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Effectiveness of Cover Crop Termination Methods on No-Till Cantaloupe

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Abstract: In a no-till system, there are many different methods available for terminating cover crops. Mechanical termination, utilizing rolling and crimping technology, is one method that injures the plant without cutting the stems. Another popular and commercially available method is mowing, but this can cause problems with cover crop re-growth and loose residue interfering with the planter during cash crop planting. A field experiment was conducted over three growing seasons in northern Alabama to determine the effects of different cover crops and termination methods on cantaloupe yield in a no-till system. Crimson clover, cereal rye, and hairy vetch cover crops were terminated using two different roller-crimpers, including a two-stage roller-crimper for four-wheel tractors and a powered roller-crimper for a two-wheel walk-behind tractor. Cover crop termination rates were evaluated one, two, and three weeks after termination. Three weeks after rolling, a higher termination rate was found for flail mowing (92%) compared to lower termination rates for a two-stage roller (86%) and powered roller-crimper (85%), while the control termination rate was only 49%. There were no significant differences in cantaloupe yield among the rolling treatments, which averaged 38,666 kg ha^{-1}. However, yields were higher for cereal rye and hairy vetch cover crops (41,785 kg ha^{-1} and 42,000 kg ha^{-1}) compared to crimson clover (32,213 kg ha^{-1}).

Keywords: roller-crimper; no-till drill; mowing; walk-behind tractor; cover crop; cantaloupe seedlings

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1. Introduction

In conservation systems, cover crops are utilized to improve soil properties and to enhance cash crop growth. The benefits associated with cover crops include reduced soil erosion, reduced runoff, and increased infiltration and water holding capacity. According to Reeves [1], cover crops also provide weed suppression due to mulching and allelopathic effects, increased soil organic carbon, and reduced soil compaction.

Cover crops must be terminated at the appropriate growth stage to optimize biomass production and to create a thick mulch layer on the soil surface through which cash crops are direct seeded [2,3]. The planting of cash crops is performed by placing seeds into soil with desiccated cover crop residue on the soil surface. Thus, the proper management of cover crop residues is key to the effective no-till planting of cash crops into residue cover without interfering with the planting operation.

Common practice in accelerating the termination process is to utilize herbicides, such as glyphosate (Roundup™), as a supplement to rolling and crimping. This practice, however, is not permitted in organic systems, where the use of commercial herbicides is prohibited. Because of this restriction, mechanical termination must be as effective as chemical application. There are different cover crop management methods. One is mechanical termination utilizing rolling and crimping technology [4,5]. This requires injuring the plant with the crimping bars without severing stems. A roller-crimper flattens the plants and damages the stems with the crimping bars (equally spaced on the roller's drum), crushing them to enhance desiccation. The desiccated residue forms a thick layer of mulch over the topsoil to protect the soil surface from harmful rainfall energy, thus reducing soil erosion and runoff. It also reduces weed germination and growth, and conserves water for the subsequent cash crop [6].

Questions are often brought up about soil compaction when discussing reoccurring rolling and crimper over the same area. In response to these concerns, a field experiment was conducted by Kornecki et al. (2013) [7] to evaluate soil compaction during 2007–2009 at the Cullman, Alabama location after rolling cereal rye and mixture (rye, crimson clover, and hairy vetch) once, twice, or three times. Researchers [7] concluded that multiple rolling operations did not cause soil compaction on the non-wheel traffic area. During drought conditions in 2007, soil strength (a soil compaction indicator) for the rolled residue was 42% lower compared to the higher soil strength for cereal rye and mixture controls (7.2 MPa), implying that rolled down cover crops help reduced soil strength by covering the soil surface with a mulch layer and conserving moisture. Furthermore, rolling two or three times over the same non-wheel traffic area did not increase soil compaction. Higher gravimetric soil moisture in 2008 and 2009 lowered soil strength below 2 MPa, a critical value for root penetration resistance (Taylor and Gardner, 1963) [8].

Another field experiment conducted by Kornecki (2020) [9] with different roller-crimpers evaluated soil strength in both the plot area (area where only roller-crimper bars contacted) and in the tractor's wheel track, before and after rolling cover crops. This study indicated that rolling two or three times over the same plot area did not cause soil compaction either in the plot area or wheel track. Data also showed that for the top 15 cm of soil, the soil strength value did not surpass 2 MPa, a level of restriction for root penetration [8], and was solely related to changes in gravimetric soil moisture content (GMC).

A typical cover crop grown in the southern US is cereal rye (*Secale cereale* L.). It can produce between 3 to 11 metric tons ha^{-1} of biomass, providing benefits that include allelopathic weed suppression and a mulch effect due to improved soil surface cover [10]. Cereal rye has the potential to generate high amounts of biomass both above and below the soil. Rye is known for taking in unused nitrogen from previous crops (scavenging), as well as bringing up potassium near the soil surface via the root system. However, the benefit from the nitrogen uptake is often not noticed in the succeeding cash crop due to the slow mineralization after termination or maturity [11]. According to Ashford and Reeves [2], rye termination rates above 90% were sufficient to plant a cash crop into desiccated residue without competing for resources. Legume cover crops, such as crimson clover and hairy vetch, are also used in the southern US to produce biomass and fix nitrogen from the air, which can then serve as a nitrogen source for subsequent crops in organic production in which artificial fertilizers are prohibited [11]. Crimson clover can produce biomass in the range of 3923 to 6165 kg ha^{-1} of dry matter, whereas hairy vetch produces slightly less at a range of 2578 to 5604 kg ha^{-1} dry matter, with vines that can reach up to 3.7 m in length. Nitrogen fixation from crimson clover can provide from 78 to 168 kg ha^{-1} of nitrogen and even more for hairy vetch, which provides a range of 101 to 224 kg ha^{-1} [11].

In the southern US, the mechanical termination of cover crops should be performed at least 3 weeks before planting a cash crop into flattened residue to minimize competition for soil moisture and nutrients [12]. As with any method that leaves residue on the soil surface, mowing can interfere with planting operations. There is also a possibility for cover crop re-growth after mowing, depending on the species and timing of termination [13]. Nevertheless, mowing is an effective method for rapidly terminating a cover crop at its appropriate growth stage before seed development. Mowed residues are left on the soil surface, resulting in cooler, wetter soils compared to cover crops that have been terminated with tillage and then incorporated. Cash crops can be no-till planted into a mowed cover crop. Flail mowers contain many small, double-edged knives that uniformly distribute finely cut residue on the soil surface. They generally require more horsepower than rotary mowers and tend to leave residue more finely chopped and evenly distributed on the soil surface, which accelerates decomposition compared to sickle bar and rotary mowers (Barbercheck and Borrelli, 2020) [14].

Depending on the farm scale, fruit and vegetable producers use different power source sizes, including larger four-wheel tractors to small two-wheel walk-behind tractors. Therefore, producers need no-till equipment compatible with both large and small-scale power sources that are used on farms, especially since the number of urban farms producing fruit and vegetables for local farmers' markets in the USA has been increasing. This increase is driven by consumer demand for healthy and fresh locally grown produce. Local farms usually own light four-wheel tractors, such as Kubota (Kubota Tractor Corporation, Osaka, Japan), or small walk-behind tractors, such as BCS (BCS S.p.A, Abbiategrasso (MI)–Italy), which has interchangeable attachments (Kornecki, 2015) [15]. The majority of these small farms realize the benefits of utilizing cover crops that are widely promoted by USDA agencies, including the ARS and NRCS, to increase the sustainability of agriculture production. A factor limiting the adoption of cover crops is the lack of commercially available equipment needed to manage cover crops, such as roller-crimpers, that are compatible with different farm scales. In addition, the tradition of tilling soil for vegetable production is still strong in this region. Conventional tillage, however, causes increased soil erosion and nutrient loss, increases soil strength, and depletes soil organic carbon content [16,17].

Therefore, the objective of this study was to evaluate the effects of rolling and crimping and flail mowing crimson clover, cereal rye, and hairy vetch cover crops on cantaloupe yield in a no-till system.

2. Materials and Methods

A replicated field experiment was initiated in 2009 at the North Alabama Horticulture Research Center, in Cullman, Alabama (34.18° N; 86.85° W; 244 m above the sea level). The experiment was conducted on Hartsells fine sandy loam soil (fine-loamy, siliceous, sub-active, thermic Typic Hapludults) that had a bulk density of 1.49 g cm^{-3} and an organic matter content of 1.3%. Prior to this no-till cantaloupe experiment, a tomato test performed on plasticulture was conducted in the experimental area. Before planting cover crops for this test, the field was disked in the fall of 2009. No tillage was conducted between each growing season for this experiment.

