Effects of Multiple Rolling Cover Crops on Their Termination, Soil Water, and Soil Strength

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Abstract: In conservation agriculture, termination of cover crops is now possible by using rollers/crimpers. In the southeastern United States, to eliminate competition for valuable soil moisture, three weeks are typically required after rolling to plant a cash crop into the desiccated cover crop residue. A common method to enhance cover crop termination process is a supplemental application of herbicides. However, herbicides cannot be used in organic production, thus requiring additional rolling operations. Multiple rolling/crimping operations might cause additional soil compaction, however, which could be detrimental for water infiltration and crop root development. The objectives of this study were to determine the effectiveness of a single-stage roller with straight bars and a two-stage roller in terminating cover crops: 1) rye (*Secale cereale* L.), 2) a mixture of rye, crimson clover (*Trifolium incarnatum* L.), and hairy vetch (*Vicia villosa* L.) in multiple rolling operations, and the effect of multiple rolling on volumetric soil water content, soil strength and associated gravimetric moisture content. In 2007 and 2008, three weeks after rolling, both roller designs effectively terminated rye (>90%), which was above the recommended rye termination rate to plant a cash crop. Rolling two or three times did not cause additional soil compaction, and rolled residue kept soil strength significantly lower compared to standing cover crops due to increased termination and thus moisture conservation. Volumetric soil water content after multiple rolling operations was significantly higher compared with standing rye and mixture covers. In the mixture, hairy vetch was actively growing two weeks after rolling, even after three rolling operations and was not effectively terminated by any roller design. Multiple rolling can be beneficial for faster mechanical termination of cover crops such as rye and crimson clover, but may not be adequate for mixtures that include hairy vetch.
Key words: cover crops, roller crimper, soil strength, conservation agriculture

INTRODUCTION

Cover crops are a crucial part of conservation agriculture, but they have to be managed appropriately to optimize their benefits (Brady and Weil, 1999). Previous research has identified benefits, including increased water infiltration, reduced runoff, reduced soil erosion, and reduced soil compaction (Kern and Johnson, 1993; Reeves, 1994; Raper et al., 2000a; Raper et al., 2000b). Flattening and crimping cereal cover crops by mechanical rollers/crimpers originated in Brazil to successfully terminate cover crops without herbicides (Derpsch et al., 1991) and this technology is now receiving significant interest within the United States. Mechanical termination of cover crops using a roller/crimper usually requires waiting at least three weeks before planting a cash crop into rolled residue (Ashford and Reeves, 2003; Kornecki, et al., 2006). Many agricultural extension services recommended termination of the cover crop at least two weeks before planting, since this period is needed to prevent the cover crop from competing for soil moisture and nutrients (Hargrove and Frye, 1987). Ashford and Reeves (2003) indicated that when rolling was conducted at the appropriate plant growth stage (i.e., soft dough, Zadoks growth stage 85, Zadoks et al., 1974), the roller was equally effective (vs. chemical herbicides) at terminating the cover crop (94%) and that rye termination rates above 90% were sufficient to begin planting of cash crop due to accelerated rye senescence. To speed up termination, producers utilize herbicides as a supplement to rolling. However, in organic vegetable production, commercial herbicides cannot be used.

Multiple rolling may be a viable method of increasing termination, however, there is a concern, that additional soil compaction could be caused which could be detrimental to water infiltration and crop root development. A field study conducted in Cullman, Alabama during the spring of 2007 and 2008 evaluated the effects of multiple rolling/crimping events on cover crop termination, soil strength, and soil moisture. To determine the effect of multiple rolling operations on soil strength, termination rate, and soil water content, two rollers, a single-stage roller with straight bars and a two-stage roller, were used in a replicated field experiment in the spring of 2007. Cover crop termination rates were evaluated one, two, and three weeks after rolling.

The objectives of this study were: (1) Determine the effectiveness of two different roller designs in terminating a single cover crop (rye) and a mixture (rye, clover, and hairy vetch) in multiple rolling operations, (2) Determine the effect of multiple rolling on volumetric moisture content (VMC) during the cover crop termination period, and (3) Determine soil strength (Cone Index; CI) and associated gravimetric soil water (GMC) content before and after application of rolling treatments.

MATERIALS and METHODS

In the spring of 2007 and 2008 replicated field experiments were conducted in Cullman, Alabama, to evaluate multiple mechanical termination of two cover crops: rye and a mixture (rye, hairy vetch, and crimson clover) using two different rollers. Rye (seeding rate of 95 kg ha^{-1}) and the mixture (rye rate 53 kg ha^{-1}, crimson clover and hairy vetch both 21 kg ha^{-1}) were drill seeded in October 2006 and 2007 using a Tye™ grain no-till drill* with 17 cm row spacing. To optimize rye growth, ammonium nitrate (33-0-0) was broadcast onto the cover crop at a rate of 50 kg ha^{-1} N in early March. In both growing seasons, the day before rolling/crimping, cover crop height and biomass were determined from each plot. The height was measured at ten randomly chosen locations throughout the plot using a custom made scale rod and then averaged. The biomass was collected from two different locations of each plot using a 0.25 m^2 area (0.5 m x 0.5 m square) fixture. The collected rye biomass was oven dried for 72 hours at 55° C using an electric oven (Model No. SC-350 from Grieve Corporation*, Round Lake, Illinois).

