CAFLA

CENTRAL ALBERTA FORAGE AND LIVESTOCK ASSOCIATION

Evaluation of Termination Methods for Cover Crops

2024 Project Report

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Introduction and Project Background

Within the agricultural industry, it is well known that decreasing the use of excessive tillage and implementing cover crops can have huge benefits on the health of the soil and the resulting crop yield. However, for organic producers in Alberta, without the ability to use herbicides, options for effectively terminating high biomass cover crops prior to reseeding can be limited (Kienlen 2024; Penn State Extension (2) 2023). As a result, many producers resort to multiple tillage passes to complete this task, however, this raises concerns about soil degradation as a result of over tillage (Frick 2012). To address this, farmers have turned to alternative methods to manage cover crop biomass, such as mowing and roller crimping, prior to a single pass of tillage to terminate (Frick 2012; Penn State Extension (2) 2023).

As shown in Figure 1, roller crimping involves utilizing a large steel cylinder with steel cleats welded at intervals around the diameter of the drum (Penn State Extension (2) 2023). This machine is then rolled over the cover crop, laying it down, and crimping the stalks of the plants as the cleats crush the plant material. These crimps do not sever the plant from its roots, however, they slow its growth and cause the plant to desiccate, thus eventually killing it and creating a mat of vegetation (Frick 2012; Penn State Extension (2) 2023). In contrast, a flail mower uses numerous spinning steel double-edged knives that sever the plant material from the roots and spread it over the top of the soil, thus creating a layer of finely chopped plant residue (Penn State Extension (2) 2023).

Figure 1. Image showing the construction of a roller crimper (Rite Way Mfg. Co. Ltd. n.d.).

Figure 2. Image showing the knife construction of a flail mower (Kuhn n.d.).

Current studies related to this topic suggest that while roller crimping can be effective for terminating cover crops under certain conditions, using mowing may result in a higher level of regrowth post-treatment (Hill and Sprague 2024; Penn State Extension (2) 2023). However, in combination with another termination technique, mowing is effective in removing high levels of biomass to increase the effectiveness of the treatment (Hill and

Sprague 2024). There is also evidence suggesting that roller crimping and mowing termination methods can impact total soil carbon and soil nitrogen due to the incorporation of plant residue (Kichler et al. 2023). Kichler et al. (2023) found that under cover crops, total soil carbon increased by 8% - 11%, while soil nitrogen increased 23% - 35% (Kichler et al. 2023). Studies further show that in certain regions, based on the soil type and climatic variances, cover crops may increase the availability of P, K, Ca, Fe, and Mg within the soil profile (Koudahe et al. 2022).

Project Objectives

Unfortunately, much of the current knowledge on these termination methods comes from the United States and thus does not necessarily apply to Alberta due to the differences in climate and growing season length (Kienlen 2022; Penn State Extension (2) 2023). To fill this gap, The Central Alberta Forage and Livestock Association (CAFLA), in partnership with the Battle River Research Group (BRRG) and Kettle Ridge Organics, developed the Evaluation of Termination Methods for Cover Crops project. The overall goal of this project was to quantify the effects of repeated mowing and roller crimping on a red clover cover crop in an Alberta context. The specific objectives of this study were to determine if mowing or roller crimping were effective for managing cover crop biomass prior to a single pass of tillage, to determine if multiple mowings or roller crimpings reduced or enhanced plant growth, and to determine if the different termination methods had an impact on the soil and/or vegetation nutrient content.

Methodology

This study took place on land owned and previously seeded to red clover by Kettle Ridge Organics, located at 40024 Range Road 240 Tees, AB. Onsite, ten 13' by 98' (4m x 30m) plots were established side by side, with the area being chosen to ensure similar topography across all plots. The plots were oriented with the 98' side running east/west, this ensured that the plots were perpendicular to the old chaff rows from the previous years cash crop. By doing so, all of the plots contained sections of the barley chaff rows, thus negating any potential impacts from this anomaly being isolated to a single plot. To facilitate easy identification of the plots for treatment and sampling purposes, the corners of each plot were marked with survey stakes and labelled as Plot 1 through 10 from north to south; this layout is shown in Figure 3.

Figure 3. Image showing the layout of Plots 1-10, facing south (Central Alberta Forage and Livestock Association – R. Caukill 2024).