The Hartsells soil consists of moderately deep, well-drained, moderately permeable, loamy residual soil, formed from weathered acidic sandstone, containing a thin band of shale or siltstone and comprising 11% clay, 26% silt, and 63% sand. At the top layer (depth from 0 to 127 mm), the soil is dark-grayish brown with a weak, fine granular structure. Here, it is very powdery, with many fine roots (10%) and sharp fragments of sandstone. In preparation for this test, a general analysis soil sample was collected that indicated a pH of 6.4 and in which liming was not recommended prior to initiating this test. The soil's CEC was 8.37, with extractable nutrients from the test results that include: phosphorus (p = 166 kg ha^{-1}), potassium (K = 290 kg ha^{-1}), magnesium (Mg = 229 kg ha^{-1}), and calcium (Ca = 2042 kg ha^{-1}), which were all at the optimum level (high or very high) for cantaloupe production. The main field activities at each growing season are shown in Table 1.

The experiment was a randomized complete block design (RCBD) in which three cover crops were used: crimson clover (*Trifolium incarnatum*, L.), cereal rye, and hairy vetch (*Vicia villosa*, L.). The selected cash crop for this experiment was cantaloupe (*Cucumis melo*, L.). The cover crop residue management treatments were assigned as depicted in Figure 1, with selected cover crops and their termination treatments (equipment).

Crimson clover, cereal rye, and hairy vetch were planted each fall (2009–2011) at a rate of 22 kg ha^{-1}, 112 kg ha^{-1}, and 22 kg ha^{-1}, respectively, utilizing a Tye no-till drill from AGCO Corporation, Duluth, GA, USA (Figure 2).

Table 1. Field activities at each growing season.

Field Activity	Growing Season		
	2010	**2011**	**2012**
Planting cover crops	5 November 2009	29 October 2010	2 November 2011
Collecting height and biomass of cover crops	12 May 2010	10 May 2011	16 April 2012
Collecting data at termination	13 May 2010	10 May 2011	19 April 2012
Rolled and mowed cover crops	13 May 2010	10 May 2011	19 April 2012
Collecting data one week after rolling	20 May 2010	17 May 2011	26 April 2012
Collecting data two weeks after rolling	27 May 2010	24 May 2011	3 May 2012
Collecting data three weeks after rolling	3 June 2010	31 May 2011	10 May 2012
Athena Var. Cantaloupe transplanted	6 June 2010	Tornado *	6 June 2012
Cantaloupe harvest 1	12 August 2010	N/A	27 July 2012
Cantaloupe harvest 2	17 August 2010	N/A	30 July 2012
Cantaloupe harvest 3	X	N/A	3 August 2012
Cantaloupe harvest 4	X	N/A	6 August 2012

* On 27 April 2011, an EF-4 tornado caused catastrophic damage to the research station, including fallen trees, structural damage of buildings and equipment, and accumulation of debris. Inability to obtain the cantaloupe seedlings and extensive cleanup and repairs did not allow the transplanting of cantaloupe seedlings in the 2011 growing season.

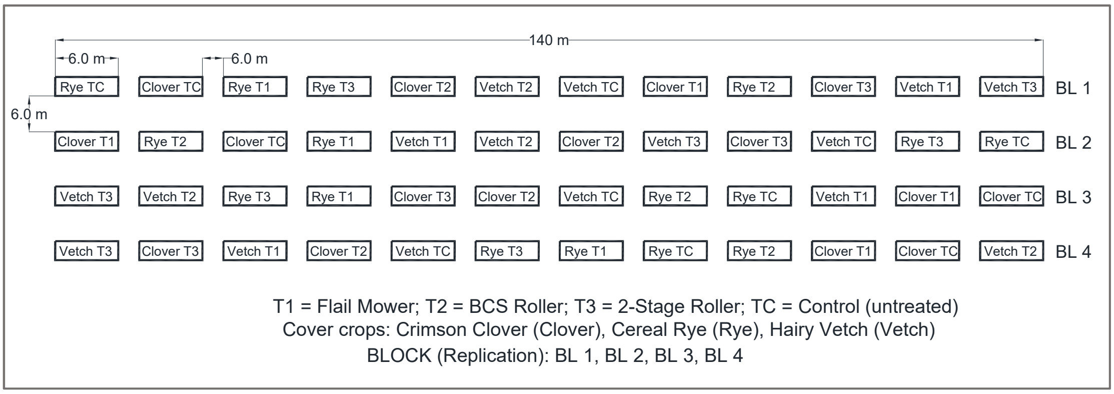

Figure 1. Experimental layout of the randomized complete block design to evaluate the effects of different management methods for selected cover crops on main crop cantaloupe yield (Athena variety, for which seedlings were obtained from Haynes Plant Farm in Cullman, AL, USA).

Figure 2. TYE Grain Drill Model No.: 124-530X, AGCO, Duluth, GA, USA.

In each spring (for the 2010–2012 growing seasons for cantaloupe) before rolling and crimping or flail mowing the cover crops, biomass samples from each plot were collected (0.25 m^2 sample area). Additionally, the plant heights (of 10 randomly selected plants per plot) for each cover crop were recorded. Biomass samples were oven dried using a programmable electric shelf oven, Model No. SC-400 [18], with forced convection air flow for 72 h at a temperature set to 55 °C (Grieve Corporation, Round Lake, IL, USA) to estimate the amount of dry biomass produced in each plot for each cover crop. The cereal rye cover crop was rolled and crimped at the early milk growth stage (Zadoks scale: #73; [19]), which is a desirable growth stage for termination that typically produces an optimum level of biomass [20]. Crimson clover was terminated at the early flowering stage [21] and hairy vetch was terminated at the 80% bloom stage [22], both of which are recommended growth stages for mechanical termination.

To terminate cover crops, two experimental roller-crimpers developed at NSDL were tested: a two-stage roller-crimper (Figure 3), and a powered roller-crimper (Figure 4). For comparison, a commercially available flail mower was utilized to manage cover crops, as the majority of farmers already own flail mowers on their farms (Figure 5).

The effectiveness of mechanical termination using roller-crimpers and flail mowers was compared with the untreated (non-rolled) cover crop. However, the control treatment with respect to cantaloupe yield was the flail mowing method. Transplanting cantaloupe into flail-mowed residue is a more practical operation for a no-till system. In contrast, in Alabama, planting the cantaloupe seedlings into an untreated, non-rolled cover crop is impractical.

Figure 3. Two-stage roller-crimper (1.8 m wide) (Multistage crop roller. Kornecki, 2011, US patent #7987917 B1) in crimson clover [23].

Figure 4. Powered roller-crimper (Kornecki, 2012, US patent # 8176991 B1) in hairy vetch. [24]; US patent #7987917 B1.

Figure 5. Flail mower (John Deere, Moline, Ill.) in cereal rye.

Cover crop termination rate data using the previously mentioned equipment were collected and evaluated 7, 14, and 21 days after treatment application, denoted as days after treatment (DAT), and compared to the control (non-rolled cover crops). During this period, volumetric soil moisture content (VMC) was also measured. The results were compared to the untreated cover crops. Termination rates were estimated using a handheld light sensor-based chlorophyll meter SPAD 502 (Konica-Minolta, Ramsey, NJ, USA). This portable sensor is capable of instantly measuring the chlorophyll content or "greenness" of plants. The SPAD 502 quantifies slight changes or trends in plant health long before they are visible to the human eye and provides a means of non-invasive measurement. The meter is clamped over leafy tissue and an indexed chlorophyll content reading (usually from 0 to 50.00) is recorded in less than 2 s. The data logging version of the SPAD 502 (item 2900DL) allowed for readings to be compiled more easily for statistical analysis. Since the state of the plant's greenness is related to its chlorophyll activity (e.g., 50 for healthy plants, and 0 for a dead plant with no chlorophyll activity), this concept was used to detect different stages of cover crop termination due to plant senescence from injury caused by mechanical termination using the roller-crimpers. To obtain an adequate assessment for each plot, five readings of plant tissue were collected in each plot by manually clamping the chlorophyll meter on randomly selected plants and storing the readings in the data logger. These five readings were averaged for each plot. Cover crop termination rates on a scale of 0% (no injury symptoms) to 100% (complete death of all plants) were based on a procedure described in Kornecki et al. [25]. The percentages of cover crop termination rates were transformed using an arcsine square root transformation method [26], but this transformation did not result in a change in the analysis of variance (ANOVA); thus, non-transformed means are presented. Similarly, volumetric water content (VWC in %) was measured (five readings per each plot and averaged) using a portable TDR 300 moisture meter with 0.12 m long rods from Spectrum Technologies (Aurora, Illinois). The selection of 0.12 m long stainless-steel rods was based on the necessity of determining the volumetric moisture content (VMC) and water availability in the root zone (~0.06 m depth) of the transplanted cantaloupe seedling. Monthly weather information for all growing seasons is presented in Figure 6 and includes rainfall, minimum temperature, and maximum temperature [27].