The rolling treatments were applied April 23, 25, and 27 in 2007, and April 30, May 02 and May 04 in 2008 when rye was in the early milk growth stage (Zadoks growth stage 73) which is a desirable growth stage for rye termination (Nelson et al., 1995). The rye was rolled parallel to the rows of the drilled winter rye cover crop. The experiment was a randomized complete block design (RCBD) with four blocks (replications). Treatments were randomized within each block. Each experimental unit was 6-m long and 1.8-m wide. Randomly assigned cover crops were rolled once, twice, and three times, and scheduled every other day from the previous rolling application.

Before the rolling/crimping operation, soil strength was measured using a mobile soil cone index penetrometer (Raper et al., 1999). 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, 2004b). Cone index data were obtained according to the procedure described in ASAE standards (ASAE, 2004a). Soil strength measurements were obtained from each plot (two per plot) from a non-trafficked area using five stainless rods with cone tips spaced 19 cm apart providing measurements on 76 cm wide strips up to 45 cm depth. 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 at each plot. Then each sample was divided equally for two depths 0-15 cm and 15 to 30 cm. Three samples from each depth were combined to make a composite sample.

Volumetric moisture content was measured the day of rolling and after the first, second, and third week using a portable TDR moisture meter from Spectrum Technologies* (Plainfield, Illinois). The sensor was equipped with 12-cm long rods and was inserted vertically into the soil surface. The length of rods was selected to measure soil volumetric moisture content at a shallow depth, available for germination of cash crop seeds planted into the residue cover. Five readings were taken close to the middle of each plot at marked locations spaced about 1.0 m apart.

Soil strength and gravimetric soil moisture content measurements were repeated after the completion of three rolling/crimping operation, to determine multiple rolling effects on soil strength. The two 1.8-m wide rollers utilized in the experiment were: a straight-bar roller (Figure 1a) and two-stage roller (Figure 1b). Rolling treatments were considered fixed effects and years were considered random effects. Analysis of variance (ANOVA) was performed on rye biomass, height, termination rates, VMC, soil strength and gravimetric moisture content using SAS (2001). Treatment means were separated by the Fisher's protected LSD test at the 0.10 probability level. Where interactions between treatments and years occurred, data were presented separately; otherwise, data were combined. Rye and mixture injury, based on visual desiccation, were estimated on a scale of 0 (no injury symptoms) to 100 (complete death) (Frans et al., 1986), and was evaluated at one,

two, and three weeks after rolling. The speed 6.4 km/h was chosen to match speeds commonly used in field chemical applications.

RESULTS and DISCUSSION

a. Cover crop height and biomass

Average height of rye was 165 cm in 2007 and 177 cm in 2008. In 2007, average dry biomass was 5071 kg ha^{-1} for rye and 5418 kg ha^{-1} for the mixture. Cover crop biomass and height were inhibited by severe drought in the spring of 2007. Biomass production before rolling in 2008 was greater compared to 2007. Rye produced 6391 kg ha^{-1} and the mixture produced 9090 kg ha^{-1} of dry biomass.

b. Cover crop termination rates

Since interactions between years and treatments with respect to rye termination rates were significant ($p<0.0001$), analyses of variance were done separately for each year (growing season). Termination rates for rye and the mixture (rye crimson clover and hairy vetch) in 2007 and 2008 are shown in Table 1. In 2007, one week after rolling, significantly higher termination rates were reported for cover crops (rye only and mixture) rolled three times compared with rolled once and no-rolled cover crops. The second week after rolling, lower termination rates were reported for the mixture (rye, crimson clover, and hairy vetch) compared to rye only. The main reason for lower rates was a recovery and new active growth of hairy vetch that altered termination rates for the mixture. Three weeks after rolling, no significant differences in termination rates (90% and above) were reported between roller types and number of rolling events. Compared to rolled residue, no rolled covers produced significantly lower termination rates (51% to 63%). It should be noted that two weeks after rolling rye three times by each roller type, rye termination rates were high enough (90% and above) to successfully establish a cash crop into the rye residue (Ashford and Reeves, 2003).

One, two, and three weeks after rolling, significantly higher termination rates were reported in 2008 for rolled residue both for rye only and the mixture compared with untreated checks (Table 1). During the same period, no difference was found between the two roller designs. Two weeks after rolling, there was a significant difference in termination rates between rolling the cover crop mixture one time (57%) and three times (69%). No differences were found between these treatments at one and three weeks after rolling. In contrast to the 2007 growing season, termination rates three weeks after rolling for the mixture were lower. The reason for lower mixture termination rates was most likely that hairy vetch in the mixture was able to recover and actively grow, possibly due to higher volumetric moisture content and a substantial warming trend (higher temperature) during the growing seasons. In spring of 2008, volumetric moisture content was significantly higher than in 2007 (Table 2). This growth was also triggered by the fact that rye and crimson clover in the mixture by the third week after rolling were effectively killed and did not compete for nutrients and moisture allowing the hairy vetch to recover.