Across the plots, the different treatment methods were alternated. As Figure 4 shows, Plots 1 and 2 were the positive and negative controls, while Plots 3, 5, 7, and 9 were subject to differing frequencies of mowing and Plots 4, 6, 8, and 10 had different frequencies of roller crimping. The frequency of these applications was determined by Kettle Ridge Organics based on what was felt to work best for their operation. Kettle Ridge Organics was also responsible for applying the treatments throughout the season as per the project schedule, with a single pass of each treatment being applied at each application date. The equipment used to achieve this was a 12’ roller crimper with offset cleats, a 10’ flail mower, and a 3 pt hitch rototiller. While the roller crimper and the mower were used for treatment application to their respective plots, the rototiller was used to simulate continual tillage on Plot 2. The plots which received a mow treatment were mown at 6” to ensure that there was sufficient vegetative material left for effective soil cover. Although Plots 3 to 8 were planned to be tilled to terminate mid season, due to the lack of soil moisture, Kettle Ridge Organics decided to stop the treatments on schedule but leave the plots untilled to reduce the risk of soil erosion. As a result, whether the treatments managed the biomass enough to allow for a single pass of tillage to terminate will be evaluated in the spring of 2025 along with all the other plots.

Plot Treatments:

- Blue code: Control plots
- Green code: Mow treatment plots
- Orange code: Roller crimp treatment plots

Plot 1: Full Growth Control – No treatments applied.
Plot 2: Summer Fallow Control – Till: June 5, June 25, July 15, Aug. 2, Sept. 5
Plot 3: Mow 1X & Till – Mow: July 15 – Till to terminate: Aug. 2 (May 2025)
Plot 4: Crimp 1X & Till – Roller Crimp: July 15 – Till to terminate: Aug. 2 (May 2025)
Plot 5: Mow 2X & Till – Mow: June 25, July 15 – Till to terminate: Aug. 2 (May 2025)
Plot 6: Crimp 2X & Till – Roller Crimp: June 25, July 15 – Till to terminate: Aug. 2 (May 2025)
Plot 7: Mow 3X & Till – Mow: June 5, June 25, July 15 – Till to terminate: Aug. 2 (May 2025)
Plot 8: Crimp 3X & Till – Roller Crimp: June 5, June 25, July 15 – Till to terminate: Aug. 2 (May 2025)
Plot 9: Mow 4X, No Till – Mow: June 5, July 10, Aug. 5, Sept. 5 – Till: May 2025
Plot 10: Crimp 4X, No Till – Roller Crimp: June 5, July 10, Aug. 5, Sept. 5 – Till: May 2025

Figure 4. Plot treatment schedule.

To assess the vegetation following treatment, samples were taken to evaluate total biomass production, as well as forage nutrient content. For the mowed plots, since the produced biomass is lost after each treatment, samples were taken prior to each mowing event. This was done by hand clipping all plant material above 6" from four randomly spaced 0.25m^2 quadrats within the plot to be treated. For plots with multiple mow passes, the next round of samples was taken adjacent to the previously sampled areas. Since roller crimping presses the vegetation into a mat, there is no lost vegetative material. As a result, roller crimped plots were sampled using the same protocol just prior to plot termination. Once samples were taken, they were bagged in labelled brown paper bags and then air dried for two to three weeks in the Battle River Research group's drying closet. Once dry, the dry weight was recorded. By adding the weights of each sampling round together, a cumulative weight for dry biomass grown above 6" was calculated for each plot. The samples were then delivered to Blue Rock Animal Nutrition for submission to A&L Labs to have a BRAN Nutrient Analysis completed (package is specific to Blue Rock Animal Nutrition). Figure 5 details what the BRAN Analysis covers, as well as its relative cost.