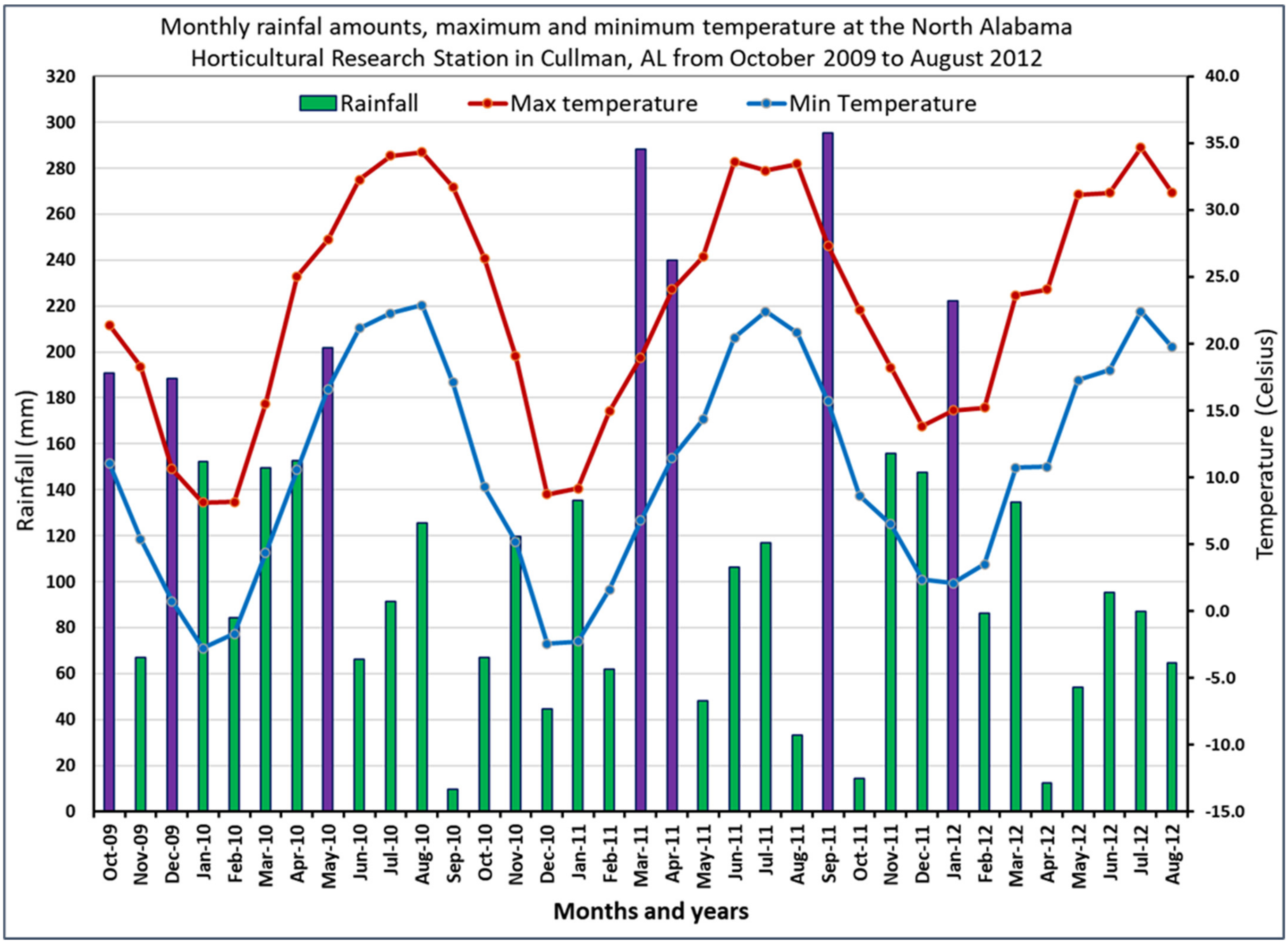

Figure 6. Monthly rainfall amounts (in mm) along with maximum and minimum temperatures in degrees Celsius during three growing seasons: October 2009 to August 2012 [27]. The purple color represents unusually high rainfall events that exceeded 190 mm of rainfall.

Three weeks after cover crop termination, the cantaloupe seedlings (cultivar Athena) were transplanted directly into cover crop residue utilizing a modified RJ one-row no-till vegetable transplanter (RJ Equipment, Blenheim, ON, Canada; Figure 7).

Figure 7. Modified RJ transplanter with added subsoiler shank to alleviate soil compaction while planting cantaloupe seedlings.

The commercially available transplanter was modified at the NSDL by outfitting it with a custom-built subframe and vertical subsoiling shank to alleviate soil compaction while transplanting the cantaloupe seedlings in a single operation. Prior to transplanting the cantaloupe seedlings, 43 kg ha^{-1} of nitrogen was applied to all plots using calcium nitrate.

Post-transplanting, 11.2 kg ha^{-1} of nitrogen was applied weekly, alternating between calcium nitrate and general purpose 20-20-20 water-soluble fertilizer. Weekly fertilization for the entire test was performed using drip irrigation.

Data were analyzed using the general linear model procedures in SAS PROC GLM (SAS Institute, 2016) [28]. All dependent variables were first analyzed to measure the effect of years as fixed effects, which was used to measure the magnitude of year interaction with cover crops and treatments. The treatment means were separated using the Fisher's protected least significant differences (LSD) test at the 10% probability level with respective probabilities (*p*-values), meaning there is a 10% chance that weather and nature could have contributed to the differences observed, which is common with agricultural field experiments. Cover and termination treatments were considered to be fixed effects and blocks were considered to be random effects [29]. Where interactions between treatments and weeks or years occurred, data were analyzed separately. In contrast, where no interactions were present, data were combined.

3. Results and Discussion

3.1. Plant Height and Biomass for Cover Crops

The analysis of variance results from three growing seasons with respect to cover crop production (Table 2) indicate that highly significant differences in biomass production were observed for the variables YEAR and COVER with significant interactions between these variables. Because of these differences, plant height and biomass for each cover crop ware analyzed separately for each cover crop, and for each year.

Table 2. Analysis of variance results for cover crops length and biomass.

Source	Degrees of Freedom	Cover Crop Height		Cover Crop Biomass	
		F-Value	Pr > F	F-Value	Pr > F
REP	3	0.78	0.5092	0.56	0.6458
YEAR	2	41.56	<0.0001	17.34	<0.0001
COVER	2	3446.77	<0.0001	46.46	<0.0001
YEAR*COVER	4	47.39	<0.0001	7.44	<0.0001

Plant height and biomass for each cover crop for each growing season are shown in Table 3. During the three growing seasons, significantly higher biomass production for crimson clover was obtained in 2010 and 2012, compared to 46% lower biomass in 2011. For cereal rye, significantly higher biomass was reported in 2012 compared to the lower biomass generated in 2010 and 2011. Similar to crimson clover, hairy vetch production was significantly higher in 2010 and 2012, compared to the 32% lower biomass obtained in 2011. Across the three years, average plant heights were 52 cm, 173 cm, and 78 cm for crimson clover, cereal rye, and hairy vetch, respectively.

Table 3. Plant height and biomass for crimson clover, cereal rye, and hairy vetch cover crops.