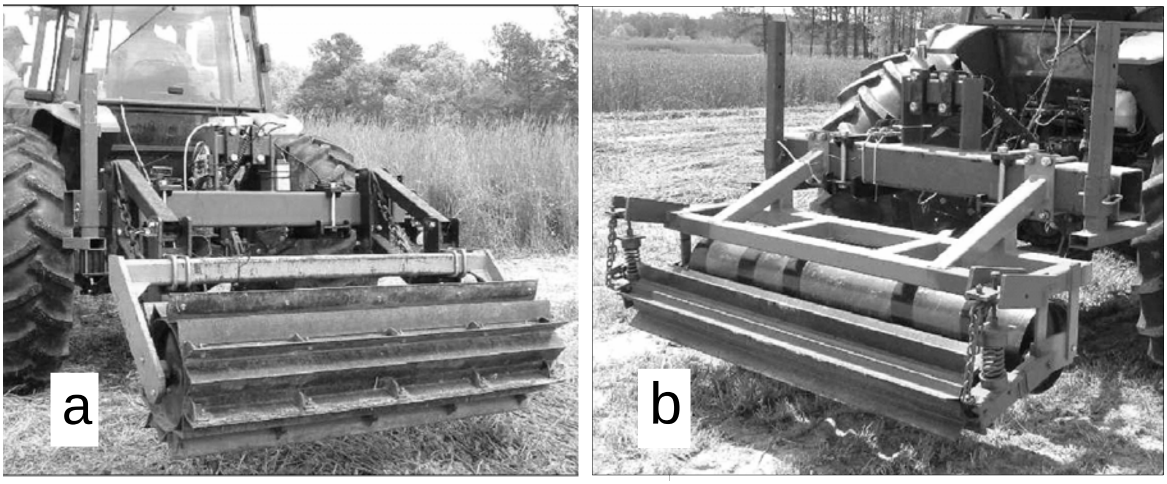

Figure 1. (a) Straight-bar roller; (b) Two-stage roller/crimper

Table 1. Rye and mixture termination rates (%) for roller types and number of rolling operations. **Same letters indicate no significant differences within each column.

Rolling Treatment	Cover Crop	Roller type	2007			2008		
			One week	Two weeks	Three weeks	One week	Two weeks	Three weeks
No rolled	Rye	No Roller	0.0f	39g	63cd	24e	44e	86b
	Mixture	No Roller	0.0f	21h	56d	21e	31e	49d
Rolled 1 time	Rye	Straight	66e	80cd	91a	88a	90a	99a
		Two-Stage	68cde	83bc	91a	82a	89a	99a
	Mixture	Straight	68de	46fg	71bc	57cd	57d	60c
		Two-Stage	69cde	46fg	71bc	54d	57d	61c
Rolled 2 times	Rye	Straight	79ab	88abc	90a	82a	94a	100a
		Two-Stage	74bcd	86abc	93a	89a	95a	100a
	Mixture	Straight	68de	53f	77b	62bcd	69b	67c
		Two-Stage	75abc	64e	71bc	65b	66bc	67c
Rolled 3 times	Rye	Straight	81a	90ab	94a	88a	95a	100a
		Two-Stage	81a	91a	93a	85a	94a	100a
	Mixture	Straight	78ab	64e	71bc	64cd	69b	69c
		Two-Stage	78ab	73d	71bc	63bcd	66bc	67c
LSD at **a** = 0.1			6.8	8.6	8.4	8.4	9.2	10.2

Volumetric Moisture Content (VMC)

Volumetric moisture content (VMC) results are shown in Table 2. Comparing two years of study, there was a significant difference in VMC between two growing seasons measured the day of rolling operation, one, two and three weeks after rolling ($p<0.0001$). In 2007 a severe drought occurred causing a major deficit of soil water. During the three weeks of the evaluation period after the rolling operation in 2007, rainfall at the Cullman, AL location was only 40 mm compared to 181 mm in 2008. Average VMC measured over a three week period was 9.8% in 2007 compared to 22.7% in 2008. In 2007 and 2008, no differences in VMC were found between treatments, except for two weeks after rolling ($p=0.002$). For standing rye (check), VMC was lower (4.8%) compared with rolled treatments (between 6.6 and 8.1%) indicating that rolled rye protected the soil from losing moisture by creating a mulch effect, whereas standing rye did not, due to the active cover crop growth and higher evaporation from exposed soil. For the untreated mixture, VMC was 4% compared with rolled residue mixture (5.4 to 6.6%). In 2007, two weeks after rolling, no significant differences in VMC were found between untreated mixture check and mixture rolled once, twice, and three times by straight bar roller. The reason for the lower VMC was most likely the recovery of the hairy vetch after rolling, also resulting in lower kill rates for the mixture, and indicating that the mixture cover crop was actively growing using available soil moisture. Reeves (1994) reported that in several studies in the U.S., hairy vetch cover depleted soil moisture and delayed planting of cash crops. By three weeks after rolling, volumetric moisture content dropped (VMC between 2.1% to 4%) due to continuing drought, and there were no differences between all rolled residue treatments and checks. As already reported, in 2008 three weeks from the rolling operation, rainfall of 181 mm depth occurred and elevated VMC above 19% (19.1 to 24.8%). Although VMC was sufficient for any cash crop to be planted, two weeks after rolling, VMC for standing rye and the untreated mixture was lower (16.7% for rye and 18.4% for mixture) compared to rolled residue (19.1 and 21.7%) indicating that the rolling operation helped to preserve VMC which is critical in drought periods such as in 2007 for successful cash crop growth. Data from two years of study suggested that the rolled residue protected the soil from losing moisture by creating a mulch effect, whereas standing residue did not, due to the still active rye and mixture growth and higher evaporationfrom exposed soil.

Table 2. Volumetric soil moisture content (%) for different covers and roller types. **Same letters indicate no significant differences within each column.