BRAN Nutrient Analysis ($55.00/sample)			
Includes	**Unit**	**Includes**	**Unit**
ESC (Simple Sugar)	%	Soluble Crude Protein	% of CP
pH	-	ADF-CP	%
Moisture	%	NDF-CP	%
Dry Matter	%	UIP (Bypass Protein)	Est. % of CP
Total Digestible Nutrients	%	Acid Detergent Fibre	%
Crude Protein	%	Lignin	%
Neutral Detergent Fibre	%	Starch	%
Calcium	%	Crude Fat	%
Phosphorus	%	Total Ash	%
Magnesium	%	NE Lactation	Mcal/kg
Potassium	%	NE Gain	Mcal/kg
Sulfur	%	NE Maintenance	Mcal/kg
Sodium	%	Total Digestible Nutrients (Weiss)	%
Copper	mg/kg	NE Lactation (Weiss)	Mcal/kg
Manganese	mg/kg	NE Gain (Weiss)	Mcal/kg
Zinc	mg/kg	NE Maintenance (Weiss)	Mcal/kg
Molybdenum	mg/kg	NFC	%
Iron	mg/kg		

Figure 5. Detailed overview of the BRAN Forage Nutrient Analysis from A&L Laboratories (A.A. Redman (P.Ag), personal communication, 2025).

In order to analyze the relationship between above ground and below ground growth, root samples were taken just prior to plot termination. The original plan was to take five samples from each plot, however, in practice ten soil cores approximately 0.75” in diameter by 3’ (1 m) in depth were required to have enough root mass for a single sample. As a result, the original plan was no longer practical. To address this, ten soil cores were taken from each of Plot 1, 2, 7, and 8 and compiled to create a single composite sample per plot. The plots that were sampled were selected to analyze the treatment extremes. These cores were then gently washed to remove soil and preserve the root material. Once dry, the dry weight of each sample was logged, and the samples were sent to Blue Rock Animal Nutrition for a nutrient analysis (A&L Labs – BRAN analysis). For the purposes of this study, the root samples are represented in US tons DM/acre to 3’ in depth. This unit can be considered as the dry matter weight of the belowground biomass under an acre of area to a depth of 3’ (1 m).

To allow for a comparison of soil health pre and post treatment, a baseline soil health sample was collected prior to treatments being applied. This was done by creating a single composite sample from ten 0.75” diameter soil cores across the trial area. To gain a representative sample, one soil core was taken from each plot. Each soil core was taken from 0” to 6” in depth and was located randomly across all ten plots. Post-treatment, plots one to ten were assessed by creating a composite sample of ten 0.75” diameter soil cores for each plot. The soil cores were taken from 0” to 6” in depth and the location within each plot was randomly selected. Plots 1, 2, 9, and 10 were reassessed on Oct. 5 using the same post-treatment protocol. For soil analysis in the lab, approximately 4 cups of soil were measured from each composite sample and bagged in labelled Ziploc bags. Bags were then stored on ice in a cooler or fridge until they reached Benalto Agri Services, where they were shipped to A&L Labs. For this study, the soil samples were assessed as per A&L Labs Complete Analysis package, what this package covers, as well as its price, is shown in Figure 6.

Complete Analysis ($50.00/sample)	
Includes	**Unit**
Organic Matter	%
Bicarb P	ppm
Bray P	ppm
Potassium	ppm
Magnesium	ppm
Calcium	ppm
Sulfur	ppm
Zinc	ppm
Manganese	ppm
Iron	ppm
Copper	ppm
Boron	ppm
Sodium	ppm
Aluminium	ppm
Soil pH	-
Buffer pH	-
K/Mg Ratio	-
Nitrate	ppm
Cation Exchange Capacity	meq/100g
% Base Saturation of Cations	%
% Saturation of Phosphorus	%

Figure 6. Detailed overview of the Complete Soil Analysis from A&L Laboratories (A&L Canada Laboratories 2024).

For the purposes of this project, the recorded values were calculated on a per plot basis. This allowed for comparisons to be made for vegetation biomass, vegetation nutrient content, and soil nutrient content between each plot treatment type. This information was then used to assess the success or failure of each plot treatment and thus the individual termination method.