Growing Season	Crimson Clover		Cereal Rye		Hairy Vetch	
	Length of Plant (cm)	Biomass (kg/ha)	Length of Plant (cm)	Biomass (kg/ha)	Length of Plant (cm)	Biomass (kg/ha)
2010	47 b *	6973 a	150 b	7127 b	82 a	5249 a
2011	49 b	3583 b	188 a	8128 b	77 b	3605 b
2012	61 a	6317 a	182 a	12,108 a	75 b	5375 a
p-value	<0.0001	0.0005	<0.0001	<0.0001	0.0054	0.0558
LSD	2.4	1360	6.5	1583	3.8	1329

* Letters followed by the same lower-case letters within each column for each cover crop and year are not significantly different according to Fisher's least significant difference test ($\alpha = 0.10$).

3.2. Cover Crop Termination Rates

The ANOVA results indicate that the termination rates (%) for cover crops (crimson clover, cereal rye, and hairy vetch) were different for the variables YEAR, WEEK of evaluation, and TRT (termination treatments: flail mowing, rolled and crimped by two roller types, and untreated cover crops as the control). Because of these highly significant differences and significant YEAR*TRT interactions, data for the termination rates of crimson clover, cereal rye, and hairy vetch were analyzed separately for each year, week, and termination treatment. The analysis of variance results are presented in Table 4, and indicate that there were highly significant differences with respect to cover crop termination rates. These differences were detected for the variables year, treatment, week, and cover type. In addition, there were significant interactions for termination rates between YEAR and TRT, YEAR by COVER, and TRT*COVER, and therefore cover crop termination data were evaluated separately by year, week, cover, and termination treatment.

Table 4. Analysis of variance results for cover crop termination.

Source	Degrees of Freedom	Cover Crop Termination F-Value	Pr > F
YEAR	2	6.75	0.0013
TRT	3	614.57	<0.0001
WEEK	2	166.70	<0.0001
COVER	2	116.84	<0.0001
REP	3	3.51	0.0155
YEAR*COVER	4	21.34	<0.0001
YEAR*TRT	6	14.83	<0.0001
TRT*COVER	6	8.01	<0.0001

Table 5 presents the termination rate results for each cover crop by treatment and week over all three growing seasons. Significant differences were found among three weeks of evaluation (p-value < 0.0001) for all crops and treatments, with termination rates of 56%, 71%, and 78% for one, two, and three weeks after rolling, respectively. Similarly, significant differences in termination rates were found for termination treatments (p-value < 0.0001). Higher termination rates averaged across years and weeks and cover crops were associated with flail mower treatment (89%), followed by the two-stage roller-crimper (78%), compared to a lower rate for the BCS roller (75%). The termination rate for the untreated cover crop was 32%. Significant differences with respect to cover crops were found (p-value < 0.0001). Higher termination rates were observed for cereal rye (79%), compared to lower rates for crimson clover (64%) and hairy vetch (62%). However, there was no difference in termination rates between crimson clover and hairy vetch. Differences in termination rates also occurred between the years (p-value = 0.0013). Higher termination rates were reported in 2011 (71%) compared to 67% for termination rates in 2010 and 2012.

Table 5. Termination rates (%) averaged over three growing seasons for three cover crops and weeks of evaluation.

Termination Treatment	Cover Crop: Crimson Clover			Cereal Rye			Hairy Vetch		
	Days after Termination								
	7	14	21	7	14	21	7	14	21
Flail mower	72 a *	84 a	89 a	95 a	95 a	99 a	83 a	90 a	97 a
Two-stage roller	56 b	75 b	82 b	73 b	91 a	99 a	71 b	75 b	78 b
BCS roller	55 b	77 ab	80 b	69 b	94 a	99 a	55 c	70 b	76 b
Stand: control	13 c	34 c	50 c	23 c	44 b	69 b	10 d	19 c	28 c
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
LSD	9.0	7.3	5.5	7.6	8.2	5.7	8.1	6.7	7.9

* Same lower-case letters indicate no differences between treatments in each column at $\alpha = 0.10$.

Overall, the flail mower had the highest termination rate for every week and crop compared to the two-stage roller and BCS roller. All termination methods demonstrated similar performance when used with the cereal rye crop, which demonstrated a rate greater than 90% for both 14 and 21 days after termination (DAT). Even at 21 DAT for crimson clover, no method recorded 90% or above, indicating that there were difficulties in the termination for this crop. The BCS roller's highest termination rate for hairy vetch was 76% for 21 DAT, which was the lowest of all termination treatments, though it was not significantly different to the two-stage roller (78% at 21 DAT for hairy vetch) indicating that there were termination difficulties for the rollers for this crop.

Over three growing seasons, termination rates for each cover crop by week using flail mowing and different rollers (termination treatments) increased with time (weeks of evaluation) and are provided in Table 5.

3.2.1. Crimson Clover Termination

The results for the crimson clover termination rates over the three growing seasons are presented in Table 6. The 2010 season recorded termination rates at 7 DAT were again higher for the flail mower (80%) compared to lower termination rates for the BCS and two-stage rollers (53–64%). The untreated control had a 12% termination rate. At 14 DAT, no significant differences were observed among rolling treatments (80–84%) compared to very low termination rates for the control (26%). Similarly, at 21 DAT, no difference among mowing and rolling treatments was reported (87–93%) compared to lower rates (49%) for the control. The termination data for 2011 shows that both rollers were as effective at 14 and 21 DAT as the flail mower.

Table 6. Termination rates (%) for crimson clover during three weeks of evaluation in three growing seasons (2010–2012).

Termination Treatment	Growing Season								
	2010			2011			2012		
	Days after Termination								
	7	14	21	7	14	21	7	14	21
Flail mower	80 a *	84 a	93 a	56 a	91 a	86 a	81 a	77 a	88 a
Two-stage roller	64 b	83 a	90 a	49 a	74 b	83 b	53 b	68 a	72 b
BCS roller	53 b	80 a	87 a	58 a	83 ab	83 b	55 b	67 a	68 b
Stand: control	12 c	26 b	49 b	13 b	44 c	64 c	14 c	32 b	38 c
p-value	<0.0001	<0.0001	<0.0001	0.0109	0.0002	0.0003	0.0002	0.0002	<0.0001
LSD	13.0	12.8	8.2	21.0	11.8	6.2	15.0	11.5	8.9

* Same lower-case letters indicate no differences between treatments in each column at $\alpha = 0.10$.

In 2011, at 7 DAT, there were no differences in termination rates among flail mowing, the powered roller for BCS, and the two-stage roller (49% to 58%), and these rates were higher than the control (13%). At 14 DAT, these rates were higher (91% for the flail mower and 83% for the BCS) but lower for the two-stage roller (74%), while the control had the lowest termination rate at 44%. At 21 DAT, no differences in termination rates were found between the two-stage roller and BCS (83%), but the flail mower was significantly higher at 86%, compared to the lower termination rate of the control (64%).

In the final year of experiment in 2012, at 7 DAT, the highest termination rate of 81% was reported for the flail mower treatment compared to the 35% and 32% lower termination rate for the two-stage rollers and BCS, respectively. The control had a termination rate of 14%. At 14 DAT, the termination rates for all rolling treatments were between 67 and 77%, without significant differences among these treatments, indicating that the rollers were as effective as the flail mower. The control had a lower termination rate of 32%. At 21 DAT, flail mowing had significantly a higher termination rate of 88% compared to the lower termination rates for the BCS and two-stage rollers (68–72%); the lowest termination rate of 38% was for the control. These termination results agree with a prior experiment using a two-stage roller-crimper [30], which generated rates of 53.3%, 85.3%, and 90%, at 7, 14, and 21 DAT. Lower termination rates were observed for the control (untreated crimson clover), with 11.6%, 34.6%, and 56.3% for the same evaluation period. In another field experiment conducted on-farm [31], the termination rates for crimson clover caused by a 2.4 m wide two-stage roller-crimper were lower, with rates of 48%, 60.7%, and 83.7% at 7, 14, and 21 DAT, respectively. These lower rates were related to the ununiform soil surface across the wider 2.4 m roller where crimping bars were unable to effectively crush stems against the soil surface due to surface voids.

3.2.2. Cereal Rye Termination

The cereal rye termination rates by termination method, week, and growing season are shown in Table 7. In 2010, at 7 DAT, no differences in termination rates among rollers were reported, all of which generated termination rates from 59 to 62%. However, the flail mower was significantly highest at 7 DAT, with a 96% termination rate. These rates were all significantly higher than the control, which had only a 2% termination rate. At 14 and 21 DAT, all rolling treatments generated similar 80–89% and 96–99% rye termination rates, respectively, compared to lower rates for the control (7% at 14 DAT and 46% at 21 DAT). This data illustrates that the flail mower showed advanced termination at 7 DAT compared to the rollers, but that this advantage dissipated at 14 DAT and 21 DAT.