Rolling treatment	Cover crop	Roller type	2007				2008			
			Day of rolling	One week after rolling	Two weeks after rolling	Three weeks after rolling	Day of rolling	One week after rolling	Two weeks after rolling	Three weeks after rolling
Untreated	Rye	No Roller	12.1	13.8	4.8de	2.1	22.7	22.6	16.7d	20.9
	Mixture	No Roller	13.4	13.8	4.0e	2.3	22.6	22.7	18.4cd	19.9
Rolled 1 time	Rye	Straight Bar	14.5	16.8	7.8a	3.2	23.9	23.6	20.8abc	21.3
		Two stage	13.4	14.6	7.9a	4.0	24.7	24.8	19.9abc	20.6
	Mixture	Straight Bar	15.1	16.6	5.4abcde	3.5	22.6	23.6	19.5abc	19.9
		Two stage	14.6	16.7	7.5abc	3.3	22.6	23.2	20.6abc	20.3
Rolled 2 times	Rye	Straight Bar	14.0	15.1	7.9 a	3.6	23.3	23.5	19.3bc	19.8
		Two stage	12.9	18.3	7.6ab	4.0	25.3	23.9	21.7a	21.6
	Mixture	Straight Bar	11.4	16.8	6.0abcde	3.6	23.5	23.0	21.9a	20.2
		Two stage	14.4	16.9	6.6abcd	3.3	25.2	24.6	21.2ab	21.9
Rolled 3 times	Rye	Straight Bar	13.1	15.5	8.1a	3.1	23.7	24.4	20.8abc	22.0
		Two stage	11.0	15.1	6.6abcd	3.0	24.5	23.5	19.1bcd	19.6
	Mixture	Straight Bar	13.5	14.4	5.3cde	2.8	23.6	23.8	21.0ab	20.5
		Two stage	15.8	17.4	6.4abcd	3.2	23.7	23.9	21.3ab	20.8
	LSD at **a** = 0.1		N/S	N/S	2.3	N/S	N/S	N/S	2.4	N/S

d. Soil Cone Index (CI) and the associated Gravimetric Moisture Content (GMC)

In two years of study, CI values for the lower layer (15-30 cm) were significantly higher compared to 0-15 cm top layer before and after the rolling operation ($p<0.0001$). In 2007, average CI for the top layer were 4.86 MPa and 4.57 MPa before and after rolling, respectively, whereas at 15-30 cm layer corresponding CI values were 6.15 MPa and 5.9 MPa. This higher CI level was caused by severe drought in the spring of 2007 and exceeded 3 times recommended soil strength level for unrestrictive root growth for cotton which is 2.0 MPa (Taylor and Gardner, 1963).

In 2007, before rolling treatment application, there was no significant difference in average GMC between depths, i.e., 0-15 cm and 15-30 cm. Average GMC at the top layer (0 to 15 cm) was 11.6% and 11.4% at depth of 15 cm to 30 cm. After the rolling treatment, average GWC at depth of 0-15 cm was higher (12.6%) compared to depth 15-30 cm (11.3%). After the rolling operation at depth increment 0-15 cm, standing rye had a lower GMC compared to rolled residue treatments

In 2008, before rolling, CI for the 0-15 cm depth was 1.4 MPa and 2.61 MPa for the 15-30 cm. After the rolling treatment application, corresponding CI values were 1.08 MPa and 1.59 MPa. Evaluation of treatment effect on CI at each layer showed that in 2007, before the rolling treatment application no significant differences in soil cone index (CI) at the top layer (0 to 15 cm) were found across all rolling treatments, roller types and number of rolling operations (Figure 2). These results provided a good base to determine rolling treatment effects on soil compaction and associated soil gravimetric moisture content (GMC). Comparing the same depth (0-15 cm) after rolling treatment application for rye and mixture treatments, significantly higher cone indices were observed for both non-rolled covers (Figure 3).

No significant differences in CI were found between non-rolled rye and the mixture rolled twice by the straight bar roller. Except for the mixture rolled twice by the straight bar roller, all soil under rolled covers exhibited lower cone index while maintaining higher GMC.Figure 4 shows GMC in 2007 after the rolling operation at depth increment 0-15 cm and this was the only time during two years of study that significant difference in GMC was observed due to treatment effect both before and after rolling operation. Standing rye had a lower GMC compared to rolled residue treatments.This was most likely associated with the evapotranspiration of the actively growing rye and increased evaporation of water due to soil exposure. There was no significant difference in GMC between checks (standing rye and the mixture). Compared to the untreated mixture, higher GMC was noted for two times rolling both covers (rye and mixture) by the two-stage roller, and one time rolling mixture by the straight bar roller. This higher GMC may likely be associated with effective crimping of cover crops by rollers and mulch effects which would reduce soil evaporation.

Significantly lower cone index for rolled cover crops residue indicates that rolling crimping operation for straight-bar and two-stage roller designs does not increase CI, thus not elevating soil compaction. In contrast, the higher CI found with non-rolled cover crops is most likely associated with decreased soil water content (Figure 4) due to reduced surface cover of standing cover crops and evapotranspiration. In 2007, at depth of 15-30 cm CI was significantly different between treatments before rolling. These differences are most likely associated with differences in soil density at lower layer (Figure 5). No differences across all treatments existed at 15-30 cm after rolling (Figure 6).