Schedule

The GANTT Chart shown in Appendix A, covers in detail the approximate schedule that this study followed, however, in practice, the timetable was adjusted as needed to fit the schedule of those involved. The planning stage of this project began in May of 2024, with the final project design being finalized by early June. During this time, the funding letter of intent was also submitted to Results Driven Agriculture Research for consideration. On June 5, the plots were staked out and baseline soil samples were taken. Following setup, the first round of treatments was applied to Plots 2, 7, 8, 9, and 10, however, no vegetation samples were taken as no growth was above 6”. Soon after, on June 25, Plots 2, 5, and 7 were sampled and received treatment. In order to engage producers and industry with this project, an extension event was held on July 10, 2024. Leading up to this point, promotional material was released to the public to raise awareness of the event. During the event, Plot 9 was sampled, and the appropriate management strategies were administered to both Plots 9 and 10. Post-event on July 15, samples were taken from Plots 2, 3, 5, and 7 and the respective treatments were carried out. By August 2, the event report had been submitted and the final mowing and roller crimping passes had been completed on Plots 3 to 8. Following this, Plots 1, 2, 9, and 10 were continued, with sampling and treatments occurring on the fifth of each month prior to completion in October of 2024. After the final results from the lab were received, data analysis was completed by February of 2025, with the final report being prepared for project committee review in mid March. As mentioned previously, the effectiveness of the treatments for biomass management prior to tillage will be evaluated in May of 2025.

Discussion of Results

Vegetation Biomass Analysis

Aboveground Biomass

As shown in Appendix B, analysis of the project results found that Plot 9 had the highest overall vegetative biomass production at 2.70 US tons DM/acre. In contrast, if Plot 2 is ignored as the negative control, Plot 6 had the lowest biomass production at 1.48 US tons DM/acre. Appendix B also shows that the plots which were mowed trended towards a higher annual biomass production than those which were roller crimped. In comparing the standard deviations, Plots 3, 4, 6, and 8 experienced a significant reduction in biomass production compared to the Plot 1 control, while the mowed Plot 9 had significantly higher production compared to the roller crimped Plots 4, 6, and 8. This is likely seen as a result of the mowing treatment keeping the plants vegetative, thus promoting regrowth (Grev 2022). Overall, for management and termination of cover crops based on limiting biomass production, the most successful treatment was seen to be Plot 6, however, since Plot 9 is mown, the additional biomass is in a form that may be easier to incorporate into the soil. As a result, if the production of Plot 9 can be successfully managed with a single tillage pass, it has the potential to add more plant residue to the soil as green manure. Based on the experience of Kettle Ridge Organics, it is expected that when tested in the spring, all of the plots will be successfully managed with a single pass of tillage.

Belowground Biomass

The dry matter weight of the root samples ranged from 0.45 US tons/acre to 3’ in depth (Plot 2) to 5.23 US tons/acre to 3’ in depth (Plot 7) (Table 1). Both the mowed (Plot 7) and roller crimped plot (Plot 8) were seen to have higher root production than the control, with the mowed Plot 7 being found to have the highest belowground biomass production. This is likely seen as a result of the mowing treatment promoting increased root growth (Li et al. 2022). By applying light mowing treatments and mowing the plants high (6”), the ground cover is reduced without negatively impacting the overall plant, thus promoting increased root growth (Li et al. 2022). Based on this, of the plots sampled for root mass, the treatment applied to Plot 7 was selected as the best to maximize belowground biomass production.

Table 1. Annual belowground dry biomass production of red clover (root biomass).

Plot #	DM Weight (US tons DM/acre to a depth of 3' (1m))
1	2.04
2	0.45
7	5.23
8	3.86

Vegetation Nutrient Analysis

Aboveground Biomass

When evaluating the nutrient content of the red clover cover crop, the levels of total digestible nutrients, crude protein, neutral detergent fibre, calcium, phosphorus, and sulfur were identified as critical to evaluate the quality of forage produced (A.A. Redman (P.Ag), personal communication, 2025). To compare the recorded levels of each nutrient between plots, a Kruskal-Wallis Test with Pairwise Comparison was run.