Table 7. Termination rates (%) for cereal rye during three weeks of evaluation in three growing seasons (2010–2012).

Termination Treatment	Growing Season								
	2010			2011			2012		
	Days after Termination								
	7	14	21	7	14	21	7	14	21
Flail-mowing	96 a *	89 a	96 a	93 a	98 a	100 a	97 a	98 a	100 a
Two-stage roller	62 b	80 a	99 a	85 a	100 a	100 a	72 b	93 a	98 a
BCS roller	59 b	87 a	97 a	82 a	99 a	100 a	66 b	95 a	98 a
Stand: control	2 c	7 b	46 b	30 b	64 b	85 b	35 c	62 b	77 b
p-value	<0.0001	<0.0001	<0.0001	0.0005	0.0002	0.0030	<0.0001	0.0002	<0.0001
LSD	8.9	8.4	3.6	17.9	7.8	6.2	7.9	9.1	4.3

* Same lower-case letters indicate no differences between treatments in each column at $\alpha = 0.10$.

In 2011, seven days after rolling, the flail mowing treatment generated a slightly higher, but not significantly different, rye termination rate of 93% compared to the lower termination rates of the BCS and two-stage rollers (82–85%). The control had the lowest termination rate of 30%. At 14 DAT, no significant differences in termination rates were reported among all rolling treatments, with termination rates from 98 to 100%, compared to lower rates of 64% for the control. Similarly, at 21 DAT, no differences were found among termination treatments, all of which generated a 100% termination rate, whereas termination for the control was only 85%.

In 2012, at seven days after rolling, significantly higher termination rates were reported for the flail mower (97%) compared to significantly lower termination rates (66% and 72%) for the BCS and two-stage rollers respectively; the control had only a 35% termination rate. At 14 days after rolling, the two-stage roller, BCS, and flail mower generated similarly higher rates (93%, 95%, and 98%) compared to control, which had a 62% termination rate. Likewise, at 21 DAT, there were no differences in termination rates among flail mowing and roller treatments (98% to 100%) compared to the lower rate for the control (77%). In summary, the rollers terminated cereal rye as well as the flail mower for all 14 and 21 DAT periods over all growing seasons. In a previous field experiment with a 1.8 m wide two-stage roller [30], the termination rates were higher (87%, 96%, and 100%) for the roller compared to lower rates (48.3%, 82.3%, and 95.6%) for the control at 7, 14, and 21 DAT. These results support the findings from this experiment. Similarly, in another field experiment conducted by Kornecki [32] with different roller-crimpers (1.8 m wide), the results indicated that the termination rates for the two-stage roller were 85%, 96%, and 99.7% at intervals 7, 14, and 21 DAT, with lower rates for the control (37.3%, 53.7%, and 86%) during the same evaluation period. The results for a field experiment conducted with rollers built for small walk-behind tractors by Kornecki [15] indicated that the powered roller-crimper generated higher termination rates of 82.4%, 89.6%, and 96.4% for 7, 14, and 21 DAT, whereas during the same evaluation period, the termination rates for the control were lower (29.2%, 44.2%, and 69.1%).

3.2.3. Hairy Vetch Termination

The results for the hairy vetch termination rates over the three growing seasons are presented in Table 8. In 2010, at 7 DAT, the two-stage roller and flail mower generated higher termination rates (85–87%) compared with lower rates for the BCS powered roller (56%). The control had only an 8% termination rate. At 14 DAT, the two-stage roller and flail mower continued to have significantly higher termination rates (85–92%) compared with the BCS roller, which had a rate of 69%, though the control had only 8%. At 21 DAT, there were no significant differences among all rolling treatments (89% to 92%), and these rates were higher than the control (19%).

Table 8. Termination rates (%) for hairy vetch during three weeks of evaluation in three growing seasons (2010–2012).

Termination Treatment	Growing Season								
	2010			2011			2012		
	Days after Termination								
	7	14	21	7	14	21	7	14	21
Flail mower	87 a *	92 a	92 a	87 a	87 a	87 a	73 a	91 a	93 a
Two-stage roller	85 a	85 a	91 a	58 b	80 b	75 ab	70 ab	60 b	68 b
BCS roller	56 b	69 b	89 a	46 b	78 b	67 b	63 b	62 b	73 b
Stand: control	8 c	8 c	19 b	6 c	24 c	38 c	14 c	25 c	26 c
p-value	<0.0001	<0.0001	<0.0001	0.0003	<0.0001	0.0013	<0.0001	<0.0001	<0.0001
LSD	7.0	9.6	9.4	19.5	4.1	14.7	7.7	9.6	9.2

* Same lower-case letters indicate no differences between treatments in each column at $\alpha = 0.10$.

In 2011, seven days after rolling, the flail mowing treatment generated a significantly higher termination rate of 87% compared to the lower termination rates of the BCS and two-stage rollers (46–58%). The control had a termination rate of 6%. At 14 DAT, the flail mower exhibited higher termination (87%) compared to the lower rates of the BCS roller and two-stage roller (78–80%); the control had rate of 24%. At 21 days after rolling, the two-stage roller and flail mower generated higher termination rates (78–87%) compared to the BCS roller (67%), but no significant difference between the rollers was found. The termination rate for the control was 38%.

In 2012, at 7 DAT, the two-stage roller and flail mower generated higher termination rates (70–73%) compared to the BCS roller (63%), but without significant differences between the rollers. The termination rate for the control was 14%. At 14 DAT, the flail mower generated higher termination rates (91%) compared to the two-stage and BCS rollers (60–62%). The control had a 25% termination rate. Similarly, at 21 DAT, the flail mower had significantly higher termination rates (93%) compared to the two-stage and BCS rollers (68–73%). The control had a 26% termination rate. The reduced effectiveness of the rollers for 2012 may have been caused by a series of rainfall events that occurred between 3 May to 10 May 2012. Heavy rainfall after applying the termination methods may have caused plant stems to rehydrate instead of desiccate compared to dryer conditions.

3.3. Cover Crop Volumetric Soil Moisture Content (VMC%)

The ANOVA results for the volumetric soil moisture content are presented in Table 9. Significant differences in VMC occurred among years (YEAR), termination treatments (TRT), covers (COVER), and weeks of evaluation (WEEK, *p*-values < 0.0001). In addition, there were significant interactions between YEAR by COVER and TRT by COVER. These differences were associated with different weather conditions, specifically precipitation in each growing season. Overall, the rolled cover crop residue provided better soil moisture conservation one, two, and three weeks after rolling compared to the untreated control by creating a uniform residue layer covering the soil surface. This layer extended the water holding capacity compared to the control standing crops.

Table 9. ANOVA table for Volumetric Moisture Content.

Source	Degrees of Freedom	Volumetric Water Content F-Value	Pr > F
YEAR	2	114.73	<0.0001
TRT	3	6.92	<0.0001
WEEK	2	68.50	<0.0001
COVER	2	11.69	<0.0001
REP	3	1.04	0.3733
YEAR*COVER	4	3.81	0.0041
YEAR*TRT	6	0.65	0.6801
TRT*COVER	6	2.40	0.0273

3.3.1. Crimson Clover VMC

Table 10 presents the VMC for the soil for crimson clover during the three growing seasons. In 2010, no differences in VMC with respect to residue management treatment were observed 7, 14 and 21 DAT with an average VMC of 18, 22, and 25%, respectively. Between 7 and 14 DAT, the site received 38 mm of rainfall, increasing the VMC for the 14 day interval. A similar weather pattern occurred between 14 and 21 DAT when 40 mm of rainfall fell on the experimental area, further increasing the soil VMC. The soil water conservation of cover crops is more profound during periods of less rainfall or drought periods compared to more rainy seasons.

Table 10. Volumetric moisture content (VMC in %) for crimson clover during three weeks of evaluation for three growing seasons.