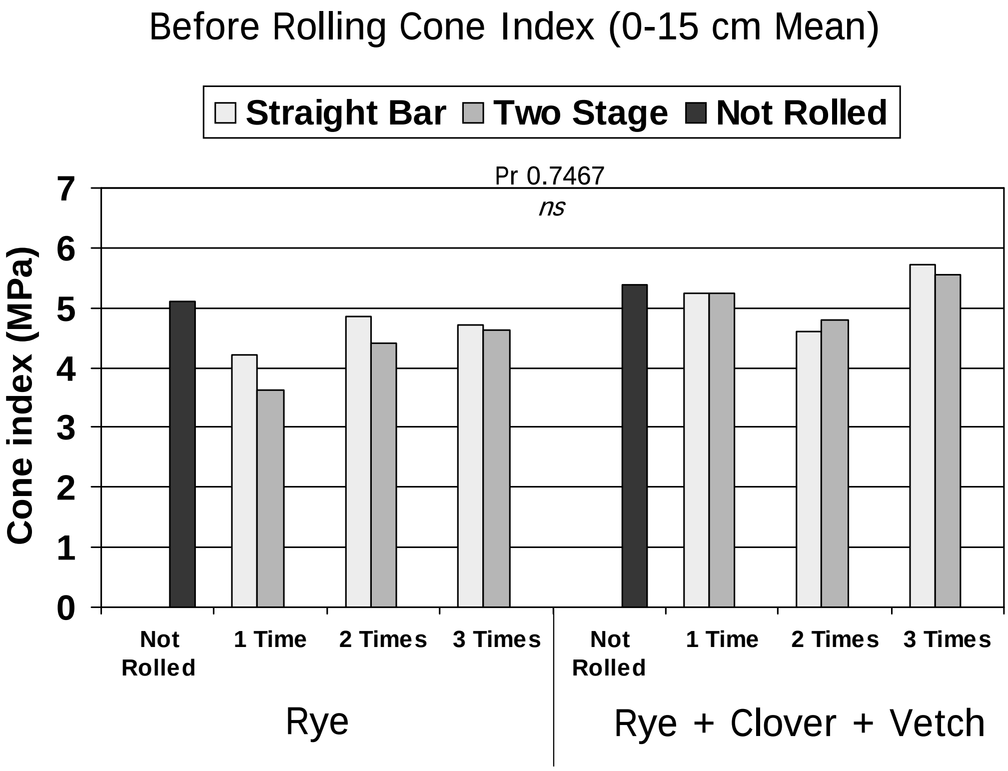

Figure 2. 2007 Growing Season: Soil Cone Index (CI) before rolling/crimping for both cover crops at depth of 0-15 cm.

In 2008, before the rolling application, at the top layer 0-15 cm no difference in CI (p=0.3807) was observed across rolling treatments, roller types and cover crops (Figure 7). Likewise, after rolling treatment applications no differences in CI (p=0.8954) existed at the top layer across all treatments (Figure 8). At the depth increment 15-30 cm, cone index was not different for all treatments before and after rolling (Figures 9 and 10).

In 2008, before the rolling treatment application, there was a significant difference (p<0.0001) in average GMC between depth increments, i.e., 18% for 0-15 cm and 16% for 15-30 cm. Similarly, after the rolling application, there was a significant difference in GMC between depth increments (p<0.0001). GMC for 0-15 cm depth was 18.1%, whereas 15-30 cm had 15.8%. However, after the rolling treatment application no significant differences in GMC were observed across any of the treatments at depth of 0-15 cm (p=0.780) and at the 15-30 cm depth (p=0.938).

Cone index results in both growing seasons indicated that multiple rolling did not cause soil compaction at non-trafficked area. Conversely, in drought conditions as occurred in 2007, after rolling treatments higher cone index values were higher and associated gravimetric soil moisture content were lower for standing rye and the mixture (checks) compared with rolled residue. It appears that rolled residue helped to conserve moisture by creating a layer of residue on the soil surface, thus preventing an increase of soil strength.

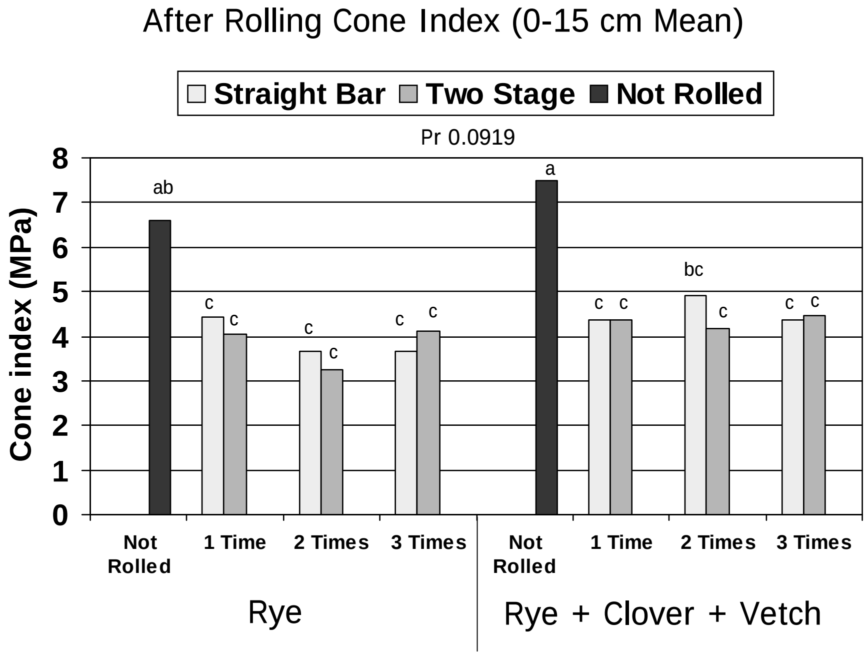

Figure 3. 2007 Growing Season: Soil Cone Index (CI) after rolling/crimping for both cover crops at depth 0-15 cm. Mean separation was performed using LSD (Fisher procedure) at α=0.1 significance level. Same letters indicate no statistical difference between all treatments (LSD=2.063 MPa).

