Type	Row Cleaners Attached to Implement	Seed Cotton Yield (kg/ha)[a]
Treatment 8, rolled	Narrow	No row cleaners	3,133 a
Treatment 6, rolled	Narrow	Subsoiler only	3,109 ab
Treatment 4, rolled	Wide	No row cleaners	3,066 ab
Treatment 7, rolled	Narrow	Planter only	3,051 ab
Treatment 5, rolled	Narrow	Subsoiler & planter	3,042 ab
Treatment 1, rolled	Wide	Subsoiler & planter	2,993 ab
Treatment 2, rolled	Wide	Subsoiler only	2,947 abc
Treatment 3, rolled	Wide	Planter only	2,941 abc
Treatment 4, non-rolled	Wide	No row cleaners	2,551 bcd
Treatment 5, non-rolled	Narrow	Subsoiler and planter	2,541 bcd
Treatment 2, non-rolled	Wide	Subsoiler only	2,538 bcd
Treatment 6, non-rolled	Narrow	Subsoiler only	2,410 cd
Treatment 1, non-rolled	Wide	Subsoiler & planter	2,349 de
Treatment 3, non-rolled	Wide	Planter only	2,218 de
Treatment 8, non-rolled	Narrow	No row cleaners	2,078 de
Treatment 7, non-rolled	Narrow	Planter only	1,785 e

[a] Means with the same letters within the last column indicate no significant differences at α = 0.1 (LSD = 574 kg/ha) among treatments.

Table 6. Soil strength values for rolled and non-rolled rye residue at different depths (from 0 to 50 cm) in 2009.

Soil Depth (cm)	Rolling Treatment	Mean Cone Index (MPa)[a]	P-value	LSD (MPa)
0	No-roll	0.344 a	0.0002	0.038
	Roll	0.252 b		
5	No-roll	0.939 a	<0.0001	0.110
	Roll	0.652 b		
10	No-roll	1.345 a	0.0002	0.156
	Roll	0.972 b		
15	No-roll	1.529 a	0.0033	0.165
	Roll	1.227 b		
20	No-roll	1.449 a	0.6517	N/A
	Roll	1.410 a		
25	No-roll	1.276 b	0.0036	0.119
	Roll	1.491 a		
30	No-roll	1.263 b	<0.0001	0.118
	Roll	1.564 a		
35	No-roll	1.362 b	<0.0001	0.134
	Roll	1.714 a		
40	No-roll	1.486 b	0.0001	0.133
	Roll	1.809 a		
45	No-roll	1.662 b	0.0187	0.176
	Roll	1.916 a		
50	No-roll	2.161 a	0.6316	N/A
	Roll	2.229 a		

[a] Means with the same letters within each depth indicate no significant differences between rolling treatments in rows at the significance level α = 0.1.

Conclusion

In each growing season, treatment responses to seed cotton yield were different. These differences were associated with factors such as weather conditions and cover crop biomass. Thus, treatment recommendations for optimizing cotton seed yield are growing season (year) specific. In 2007, drought conditions in Alabama affected the seed cotton yields. Also, in 2009, excess water in the field significantly affected seed cotton yield. In all growing seasons, the width of the subsoil strip did not have any effect on yield, thus producers can use the wide or slim type subsoiler they already have instead of purchasing a new subsoiler.

In 2007, the rye biomass production and the rye height were the highest, the rolled residue helped to achieve higher cotton stands compared to non-rolled standing rye. When rye production is high, rolling rye, utilizing narrow strip subsoiling, and using row cleaners attached to both subsoiler and planter was necessary to obtain the highest seed cotton yield. However, attaching row cleaners (either on subsoiler or planter) also produced statistically equal yield regardless of the width of the subsoiler, thus it is recommended to have row cleaners on at least one of the two implements. The treatment combination of non-rolled rye and wide strip with row cleaners on either implement also generated statistically equal high seed cotton yield. These findings are important for producers transitioning to conservation systems, who do not have the roller and the slim type of subsoiler. Farmers having the wide subsoiler type (disruption of more soil) and row cleaners with traditional planters can utilize these implements in the transition period without the need of purchasing the expensive roller and slim subsoiler. With high rye biomass, it is not recommended to have row cleaners removed from the subsoiler and planter (especially if rye was not rolled) because within these settings the seed cotton yield was the lowest.