Termination Treatment	Growing Season								
	2010			2011			2012		
	Days after Rolling and Crimping								
	7	14	21	7	14	21	7	14	21
Flail mower	20.8	24.3	26.5	16.1 a *	9.3	11.1	11.4 ab	35.2 a	25.7
Two-stage roller	18.5	22.7	24.0	14.6 ab	8.1	10.1	13.6 a	33.7 a	25.5
BCS roller	17.2	21.6	24.6	14.0 b	8.0	8.7	10.2 b	33.8 a	23.8
Stand: control	15.5	20.0	25.0	12.8 b	6.7	9.8	8.0 b	30.3 b	22.0
p-value LSD	0.4811 N/S	0.3660 N/S	0.7415 N/S	0.0792 2.0	0.2707 N/S	0.4279 N/S	0.0764 3.4	0.0529 2.8	0.1422 N/S

* Same lower-case letters indicate no differences between treatments in each column at $\alpha = 0.10$.

In 2011, at 7 DAT, a higher VMC was found for the flail mower (16.1%) and this was similar for the two-stage roller (14.6%) but higher than the BCS (14.0%). The control had 12.8%, which was similar to the BCS. At 14 and 21 DAT, no differences among residue management treatments were observed, with an average VMC of 8% and 10%, respectively.

In 2012, at 7 DAT, a higher VMC was observed for the two-stage roller (13.6%) followed by the flail mower (11.4%), although these were not significantly different. The VMC for the BCS was lower (10.2%), and the control was 8%, without any significance difference between the BCS roller, flail mower, and the control. At 14 DAT, an unusually high VMC was reported for all residue treatments (33.7% to 35.2%) without significant differences among treatments. The control was significantly lower at 30.3%. Despite differences between the treatments and the control, the VMC was obtained after a rainfall event in the amount of 22 mm (May 03, 2012) and this raised the VMC to an unusually high level, near soil saturation. At 21 DAT, there were no difference between the treatments and the control, with an average VMC of 24.3%, which maintained the high VMC between 14 and 21 days after rolling (May 3 to May 10) due to four additional rainfall events with a total rainfall of 15 mm. A lack of significant differences between the termination treatments and numerically lower VMC values for the control can be attributed to the ability of crimson clover to vegetatively expand and remain close to the soil surface, decreasing soil evaporation for the control. In addition, an inability for rollers to completely terminate crimson clover (most likely due to a non-uniform soil surface across the working width of the roller) might have contributed to the evapotranspiration of the surviving plants. Results from another field experiment [31] have shown that soil VMC due to rolling and crimping with a 2.4 m wide two-stage roller was higher (5.8%) compared to the lower soil VMC for tilled plots (4.4%) due to higher soil water evaporation and a lack of the soil surface cover.

3.3.2. Cereal Rye VMC

The soil VMC results for the cereal rye from the three growing seasons are presented in Table 11. In 2010, at 7 DAT, the highest VMC was obtained for flail mowing (16.6%) compared with lower a VMC for the two-stage and BCS rollers (13.3% to 14.5%). The control had the lowest VMC of 6.7%, which was 8.1% lower than the average VMC for all residue management treatments. At 14 days, a higher VMC was measured for the BCS roller and flail mower (22.1% and 25.0%) compared to a lower VMC of 21.8% for the BCS roller. The lowest VMC of 13.8% was found for the control (standing rye). The average VMC for the termination treatments was 23%, which was significantly higher than the control (13.8%). At 21 DAT, all rolling treatments had significantly higher VMC scores without differences among the termination treatments, which averaged 25.6% compared to the control, which had a VMC of 21.9%.

Table 11. Volumetric soil water content (VMC in %) for cereal rye during three weeks of evaluation for three growing seasons.

Termination Treatment	Growing Season								
	2010			2011			2012		
	Days after Rolling and Crimping								
	7	14	21	7	14	21	7	14	21
Flail mower	16.6 a *	25.0 a	25.0 a	16.6 a	11.1 a	16.4 b	9.2	34.4 a	26.1 a
Two-stage roller	13.3 b	21.8 b	26.0 a	18.2 a	13.3 a	19.0 a	8.6	32.3 ab	25.7 a
BCS roller	14.5 b	22.1 ab	25.9 a	17.9 a	12.3 a	17.5 ab	8.6	30.7 b	24.5 a
Stand: control	6.7 c	13.8 c	21.9 b	12.6 b	6.6 b	11.9 b	6.4	27.0 c	22.7 b
p-value	<0.0001	<0.0001	0.0136	0.0046	0.0064	0.0027	0.3326	0.0067	0.0161
LSD	1.9	2.2	2.0	2.2	2.7	2.5	N/S	2.9	1.6

* Same lower-case letters indicate no differences between treatments in each column at $\alpha = 0.10$.

In 2011, at 7 and 14 DAT, all residue management treatments had a significantly higher VMC without significant differences among these treatments compared to the control. The average VMC was 17.6% and 12.3% for the termination treatments, whereas the control had significantly lower VMCs of 12.6% and 6.6% at 7 and 14 days, respectively. At 21 DAT, the flattened rye residue had a higher VMC of 17.6% compared to the control of 11.9%.

In 2012, at 7 DAT, there were no differences in VMC among the termination treatments and the control (with VMC scores ranging from 6.4% to 9.2%). In contrast, at 14 days, the VMC for all residue management treatments was unusually high (from 30.7% to 34.4%) compared to a slightly lower VMC for the control (27%). This relatively higher VMC was caused by a 22 mm rainfall event on May 03, 2012, when the VMC was measured. This high VMC continued at 21 DAT due to additional rainfall events (15 mm) between the 14 and 21 day intervals. There were no differences in the VMC among the termination treatments, with an average VMC of 25.4%, compared to a lower VMC for the control (22.7%).

Overall, VMC data were related to the amounts of rainfall during the evaluation period. However, the data have consistently showed that rolled down rye has beneficial effects on soil water conservation compared to living plants. Flattening the cover crop against the soil surface reduces soil evaporation and reduces water intake and plant evapotranspiration.

These results agreed with other field experiments that have investigated the mechanical termination of cover crops. In a previous field experiment [30], during the 21 DAT of the evaluation period, the flattening and crimping of cereal rye by a two-stage roller-crimper retained a higher soil VMC (14.1%) compared to the untreated standing rye (12.7%). In another study [15], the soil VMC was higher (14.4%) due to the flattening and crimping of cereal rye by the powered roller for walk-behind tractors, compared to the lower soil VMC for the control (11.5%). Results from this and previous experiments [7,15,31,32] clearly indicate that flattening and crimping cereal rye on the soil surface provides improved soil coverage, which results in better soil water conservation (higher water holding capacity for soil) compared to unrolled cereal rye.

3.3.3. Hairy Vetch VMC

The results of the soil VMC for the hairy vetch from the three growing seasons are presented in Table 12. In 2010, for all three collection intervals (7, 14, and 21 DAT), no significant differences in VMC were reported between the termination treatments and the control. The average VMC was 19.8%, 24.3%, and 26.4% at 7, 14, and 21 DAT, respectively. This higher VMC during 2010 was associated with rainfall events that occurred during the observation period.

Table 12. Volumetric moisture content (VMC in %) for hairy vetch during three weeks of evaluation for three growing seasons.

Termination Treatment	Growing Season								
	2010			2011			2012		
	Days after Rolling and Crimping								
	7	14	21	7	14	21	7	14	21
Flail mower	16.9	22.7	25.5	17.8 b *	10.2 b	12.2 bc	12.2	34.1	26.0
Two-stage roller	18.6	24.4	26.2	22.4 a	15.3 a	18.4 a	14.2	35.8	27.0
BCS roller	20.8	24.6	26.0	21.0 a	14.2 a	15.9 ab	13.2	34.8	26.6
Stand: control	22.8	25.3	27.9	15.2 b	9.7 b	11.5 c	14.3	32.8	25.8
p-value	0.4305	0.4759	0.5214	0.0033	0.0155	0.0264	0.6727	0.3978	0.8889
LSD	N/S	N/S	N/S	2.7	3.0	3.7	N/S	N/S	N/S

* Same lower-case letters indicate no differences between treatments in each column at $\alpha = 0.10$.