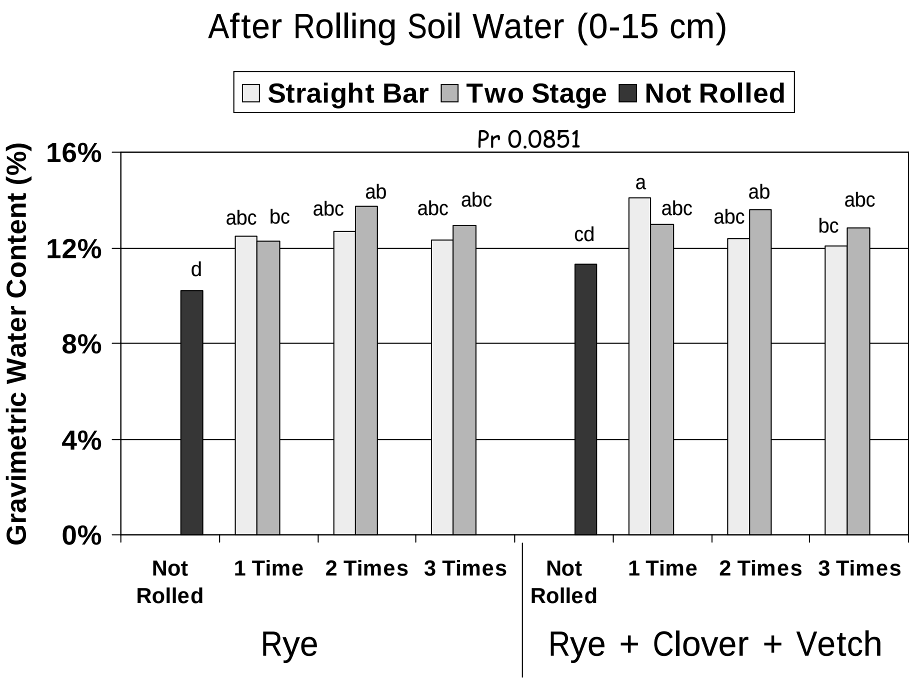

Figure 4. 2007 growing season: Gravimetric soil water content after rolling/crimping for both cover crops at 0-15 cm depth. Mean separation was performed using LSD (Fisher procedure) at α=0.1 significance level. Same letters indicate no statistical difference between all treatments (LSD=1.77%).

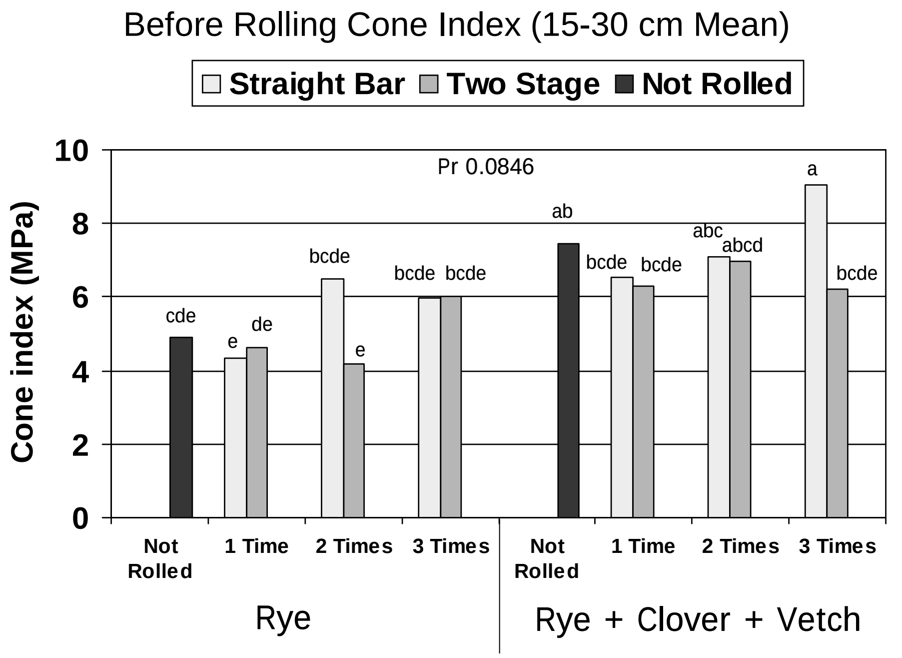

Figure 5. 2007 Growing Season: Soil Cone Index (CI) before rolling/crimping for both cover crops at the depth of 15-30 cm. Mean separation was performed using LSD (Fisher procedure) at α=0.1 significance level. Same letters indicate no statistical difference between all treatments (LSD=2.063 MPa).

