Effects of rolling operations on cover crops termination, soil moisture, and soil strength in a Southeastern US no-till system

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Abstract
In the Southeastern US, three weeks are typically required after rolling/crimping cover crops before planting cash crops in no-till systems. To enhance cover crop termination, a supplemental application of herbicide is usually needed. However, herbicides cannot be used in organic production, thus requiring additional rolling operations, but multiple rolling operations might contribute to soil compaction, which could be detrimental for cash crop development. Our objectives were to determine the effectiveness of two roller designs in terminating rye and a mixture of rye, crimson clover, and hairy vetch in multiple rolling operations, and the effects on volumetric moisture content (VMC) and soil strength. In 2007, 2008, and 2009, two weeks after rolling, both roller designs terminated rye above 90%, which was the recommended rye termination 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 soil moisture conservation. Results indicated that VMC after three rolling operations was significantly higher compared with standing rye and untreated mixture. Multiple rolling can be beneficial for faster mechanical termination of cover crops but may not be adequate for mixtures that include hairy vetch.

Key Words
Cover crops, roller crimper, cone index, conservation agriculture.

Introduction
Cover crops are a key component of conservation agriculture, but they must be managed appropriately to optimize their benefits which include increased water infiltration, reduced soil erosion, runoff, and soil compaction (Revees 1994). Mechanical rollers/crimpers have been used to successfully terminate cover crops without herbicides (Derpsch *et al.* 1991) but should be used at least three weeks before planting a cash crop into rolled residue 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 due to accelerated rye senescence rye termination rates above 90% were sufficient to plant a cash crop. To speed up cover crops termination, producers utilize herbicides to supplement rolling/crimping. However, in organic vegetable production, commercial herbicides cannot be used. Because of this restriction, several rolling applications may be required to increase termination. However, there is a concern that additional soil compaction may occur which could be detrimental to water infiltration and cash crop root development. A three year (2007-2009) field study was conducted in northern Alabama, USA, to evaluate the effects of multiple rolling/crimping events on termination of two cover crops, soil strength, and soil moisture using two rollers in a replicated field experiment. Cover crop termination rates were evaluated one, two, and three weeks after rolling. The objectives of this study were: (1) Determine the effectiveness of a roller with straight bars, and a two-stage roller in terminating a single cover crop (rye, *Secale cereale* L.) and a mixture of rye, crimson clover (*Trifolium incarnatum* L.), and hairy vetch (*Vicia villosa* L.) in one, two, and three rolling applications, (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) before and after application of rolling treatments.

Methods
In the spring of 2007, 2008 and 2009, replicated field experiments were conducted in Cullman, Alabama, USA, with two cover crops: rye and a mixture (rye, hairy vetch, and crimson clover) using two different rollers for termination. Rye and the mixture were drill seeded with 17 cm row spacing in October 2006, 2007 and 2008. The rolling treatments were applied 23 April 2007, 30 April 2008, when rye was in the early milk growth stage, and 13 May 2009 in the soft dough stage. These stages are desirable for rye termination (Nelson *et al.* 1995). The rye was rolled parallel to the rows of the drilled winter rye cover crop using a 1.8 m

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

wide straight bar roller (Figure 1a) and the two stage roller (Figure 1b). Before and after rolling application, cone index data were obtained from non-trafficked areas (two per plot) using a mobile soil cone index (CI) penetrometer (Raper *et al.* 1999; Figure 1c) with stainless steel cone tips (ASAE 2004).

Soil strength measurements were repeated after three rolling/crimping operations, to determine the effect of multiple rolling on soil strength. The experiment was a randomized complete block design (RCBD) with four blocks (replications). Randomly assigned cover crops were rolled once, twice, and three times at 6.4 km/h and scheduled every other day from the previous rolling application. Injury (visual desiccation) of the rye and mixture 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. Volumetric moisture content was measured after the first, second, and third week using a portable TDR moisture meter with 12-cm long rods (Spectrum Technologies, Plainfield, Illinois). Rolling treatments were considered fixed effects and years were considered random effects. Analysis of variance (ANOVA) was performed on termination rates, VMC, and soil strength 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. Also, a preplanned single degree of freedom contrast procedure was performed to detect differences (α=0.10) between two specific means (SAS 2001).