Table 12 indicates that there were significant differences between termination treatments and the control for all weeks in the 2011 growing season for hairy vetch VMC. The weather patterns for this year contributed to this, noticed with the heaviest rainfall for all three growing seasons in April of 2011, followed by the least rainfall for May of 2011 out of the three years (Figure 6). The biomass production for 2011 was also the least (3605 kg ha^{-1}) out of all three growing seasons. The soil moisture left over from April slowly dissipated throughout the month of May, thus allowing termination treatments to show differences with the rolled and crimped treatments, whose VMC increased for all three weeks compared to the flail-mowed and control treatments. In 2011, at 7 DAT, a significantly lower VMC was reported for the flail mower (17.8%) compared to the two-stage roller and BCS (21% to 22.4%), but it was similar to the control (15.2%). Comparable results were obtained at 14 DAT, with a higher VMC found for the BCS and two-stage roller (14.2% and 15.3%) whereas the VMC for the flail mower and the control were lower (10.2% and 9.7%). At 21 DAT, the two-stage roller had the highest VMC (18.4%) followed by the not statistically different BCS (15.9%). However, the BCS and flail mower (12.2%) were similar, while the control had the lowest VMC for this interval with 11.5%. The results clearly indicate that rolling and crimping by either roller exhibited significantly a higher VMC compared to flail mowing and the control at 7, 14, and 21 DAT. The low biomass along with the heavy plant damage caused by the flail mower meant that the soil surface was loosely and unevenly covered, resulting in higher soil evaporation and moisture lost. In contrast, the rolled and crimped cover crops were pressed against the soil surface with stems left interconnected, thus not allowing more soil moisture to escape. This improvement in the soil surface coverage achieved by rolling resulted in better soil water conservation compared to the flail-mowed residue and the control.

Similar to the results obtained for the 2010 growing season, 2012 had no significant differences in VMC reported between termination treatments and the control, with average VMCs of 13.5%, 34.4%, and 26.4% at 7, 14, and 21 DAT, respectively.

3.4. Cantaloupe Production: Number Fruit ha^{-1}, Yield, and Fruit Weight

Analysis of variance results with respect to cantaloupe yield, number of fruits, and fruit weight are presented in Table 13 for two growing seasons. The results indicate that there were significant differences in cantaloupe yield and fruit number between COVER and YEAR, with significant interactions detected between the variables YEAR*COVER. For weight per fruit, significance was indicated for the relationship between YEARS and TRT. Because of these differences, the data were re-analyzed separately for each YEAR and COVER and the results are presented in Table 14.

Table 13. Analysis of variance results for cantaloupe production.

Source	Degrees of Freedom	Yield		Fruit Number		Fruit Weight	
		F-Value	Pr > F	F-Value	Pr > F	F-Value	Pr > F
REP	3	3.27	0.0279	2.74	0.0521	1.43	0.2446
COVER	2	4.21	0.0199	3.30	0.0442	1.81	0.1736
YEAR	1	183.13	<0.0001	183.71	<0.0001	28.52	<0.0001
TRT	2	0.12	0.8904	0.77	0.4676	2.57	0.0857
YEAR*TRT	2	0.21	0.8090	0.00	0.9972	2.12	0.1301
YEAR*Cover	2	2.64	0.0808	2.77	0.0713	0.21	0.8145

Table 14. Cantaloupe yield, fruit number, and fruit weight for rolling treatment (2010 and 2012 combined) and by each year for each cover crop.

Growing Season	Treatment (Combined) Cover Crop (Each Year)	Cantaloupe Yield (kg ha^{-1})	Number of Fruits ha^{-1}	Fruit Weight (kg)
2010 and 2012 combined	Flail mower	38,114	17,521	2.12 b *
	2-stage roller	39,739	17,970	2.10 ab
	BCS roller	38,145	16,136	2.25 a
	p-value	0.8904	0.4676	0.0875
	LSD	N/A	N/A	0.12
2010	Crimson Clover	49,946 b *	22,014 b	2.26
	Cereal Rye	68,019 a	28,678 a	2.34
	Hairy Vetch	61,875 a	26,506 a	2.34
	p-value	0.0374	0.0478	0.5446
	LSD	11,437	4420	N/S
2012	Crimson Clover	14,480 b	7862 b	1.90
	Cereal Rye	15,551 b	7563 b	2.04
	Hairy Vetch	22,124 a	10,632 a	2.07
	p-value	0.0409	0.0802	0.3625
	LSD	5231.5	2443.9	N/S

* Same lower-case letters indicate no differences between cover crops separately for each year (in respective columns) at $\alpha = 0.10$.

Cantaloupe yield was obtained only for two years (2010 and in 2012) due to tornado activity in 2011. Significant difference in cantaloupe yield was measured between years for all crops and years (p-value < 0.0199 for CROP; p-value < 0.0001 for YEAR), with the 2010 yield producing 59,947 kg ha^{-1}, and with 17,385 kg ha^{-1} in 2012. These differences were attributed to different climatic growing conditions and weed pressure. For all years combined, there were no significant differences in cantaloupe yield among termination treatments (38,144 to 39,739 kg ha^{-1}). In contrast, a higher yield was obtained for hairy vetch and cereal rye cover crops (41,785 to 42,000 kg ha^{-1}) compared to a lower yield for crimson clover (32,213 kg ha^{-1}). There was no difference in the number of fruits for rolling treatments (16,136 to 17,970 fruits ha^{-1}), whereas a higher fruit number was associated with hairy vetch (18,569 fruits ha^{-1}) and for cereal rye (18,120 fruits ha^{-1}) compared with a lower number (14,938 fruits ha^{-1}) for crimson clover. Cover crop did not affect the weight of the produced fruits, which ranged from 2.2 kg per fruit for hairy vetch, 2.19 kg per fruit for rye, to 2.08 kg per fruit for crimson clover.

For the 2010 growing season, crimson clover had the lowest yield with 49,946 kg ha^{-1} compared to cereal rye (68,019 kg ha^{-1}, depicted in Figure 8) and hairy vetch (61,875 kg ha^{-1}). Possible reasons for the reduced yield for the crimson clover may be due to the low termination rates (<90% at 21 DAT) noticed for the crop throughout the different termination methods. This could lead to competition for water and nutrients between the cash crop and cover crop. For fruit weight, a significant (p-value < 0.0001) difference between the years existed, with 2010 having an average fruit weight of 2.31 kg compared to a lower weight of 2.0 kg for 2012. Over the two growing seasons, significant differences in fruit weight occurred among rolling treatments (p-value = 0.0857), with a higher fruit weight for the powered roller, shown in Table 14 (2.25 kg), compared to a lower weight for the two-stage roller (2.10 kg) and for the flail-mowed residue (2.12 kg), without differences between these treatments (LSD = 0.12 kg). Moreover, over two growing seasons, fruit weight with respect to cover crop type indicated no significant difference in fruit weight among covers (p-value = 0.1736), with 2.20 kg, 2.19 kg, and 2.08 kg generated for hairy vetch, cereal rye, and crimson clover, respectively.

Figure 8. Cantaloupe fruits (Var: Athena) on cereal rye cover crop residue in 2010.

The yield response for the 2012 growing season was overall substantially less compared to 2010. No significant differences existed between the termination treatment for the yield and number of fruits ha^{-1}. However, significant differences existed between the cover crops for yield and number of fruits. Hairy vetch had a significantly higher yield with 22,124 kg ha^{-1} compared to statistically similar cereal rye (15,551 kg ha^{-1}) and crimson clover (14,480 kg ha^{-1}). Accordingly, the significantly highest number of fruits was collected for hairy vetch at 10,632 fruits ha^{-1}, compared with 7563 and 7862 fruits ha^{-1} for cereal rye and crimson clover, respectively. Although no differences in weight per fruit were observed for 2012, crimson clover had the lowest weight per fruit on average across the termination treatments with 1.90 kg per fruit, with hairy vetch having the heaviest at 2.07 kg, followed by cereal rye with 2.04 kg per fruit. The increased yield for the hairy vetch could be contributed to the nitrogen release and availability from the vetch to the cantaloupe. The lower yield across all cover crops in 2012 could be attributed to the increased weed populations during the third cover crop year, coupled with increases in June rainfall compared to the 2010 cantaloupe season. However, yield for all years is comparable to Bhardwaj [33], who reported a yield for muskmelon grown in hairy vetch ranging from 26.3 to 45 metric tons ha^{-1}. Moreover, a cantaloupe yield, grown in cereal rye, was reported from Campanelli et al. [34] with an average of 16.7 metric tons ha^{-1} and average fruit weight of 1.2 kg, which is similar to a yield in 2012 for cereal rye at 15,551 kg ha^{-1}.