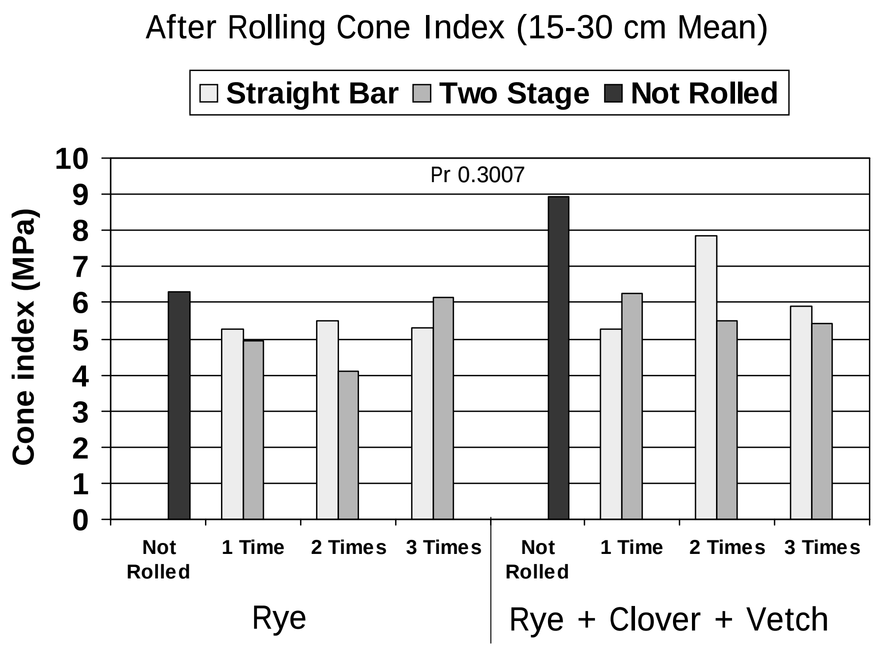

Figure 6. 2007 Growing Season: Soil Cone Index (CI) after rolling/crimping for both cover crops at the depth of 15-30 cm.

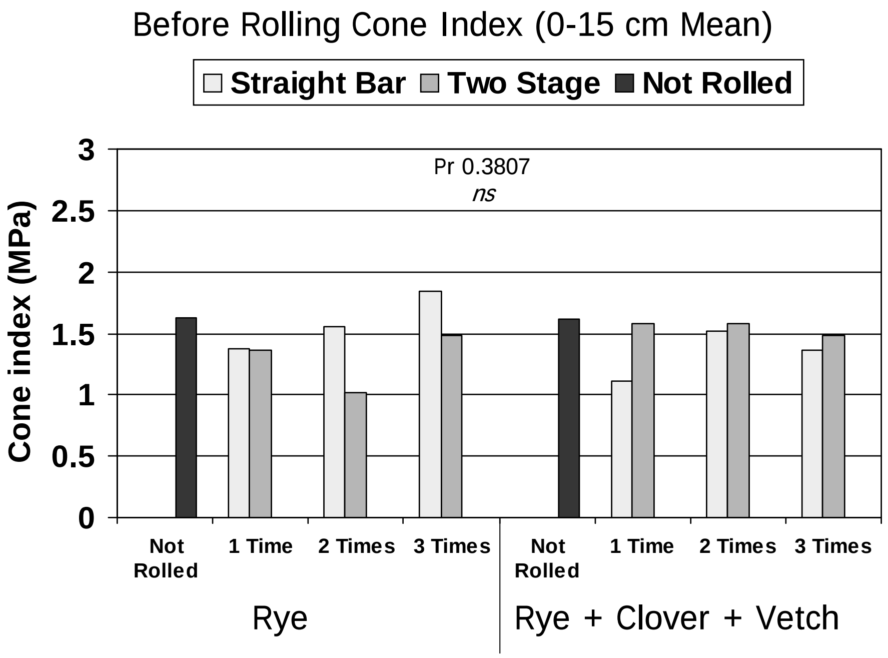

Figure 7. 2008 Growing Season: Soil Cone Index (CI) before rolling/crimping for both cover crops at the 0-15 cm layer.

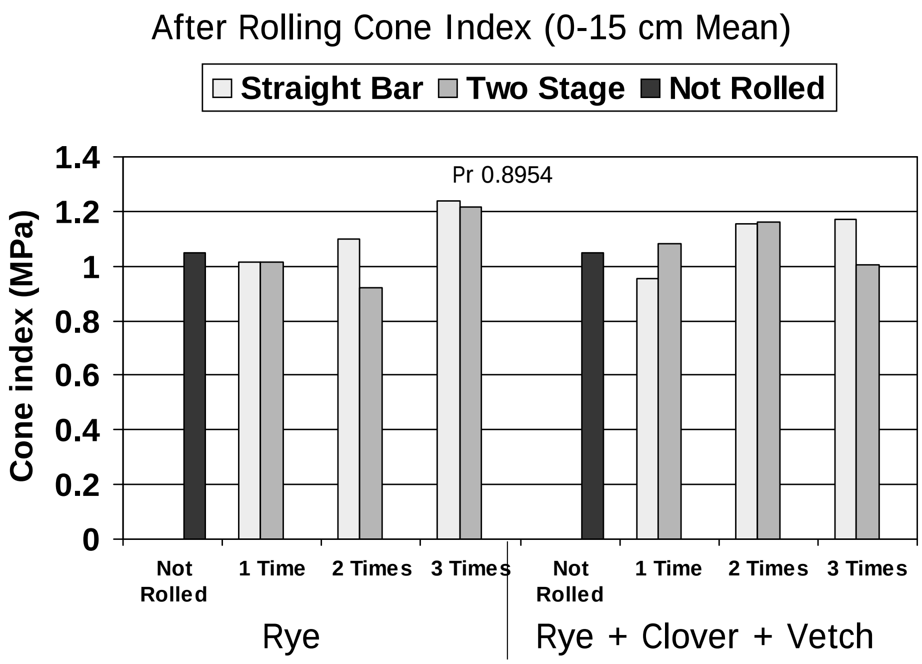

Figure 8. 2008 Growing Season: Soil Cone Index (CI) after rolling/crimping for both cover crops at the 0-15 cm layer.