Results

a. Cover crop termination rates

Since interactions between years and treatments (with respect to cover crops termination rates) were significant ($p<0.0001$), analyses of variance were done separately for each year. Termination rates for rye and the mixture from 2007-2009 are shown in Table 1.

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 Treatmen	Cover Crop	Roller type	2007, weeks after rolling			2008, weeks after rolling			2009, weeks after rolling		
			One	Two	Three	One	Two	Three	One	Two	Three
No rolled	Rye	No Roller	0.0f	39g	63cd	24e	44e	86b	75d	96ab	100a
	Mixture	No Roller	0.0f	21h	56d	21e	31e	49d	57e	81d	88c
Rolled 1 time	Rye	Straight	66e	80cd	91a	88a	90a	99a	96ab	100a	100a
		Two-Stage	68cde	83bc	91a	82a	89a	99a	97ab	99a	100a
	Mixture	Straight	68de	46fg	71bc	57cd	57d	60c	76d	87cd	92bc
		Two-Stage	69cde	46fg	71bc	54d	57d	61c	84c	86cd	91bc
Rolled 2 times	Rye	Straight	79ab	88abc	90a	82a	94a	100a	96ab	99a	100a
		Two-Stage	74bcd	86abc	93a	89a	95a	100a	98a	100a	100a
	Mixture	Straight	68de	53f	77b	62bcd	69b	67c	87c	89bc	96ab
		Two-Stage	75abc	64e	71bc	65b	66bc	67c	90c	89bc	94bc
Rolled 3 times	Rye	Straight	81a	90ab	94a	88a	95a	100a	98a	100a	100a
		Two-Stage	81a	91a	93a	85a	94a	100a	97ab	100a	100a
	Mixture	Straight	78ab	64e	71bc	64cd	69b	69c	95ab	96ab	96ab
		Two-Stage	78ab	73d	71bc	63bcd	66bc	67c	96ab	96ab	97ab
LSD at α = 0.1			6.8	8.6	8.4	8.4	9.2	10.2	7.1	7.7	6.2

In 2007, one week after rolling, significantly higher termination rates were reported for cover crops (rye and mixture) rolled three times compared to plots that were rolled once or non-rolled. Two weeks after rolling, lower termination rates were reported for the mixture compared to rye. 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 among roller types and number of rolling events. Compared to rolled residue, non-rolled covers showed 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 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, the mixture showed significant differences in termination rates between one rolling application (57%) and three applications (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 were most likely that the hairy vetch in the mixture was able to recover and actively grow during the intervening weeks. In the spring of 2008, volumetric moisture content was significantly higher than in 2007. This growth was also triggered by the fact that rye and crimson clover in the mixture were effectively killed by the third week after rolling and did not compete for nutrients and moisture, allowing the hairy vetch to recover. In 2009, because of substantial rainfall in the spring, rolling was done two weeks later than in 2008 which accelerated rye growth to soft dough stage. Since rye is more susceptible to termination at this stage, termination rates were higher one week after rolling compared to 2007 and 2008. One week after rolling all rolled treatments had higher termination rates compared to untreated checks. One and two weeks after rolling, higher termination for the mixture was found for rolling three times versus rolling once.

b. Volumetric Moisture Content (VMC)

VMC was measured on the day of rolling operation, one, two and three weeks after rolling. Comparing the three years of study, there was a significant difference in VMC among three growing seasons ($p<0.0001$).

Table 2. Mean VMC (%) for untreated rye and mixture and rolled residue during three growing seasons.

Year	2007			2008			2009		
Time after rolling	Week 1	Week 2	Week 3	Week 1	Week 2	Week 3	Week 1	Week 2	Week 3
Untreated Rye	13.8	4.8	2.1	22.6	16.7	20.9	17.6	22.8	17
Untreated mixture	13.8	4	2.3	22.7	18.4	19.9	18.1	23.2	17.5
Rolled Residue	14.4 ÷18.3	5.3 ÷8.1	2.8 ÷4.0	23.0 ÷24.8	19.1 ÷21.7	19.6 ÷ 22	21.4 ÷24.6	23.5 ÷ 25.9	20.8 ÷ 23.5