The level of total digestible nutrients, or %TDN, was used to evaluate the energy content of the feed. This was based on the digestible fibre, fat, protein, and carbohydrate content of the forage samples (Montana State University n.d.; Van Emon et al. 2016). In comparison, samples with a higher %TDN are considered to be a higher quality forage and thus a higher %TDN is more desirable (A.A. Redman (P.Ag), personal communication, 2025). For this study, Plots 5 and 7 had a higher energy content and were a higher quality feed than Plot 1, while Plot 10 had less energy and was a lower quality feed than Plots 5, 7, and 9. Table 2 presents these results. Overall, this suggests that mowing at a higher frequency results in a higher energy content and a higher quality feed than if the crop is left untouched or, in certain instances, if roller crimping is used. This is likely because of the mowing frequency keeping the plant in a younger, more vegetative state, thus keeping the fibre content lower and %TDN higher (Government of Manitoba (1) n.d.). In comparison, the roller crimped plots and Plot 1, mature steadily throughout the season, which results in an increased fibre content and decreased %TDN as they age (Rotz 2003). To maximize %TDN, this study suggests that the mowing treatment applied to Plot 7 be employed as Plot 7 was seen to have the highest %TDN.

Table 2. Percent content of total digestible nutrients within vegetation samples per plot.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Median (%)	**58.64**	**No Data**	**59.73**	**58.32**	**64.66**	**58.85**	**65.09**	**59.23**	**62.27**	**52.57**
Rank Sum	154.00	No Data	211.00	71.00	606.00	89.00	608.00	84.00	507.00	16.00
Count	8	No Data	8	4	12	4	12	4	12	4
Average Rank	19.25	No Data	26.38	17.75	50.50	22.25	50.67	21.00	42.25	4.00

An increase in the fibre content of forages also has an impact on the crude protein content, with the level of crude protein decreasing as the proportion of fibre increases (Penn State Extension (1) 2023). Referring to Table 3, Plot 7 had a significantly higher protein content and was a higher quality forage than Plots 1 and 4, while Plot 10 had significantly less crude protein and was of lower quality than Plots 5, 7, and 9. In the same way the mowing frequency impacted the %TDN, it can be inferred that it also caused a higher percentage of crude protein to be present in the mowed plots compared to the roller crimped plots by keeping the plants vegetative (Government of Manitoba (1) n.d.). In a study on false wheatgrass, Zhao et al. (2021) found that the optimum annual mowing frequency to maximize crude protein content was three times per year. The results of the study by Zhao et al. (2021) are similar to the results for Plot 7, which was mowed three times and found to have the highest crude protein level. This implies that the mowing treatment applied to Plot 7 is the most effective to maximize crude protein content in a red clover cover crop.

Table 3. Percent content of crude protein within vegetation samples per plot.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Median (%)	**13.26**	**No Data**	**14.21**	**12.26**	**17.85**	**13.01**	**18.83**	**13.14**	**17.05**	**10.71**
Rank Sum	165.50	No Data	200.50	54.50	584.00	81.50	629.50	77.50	526.00	27.00
Count	8	No Data	8	4	12	4	12	4	12	4
Average Rank	20.69	No Data	25.06	13.63	48.67	20.38	52.46	19.38	43.83	6.75

Neutral detergent fibre, or NDF, is the proportion of cellulose, hemicellulose, and lignin that makes up part of the fibre content of forages (Montana State University 2012). This helps to determine the bulk and quality of the forage, thus a forage low in %NDF has a lower percentage of these fibre types and is higher in quality and less bulky than one which is high in %NDF (Montana State University 2012). Ideally, the %NDF of a forage will be below 60% (A.A. Redman (P.Ag), personal communication, 2025). Taking this into consideration, although Table 4 shows that all plots fall below 60% NDF, the mowed plots, with the exception of Plot 3, were seen to have the lowest %NDF. This means that the mowed plots are of higher quality and contain less bulk than the roller crimped plots. Overall, this result was seen as the mowing treatment kept the mowed plots vegetative, reducing the fibre content and increasing the digestibility (A.A. Redman (P.Ag), personal communication, 2025; Government of Manitoba (1) n.d.). This is the most apparent in Plots 5 and 7, with these two plots being of higher quality due to having a significantly lower %NDF than Plots 1 and 10. Forage from Plot 7 was also seen to be of higher quality than forage from Plots 3 and 4. Overall, the trends suggest that mowing the cover crop over roller crimping is a more effective method to reduce higher levels of neutral detergent fibre and increase the quality and digestibility of the forage. Of the mowed plots, Plot 7 was seen to be the best treatment to minimize %NDF.