In 2008 the rye biomass was the lowest (42% less than in 2007 and 2009). With such low rye production, our recommendation is to use row cleaners on at least one implement, but rolling is not necessary to obtain high seed cotton yield. With low cover crop biomass, producers transitioning to no-till system do not have to purchase roller, but row cleaners are needed to manage the residue. The strip width had no effect on seed cotton yield, so adaptation of the slim subsoiler is not required.

In 2009, the cotton yield was substantially reduced by prolonged standing water in the experimental area. Because of excess water, cotton stand and yield were lower compared to the 2007 and 2008 growing seasons. In 2009, the cotton stand and seed cotton yield for rolled residue was higher compared to non-rolled residue. There was a 43% reduction in seed cotton yield between the best treatment combination (rolled rye, narrow strip, no row cleaners) and the worst (non-rolled rye, narrow strip, and row cleaners on the planter) (3,133 vs. 1,785 kg/ha). When cover biomass is high and the spring is wet our recommendation is to roll the cover crop, as rolling helps to increase water infiltration. When rye was rolled, the use of row cleaners was not critical to produce high seed cotton yield. It appears that rolled residue helped to minimize interferences between cover crop residue and the planter and influenced higher seed cotton yield. Rolled residue also helped lowering soil strength (to 15 cm of depth) compared to non-rolled residue providing more favorable growing conditions for cotton.

Acknowledgments

This project was conducted with financial support from the Alabama Cotton Producers Association: GRANT Number: G00002450, 2007.

References

ASAE Standards. 2004a. EP542: Procedures for obtaining and reporting data with the soil cone penetrometer. St. Joseph, Mich.: ASAE.

ASAE Standards. 2004b. S313.3: Soil cone penetrometer. St. Joseph, Mich.: ASAE.

Ashford, D. L., and D. W. Reeves. 2003. Use of a mechanical roller crimper as an alternative kill method for cover crop. *American J. Alternative Agric.* 18(1): 37-45.

Gomez, K. A., and A. A. Gomez. 1984. *Statistical Procedures for Agricultural Research.* 2nd ed. New York: John Wiley & Sons.

Hargrove, W. L., and W. W. Frye. 1987. The need for legume cover crops in conservation tillage production. In *The Role of Legumes in Conservation Tillage Systems,* 1-5. J. F. Power, ed. Ankeny, Iowa: Soil Conservation Society of America.

Kasper, T. C., J. K. Radke, and J. M. Laflen. 2001. Small grain cover crops and wheel traffic effects on infiltration, runoff, and erosion. *J. Soil Water Conserv.* 56(2): 160-164.

Kern, J. S., and M. G. Johnson. 1993. Conservation tillage impacts on national soils and atmospheric carbon levels. *SSSA J.* 57(1): 200-210.

Kornecki, T. S., R. L. Raper, F. J. Arriaga, E. B. Schwab, and J. S. Bergtold. 2009. Impact of rye rolling direction and different no-till row cleaners on cotton emergence and yield. *Trans. ASABE* 52(2): 383-391.

McGregor, K. C., and C. K. Mutchler. 1992. Soil loss from conservation tillage for sorghum. *Trans. ASAE* 35(6): 1841-1845.

Nelson, J. E., K. D. Kephart, A. Bauer, and J. F. Connor. 1995. Growth stage of wheat, barley, and wild oat. Columbia, Mo.: University of Missouri. Available at: plantsci.missouri.edu/cropsys/growth.html.

Raper, R. L., B. H. Washington, and J. D. Jarrell. 1999. A tractor-mounted multiple-probe soil cone penetrometer. *Applied Eng. in Agric.* 15(4): 287-290.

Raper, R. L., D. W. Reeves, E. B. Schwab, and C. H. Burmester. 2000. Reducing soil compaction of Tennessee Valley soils in conservation tillage systems. *J. Cotton Sci.* 4(2): 84-90.

Reeves, D. W. 1994. Cover crops and rotations. In *Advances in Soil Science: Crops Residue Management,* 125-172. J. L. Hatfield and B. A. Stewart, eds. Boca Raton, Fla.: Lewis Pub.

SAS. 2009. Proprietary Software Release 9.2. Cary, N.C.: SAS Institute, Inc.

Snapp, S. S., S. M. Swinton, R. Labarta, D. Mutch, J. R. Black, R. Leep, J. Nyiraneza, and K. O'Neil. 2005. Evaluating cover crops for benefits, costs, and performance within cropping niches. *Agron. J.* 97(1): 322-332.

Taylor, H. M., and H. R. Gardner. 1963. Penetration of cotton seedling taproots as influenced by bulk density, moisture content, and strength of soil. *Soil Science* 96(3): 153-156.