In 2007, a severe drought caused a major deficit of soil water. During the three weeks of evaluation after rolling in 2007, rainfall at the Cullman, AL, location was only 40 mm compared to 181 mm in 2008 and 214 mm in 2009. Average VMC measured over the three week period was 9.8% in 2007 compared to 22.7% in 2008 and 24.4% in 2009. In 2007 and 2008, no differences in VMC were found among treatments except for two weeks after rolling (Table 2). For untreated checks, VMC was lower (4.8% for rye and 4% for the mixture) compared to the rolled treatments (between 5.3 and 8.1%). This probably because of two factors: the untreated checks were actively growing, and the standing vegetation allowed more evaporation than the rolled plots. The lower VMC for the mixture compared to rye was most likely because the hairy vetch recovered from rolling and used available soil moisture (data not presented). Reeves (1994) reported that in several studies in the U.S., hairy vetch cover depleted soil moisture and delayed planting of cash crops. Due to drought in 2007, three weeks after rolling VMC decreased further (2.1% to 4%) and there were no differences in VMC among all treatments. In spring of 2008, one week after rolling, VMC was higher than in 2007 due to preceding rainfall (22.6% and 24.8%), and there were no differences in VMC among all treatments. Two weeks after rolling, VMC was higher for rolled residue (19.1 to 21.7%) compared to untreated checks (16.7% for rye and 18.4% for the mixture). Three weeks after rolling no differences in VMC were found among treatments (19.6 to 22%). In 2009, substantial rainfall during the evaluation period kept VMC high: after the first week VMC for checks was 17.6% for rye and 18.1% for mixture and 21.4 to 24.6% for rolled treatments. Similar VMC was measured in the second and the third week after rolling. Overall, the rolled residue protected the soil from moisture loss by creating a mulch effect; standing residue actively used moisture due to rye and mixture growth and allowed higher evaporation from exposed soil. The rolling helped to preserve VMC which is critical in drought periods such as in 2007 for successful cash crop establishment.

c. Soil Cone Index (CI)

In 2007, average CI value for the top layer (0-15 cm) for the untreated rye and mixture was 7.1 MPa and was significantly higher than for CI observed for rolled covers (4.15 MPa). CI for untreated checks were significantly higher compared to covers rolled once, twice and three times (P=0.0008 to 0.0002, probability table not presented). The higher CI found with untreated checks is most likely associated with decreased soil water content due to reduced surface cover of standing cover crops and evapotranspiration during the drought in spring of 2007. The CI for untreated checks exceeded (3 times) the 2.0 MPa recommendation for unrestricted root growth in cotton (Taylor and Gardner 1963).

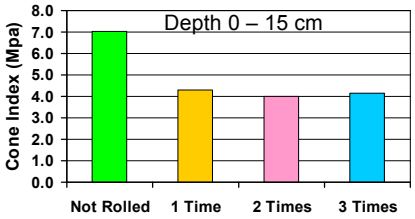

Figure 2a. 2007 CI after rolling

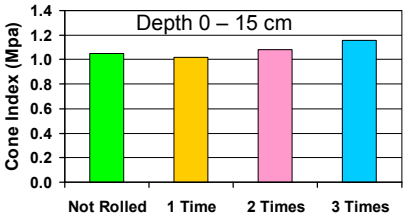

Figure 2b. 2008 CI after rolling

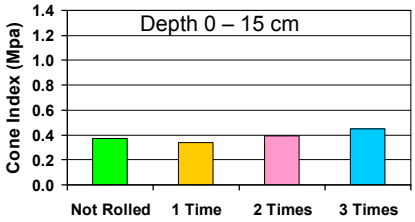

Figure 2c. 2009 CI after rolling

In 2008, after rolling treatment applications, no differences in CI (from 1.02MPa to 1.15MPa) existed at the top layer across all treatments including checks (Figure 2b). Corresponding probabilities were from 0.145 to 0.798. In 2009, the Cullman location received unusually high rainfall (214 mm) which caused delays in cover crop termination. During wet soil conditions, significantly higher CI were obtained from rolling 3 times versus untreated covers (P=0.016), rolling once (P=0.0002), and twice (P=0.0452), although these differences were very small. Despite these differences, CI was very low (0.34 to 0.42 MPa) and was related to the soil high moisture content.

Conclusion

During three growing seasons, rolling two or three times did not cause additional soil compaction, and rolled residue kept soil strength (Cone Index) significantly lower compared to standing cover crops due to cover crop termination and moisture conservation. VMC after three rolling operations was significantly higher compared with standing rye and mixture. Multiple rolling can be beneficial for faster mechanical termination of cover crops but may not be adequate for mixtures that include hairy vetch.

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