Table 4. Percent content of neutral detergent fibre within vegetation samples per plot.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Median (%)	**51.74**	**No Data**	**51.46**	**51.76**	**44.43**	**50.94**	**43.50**	**49.92**	**47.25**	**55.21**
Rank Sum	416.00	No Data	358.00	209.00	227.00	178.00	194.00	165.00	353.00	246.00
Count	8	No Data	8	4	12	4	12	4	12	4
Average Rank	52.00	No Data	44.75	52.25	18.92	44.50	16.17	41.25	29.42	61.50

Regarding the mineral content of the aboveground biomass, the calcium and phosphorus levels all trended higher within most of the mowed plots compared to those which were roller crimped. As shown in Table 5, the calcium content in Plots 5 and 9 was higher than that found in Plots 4 and 8, while Plot 9 was also found to have more calcium than Plots 3 and 6. Similarly, Table 6 indicates that higher phosphorus was found in the mowed Plots 5, 7, and 9 compared to Plots 1 and 10, while Plot 3 had significantly less phosphorus than Plots 5 and 7. Plot 7 was also found to have higher phosphorus than Plot 4. The reason that these minerals are found in higher concentrations in the mowed plots is for the same reasons as the other nutrients, namely that the mowing treatment keeps the vegetation within these plots in a younger, more vegetative state which retains a higher amount of minerals and keeps them available for use (Wrobel and Zielewicz 2019).

Table 5. Percent content of calcium within vegetation samples per plot.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Median (%)	**1.56**	**No Data**	**1.22**	**1.20**	**1.76**	**1.26**	**1.51**	**1.19**	**1.79**	**1.40**
Rank Sum	310.50	No Data	166.00	39.00	563.50	53.50	446.50	46.00	620.50	100.50
Count	8	No Data	8	4	12	4	12	4	12	4
Average Rank	38.81	No Data	20.75	9.75	46.96	13.38	37.21	11.50	51.71	25.13

Table 6. Percent content of phosphorus within vegetation samples per plot.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Median (%)	**0.11**	**No Data**	**0.12**	**0.10**	**0.18**	**0.14**	**0.19**	**0.14**	**0.18**	**0.07**
Rank Sum	130.00	No Data	161.00	59.50	578.00	95.00	649.00	108.50	542.50	22.50
Count	8	No Data	8	4	12	4	12	4	12	4
Average Rank	16.25	No Data	20.13	14.88	48.17	23.75	54.08	27.13	45.21	5.63

To provide a metric to quantify calcium and phosphorus levels within the vegetation, nutritional requirements of beef cattle were considered. Requirements for calcium in beef cattle range from 0.16% to 0.89%, while phosphorus ranges from 0.12% to 0.40% (Gadberry 2018). Within these ranges, the individual requirements of an animal are influenced by the age, gender, weight, and life stage of the animal (Gadberry 2018). Therefore, although the mowed plots have higher levels overall, all plots meet the minimum percent mineral requirements, with the exception of Plots 1, 4, and 10 for phosphorus. However, these minerals must also be in a ratio of between 1.5 to 7 Ca:P, with the ideal value being around 2 (A.A. Redman (P.Ag), personal communication, 2025). As shown in Table 7, due to the high calcium levels, all plots exceed the maximum of 7 Ca:P and, as a result, will require some level of phosphorus supplementation to equalize the ratio (A.A. Redman (P.Ag), personal communication, 2025). Overall, from a management perspective, the mowing treatment applied to Plot 7 provides the best balance of meeting the mineral requirements while minimizing the need for additional supplementation to maintain desired ratios.

Table 7. Calcium to phosphorus ratio within vegetation samples per plot.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Ca:P Ratio	14.14	No Data	10.13	12.00	10.06	9.30	7.92	8.50	9.92	21.54

In comparing sulfur, Plots 5 and 7 had higher sulfur levels than Plots 1, 3, 4, and 10 (Table 8). Certain cover crop mixes can be prone to accumulating sulfur and thus pose a danger for polio in beef cattle (A.A. Redman (P.Ag), personal communication, 2025). The results suggest that this is not a high risk for red clover as the sulfur content of all the plots fell well below the threshold risk value of 0.40% sulfur (Gadberry 2018).