4. Conclusions

Termination rates for all cover crops by the flail mower were higher compared to the roller-crimpers at one and two weeks after rolling. Three weeks after rolling, there were no differences by termination methods for rye. However, for hairy vetch and clover, higher termination rates were noticed using flail mowing. Cover crop termination methods did not have any effect on cantaloupe yield. However, cover crop type had a significant effect on cantaloupe yield and fruit number. Over two growing seasons, cover crop residue management treatments had no effect on the cantaloupe yield and fruit number, but it had an effect on the fruit weight. Based on these results, the highest yield was produced with a cereal rye cover crop and the lowest was with crimson clover. However, weather effects and inadequate cover crop termination for crimson clover contributed to reduced yields in cantaloupe production.

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References

1. Reeves, D.W. Cover crops and rotations. In *Advances in Soil Science: Crops Residue Management*; Hatfield, J.L., Stewart, B.A., Eds.; Lewis Publishers: Boca Raton, FL, USA, 1994; pp. 125–172.
2. Ashford, D.L.; Reeves, D.W. Use of a mechanical roller crimper as an alternative kill method for cover crop. *Am. J. Altern. Agric.* **2003**, *18*, 37–45. [CrossRef]
3. Kornecki, T.S.; Price, A.J. Effects of different roller/crimper designs and rolling speed on rye cover crop termination and seedcotton yield in a no-till system. *J. Cotton Sci.* **2011**, *14*, 212–220.
4. Nelson, J.E.; Kephart, K.D.; Bauer, A.; Connor, J.F. *Growth Stage of Wheat, Barley, and Wild Oat*; University of Missouri Extension Service: Columbia, MO, USA, 1995; pp. 1–20.
5. Kornecki, T.S.; Price, A.J.; Raper, R.L. Performance of different roller designs in terminating rye cover crop and reducing vibration. *Appl. Eng. Agric.* **2006**, *22*, 633–641. [CrossRef]
6. Derpsch, R.; Friedrich, T.; Kassam, A.; Hongwen, L. Current status of adoption of no-till farming in the world and some of its main benefits. *Int. J. Agric. Biol. Eng.* **2010**, *3*, 1–25. [CrossRef]
7. Kornecki, T.S.; Arriaga, F.J.; Price, A.J.; Balkcom, K.S. Effects of recurrent rolling/crimping operations on cover crop termination, soil moisture, and soil strength for conservation organic systems. *Appl. Eng. Agric.* **2013**, *29*, 841–850.
8. Taylor, H.M.; Gardner, H.R. Penetration of cotton seedling taproots as influenced by bulk density, moisture content, and strength of soil. *Soil Sci.* **1963**, *96*, 153–156. [CrossRef]
9. Kornecki, T.S. Influence of Recurrent Rolling/Crimping on Cover Crop Termination, Soil Strength and Yield in No-Till Cotton. *AgriEngineering* **2020**, *2*, 631–648. [CrossRef]
10. Barnes, J.P.; Putnam, A.R. Rye residues contribute weed suppression in no-tillage cropping systems. *J. Chem. Ecol.* **1983**, *9*, 45–57. [CrossRef] [PubMed]

11. Clark, A. (Ed.) *Managing Cover Crops Profitably*, 3rd ed.; Handbook Series Book 9; Sustainable Agriculture Research & Education (SARE): Beltsville, MD, USA, 2008; p. 244.
12. Hargrove, W.L.; Frye, W.W. The need for legume cover crops in conservation tillage production. In *The Role of Legumes in Conservation Tillage Systems*; Power, J.F., Ed.; Soil Conservation Society of America: Ankeny, IA, USA, 1987; pp. 1–5.
13. De Bruin, J.L.; Porter, P.M.; Jordan, N.R. Use of a Rye Cover Crop following Corn in Rotation with Soybean in the Upper Midwest. *Agron. J.* **2005**, *97*, 587–598. [CrossRef]
14. Barbercheck, M.; Borrelli, K. Terminating Winter Cover Crops in Organic Feed and Forage Crops. PennState Extension. 2020. Available online: https://extension.psu.edu/terminating-winter-cover-crops-in-organic-feed-and-forage-crops#:~{}:text=There%20is%20also%20a%20possibility%20for%20cover%20crop,soil%20surface%2C%20increasing%20the%20likelihood%20of%20effective%20termination (accessed on 16 August 2021).
15. Kornecki, T.S. Rye termination by different rollers/crimpers developed for no-till small-scale farms. *Appl. Eng. Agric.* **2015**, *31*, 849–856. [CrossRef]
16. Blough, R.F.; Jarrett, A.R.; Hamlett, J.M.; Shaw, M.D. Runoff and erosion water from silt, conventional, and chisel tillage under simulated rainfall. *Trans. ASAE* **1990**, *33*, 1557–1562. [CrossRef]
17. Mahboubi, A.A.; Lal, R.; Faussey, N.R. Twenty-eight years of tillage effects on two soils in Ohio. *Soil Sci. Soc. Am. J.* **1993**, *57*, 506–512. [CrossRef]
18. Grieve Corporation. Available online: https://www.grievecorp.com/product-category/shelf-loading-ovens/shelf-ovens/ (accessed on 2 July 2021).
19. Zadoks, J.C.; Chang, T.T.; Konzak, C.F. A decimal code for the growth stages of cereals. *Weed Res.* **1974**, *14*, 415–421. [CrossRef]
20. Balkcom, K.; Schomberg, H.; Reeves, W.; Clark, A.; Baumhardt, L.; Collins, H.; Delgado, J.; Duiker, S.; Kaspar, T.; Mitchell, J. Managing cover crops in conservation tillage systems. In *Managing Cover Crops Profitably*, 3rd ed.; Clark, J., Ed.; Handbook Series Book 9; Sustainable Agriculture Network: Beltsville, MD, USA, 2007; pp. 44–61.
21. Cover Crop Information Sheet. Clover, Crimson (*Trifolium incarnatum*). Southern Cover Crop Council. 2018. Available online: https://southerncovercrops.org/wp-content/uploads/2018/10/Clover-Crimson-Row-Crop-CP-Info-Sheet.pdf (accessed on 19 August 2021).
22. Cover Crop Information Sheet. Vetch, Hairy (*Vicia villosa*). Southern Cover Crop Council. 2018. Available online: https://southerncovercrops.org/wp-content/uploads/2018/10/Vetch-Hairy-Row-Crop-CP.pdf (accessed on 20 August 2021).
23. Kornecki, T.S. Multistage Crop Roller. U.S. Patent 7,987,917, 2 August 2011.
24. Kornecki, T.S. Powered Rolling and Crimping Device for Crop Termination. U.S. Patent 8,176,991, 15 May 2012.
25. Kornecki, T.S.; Arriaga, F.J.; Price, A.J. Evaluation of methods to assess termination rates of cover crops using visual and non-visible light active sensors. *Trans. ASABE* **2012**, *55*, 733–741. [CrossRef]
26. Steel, R.G.D.; Torrie, J.H. *Principles and Procedures of Statistics. A Biometrical Approach*, 2nd ed.; McGraw-Hill Publishing Company: New York, NY, USA, 1980.
27. AWIS Weather Services Home Page. Available online: http://www.awis.com/ (accessed on 23 June 2021).
28. SAS. *Proprietary Software Release 9.4*; SAS Institute, Inc.: Cary, NC, USA, 2016.
29. Gomez, K.A.; Gomez, A.A. *Statistical Procedures for Agricultural Research*, 2nd ed.; John Wiley & Sons, Inc.: New York, NY, USA, 1984.
30. Kornecki, T.S.; Price, A.J.; Balkcom, K.S. Cotton population and yield following different cover crops termination practices in an Alabama no-till system. *J. Cotton Sci.* **2015**, *19*, 375–386.
31. Kornecki, T.S.; Price, A.J. Management of High-Residue Cover Crops in a Conservation Tillage Organic Vegetable On-Farm Setting. *Agronomy* **2019**, *9*, 640. [CrossRef]
32. Kornecki, T.S. Effects of Different Rollers and Rye Termination Methods on Soil Moisture and Cotton Production in a No-Till System. *J. Cotton Sci.* **2020**, *24*, 197–210.
33. Bhardwaj, H.L. Muskmelon and sweet corn production with legume cover crops. *HortScience* **2006**, *41*, 1222–1225. [CrossRef]
34. Campanelli, G.; Testani, E.; Canali, S.; Ciaccia, C.; Leteo, F.; Trinchera, A. Effects of cereals as agro-ecological service crops and notill on organic melon, weeds and N dynamics. *Biol. Agric. Hortic.* **2019**, *35*, 275–287. [CrossRef]