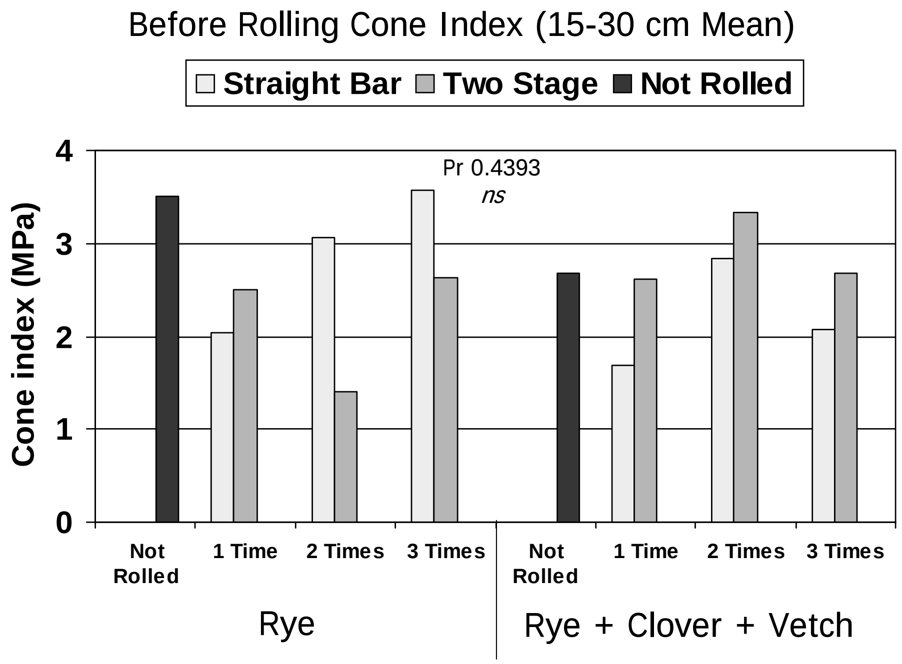

Figure 9. 2008 Growing Season: Soil Cone Index (CI) before rolling/crimping for both cover crops at the 15-30 cm depth.

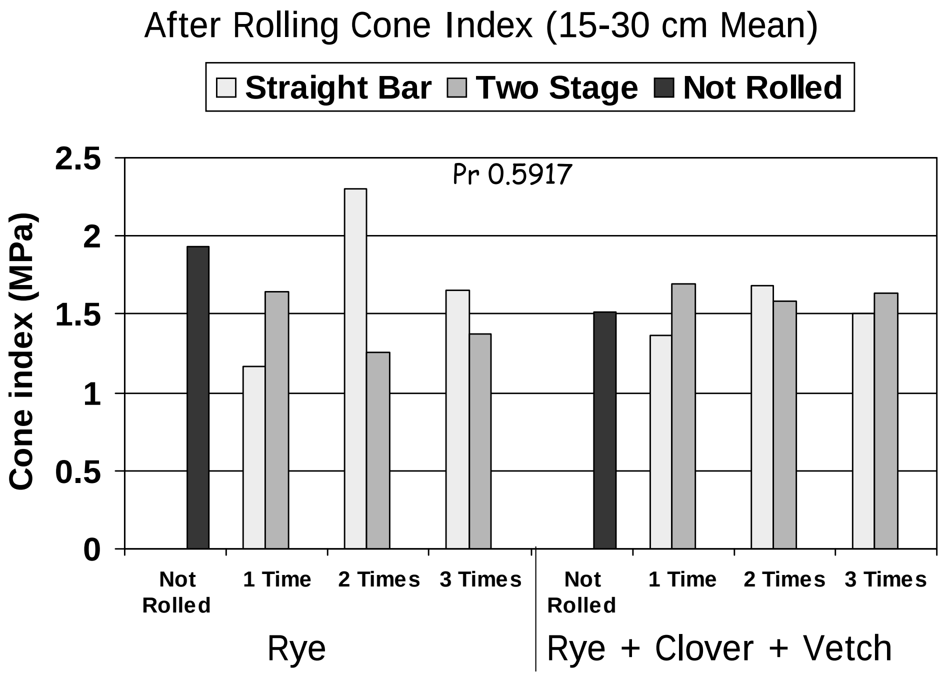

Figure 10. 2008 Growing Season: Soil Cone Index (CI) after rolling/crimping for both cover crops at the 15-30 cm depth.

SUMMARY AND CONCLUSION

- In 2007 and 2008 growing seasons, both roller types effectively terminated rye (> 90%) three weeks after rolling, which was above the recommended rye termination rates of 90% to plant a cash crop. In contrast, for the cover crop mixture (rye, crimson clover, and hairy vetch) termination rates were affected by recovered and actively growing hairy vetch during the three weeks of the evaluation period following the rolling operation.

- In spring of 2007, during a severe drought period, rolled cover crop residue helped to preserve volumetric soil moisture content (7%) up to 2 weeks after rolling compared to standing rye and mixture.
- Rolling two or three times did not cause soil compaction, and rolled residue kept soil strength (Cone Index) significantly lower compared to standing (untreated) cover crops. This was evident in the 2007 growing season during which a severe drought occurred and elevated soil strength for non-rolled residues, whereas rolled residue covers kept cone index lower and gravimetric soil water higher. Gravimetric soil water content after rolling residue once, twice, or three times was significantly higher compared to standing rye and the untreated mixture covers.
- In Alabama, multiple rolling can be beneficial for faster mechanical termination of single cover crops such as rye and the mixture (rye and crimson clover,) but not for mixtures which include hairy vetch. Mixtures with hairy vetch, even after three rolling operations exhibited active growth two and three weeks after rolling in both the 2007 and 2008 growing seasons.

Disclaimer:

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

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