Table 8. Percent content of sulfur within vegetation samples per plot.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Median (%)	**0.10**	**No Data**	**0.11**	**0.09**	**0.15**	**0.10**	**0.15**	**0.11**	**0.13**	**0.07**
Rank Sum	180.50	No Data	156.00	58.50	633.50	83.00	618.50	88.00	500.00	28.00
Count	8	No Data	8	4	12	4	12	4	12	4
Average Rank	22.56	No Data	19.50	14.63	52.79	20.75	51.54	22.00	41.67	7.00

Belowground Biomass

Across the plots sampled for belowground biomass, nutrient distributions were seen to differ slightly compared to the trends seen in the aboveground biomass. Plot 1 was found to have the highest percentage of total digestible nutrients (%TDN) at 54.06%, while the Plot 2 control had the least at 40.46% (Table 9). Results also showed that the mowed Plot 7 had a higher %TDN than what was seen in the roots of Plot 8. Comparatively, Plot 8 was found to have the highest percentage of crude protein at 10.31%, while Plot 7 had lower at 9.56%. The control Plots 1 and 2 were found to have 10.19% and 3.85% crude protein respectively. Results also showed that Plot 1 had the lowest percentage of neutral detergent fibre (%NDF) at 54.34%, compared to Plot 2 with the highest at 71.47%. Of the treated plots, Plot 7 had a lower %NDF (54.96%) than did Plot 8 (57.00%). These values show that Plot 1 had the highest %TDN, and lowest %NDF, while between the treated plots, the mowed Plot 7 was seen to have a higher nutrient content, with the exception of crude protein, and be of better quality than was the roller crimped Plot 8.

Table 9. Nutrient content of root samples from Plots 1, 2, 7, and 8.

Plot ID	Total Digestible Nutrients (%)	Crude Protein (%)	Neutral Detergent Fibre (%)	Calcium (%)	Phosphorus (%)	Sulfur (%)
Plot 1	54.06	10.19	54.34	0.87	0.09	0.12
Plot 2	40.46	3.85	71.47	0.93	0.06	0.06
Plot 7	53.47	9.56	54.96	1.17	0.11	0.17
Plot 8	47.69	10.31	57.00	1.23	0.10	0.13

As shown in Table 9, the roots of Plot 7 were found to have the highest phosphorus (0.11%) and sulfur content (0.17%), while Plot 8 had the highest calcium content (1.23%). Recorded values also indicated that Plot 7 had a calcium content of 1.17%, while Plot 8 had a phosphorus level of 0.10% and a sulfur level of 0.13%. In comparison, Plot 1 had levels of 0.87%, 0.09%, and 0.12% for calcium, phosphorus, and sulfur respectively. For further reference, belowground biomass from Plot 2 recorded values of 0.93% for calcium, 0.06% for phosphorus, and 0.06% for sulfur. Overall, the treated plots were seen to have the highest mineral content of the plots, with minor differences between the mow and roller crimp treatments.

These results are likely seen due to the increased root growth seen in Plot 7 and thus the increased fine root production (Luo et al. 2021). By increasing the fine root production, the concentration of nutrients will be higher as there is a higher concentration of nutrients within finer roots (Gordon and Jackson 2000). As a result, to maximize the nutrient content of the roots under a management regime, Plot 7 was seen to be the most effective treatment method overall.

Soil Nutrient Analysis

Unfortunately, the baseline soil samples were not submitted to A&L Labs but were processed by a different lab. As a result, when comparing the soil organic matter across the plots, the baseline value for total soil organic carbon cannot be directly compared to the later numbers for organic matter, as the soil organic carbon is but a component of the larger organic matter fraction (Edwards, 2021). However, as shown in Table 10, the soil organic matter that is found throughout the plots is sufficient and well within the ideal 4%

to 12% range that allows for the efficient and steady release of nutrients (D. Knopp (P.Ag), personal communication, 2025). Overall, the results suggest that mowing the cover crop results in slightly more soil organic matter than roller crimping, and that the plots with more mowing passes are capable of developing higher levels of organic matter than those with fewer passes. This noticeable difference is likely as a result of the cut plant biomass that is deposited on the soil surface by mowing (Penn State Extension 2007; Sustainable Agriculture Research and Education 2025). Compared to mowing, the mat of biomass that is created by roller crimping is slower to break down and be incorporated into the soil, as a result, the mowed plots will experience an increase in organic matter in a shorter time period than roller crimped plots (Penn State Extension (1) 2023). Due to this, the short sampling timeframe of this study is likely unable to accurately represent the true impact of roller crimping on the soil organic matter content. By increasing the mow passes over the plots, more cut plant biomass is deposited, thus increasing the plant biomass being converted to soil organic matter. Overall, this suggests that to maximize the organic matter content of the soil beneath a red clover cover crop, mowing is the most effective, with the treatment applied to Plot 9 being the best balance of timing and frequency.

Table 10. Soil organic carbon baseline (ppm) and percent soil organic matter per plot.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Baseline: Total Soil Organic Carbon (ppm)	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0
Aug. 2/24: Soil Organic Matter (%)	6.3	5.5	6.4	6.5	6.7	6.3	7.5	6.8	8.0	6.5
Oct. 5/24: Soil Organic Matter (%)	7.4	6.9	No Data	No Data	No Data	No Data	No Data	No Data	7.6	7.8

Throughout the plots, the base saturation of hydrogen (%H) was relatively high, this links directly to the low pH levels that were found and helps to explain the high acidity of the soil (D. Knopp (P.Ag), personal communication, 2025). As the base saturation of hydrogen increases, the number of hydrogen ions adsorbed onto the soil surface increases, thus displacing calcium ions and decreasing the soil pH (A&L Canada Laboratories 2013; D. Knopp (P.Ag), personal communication, 2025). As the ideal pH range is around 6.3 to 7, the pH levels shown by Table 11 are a potential concern for limiting the release of macronutrients due to low pH levels (D. Knopp (P.Ag), personal communication, 2025). To buffer the pH and decrease acidity, lime can be applied to increase the base saturation of calcium, thus reverting the process and increasing the number of calcium ions adsorbed onto the soil surface (A&L Canada Laboratories 2013; D. Knopp (P.Ag), personal communication, 2025). No trends between the pH of the mowed and the pH of the roller crimped plots were identified, suggesting the need for greater study. However, the pH of most of the plots was seen to increase in acidity, prior to becoming slightly less acidic in the fall. This is likely as a result of natural buffering of the acidic plant root exudates by microbial activity, resulting in a higher pH towards the end of the season (D. Knopp (P.Ag), personal communication, 2025).

Table 11. Soil pH and base saturation of hydrogen (%H) per plot.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Baseline: pH	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Baseline: %H	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
Aug. 2/24: pH	5.6	5.6	5.6	5.4	5.6	6.1	5.3	5.8	5.7	5.3
Aug. 2/24: %H	41.6	39.3	46.9	46.5	43.6	35.6	44.9	44.1	45.7	42.3
Oct. 5/24: pH	5.9	5.8	No Data	No Data	No Data	No Data	No Data	No Data	5.8	5.8
Oct. 5/24: %H	37.4	39.5	No Data	No Data	No Data	No Data	No Data	No Data	46.6	42.2

Although the nitrate nitrogen content of the plots was seen to be very low throughout the trial, the estimated nitrogen release, or ENR values, were higher relative to the concentration in the soil. This is detailed in Table 12. The ENR values, being closely linked to the organic matter content, represent the amount of nitrogen that is estimated to be released from the soil organic matter within a year (A&L Canada Laboratories n.d.; D. Knopp (P.Ag), personal communication, 2025). As a result, although the nitrogen concentration was low, the soil across the plots has a high potential to release nitrogen throughout the growing season (D. Knopp (P.Ag), personal communication, 2025). The higher concentration of nitrogen seen in Plot 2 shows that tillage can increase the available nitrogen in the short term through the incorporation of plant biomass, however, the lower ENR values also show the relative depletion of the incorporated organic matter and the inability of the tilled soil to release consistent amounts of nitrogen in the long term (Canisares et al. 2021; D. Knopp (P.Ag), personal communication, 2025). The difference in nitrogen concentration between the baseline value of 138.93 ppm and the later season values is likely as a result of the different test sensitivities between labs, as well as the uptake of the available nitrogen by plants as they begin growth, thus decreasing the concentration (D. Knopp (P.Ag), personal communication, 2025). Overall, the mowed plots tended to have a slightly higher ENR value than did the roller crimped plots; this relates back to the organic matter content and is likely due to the higher organic matter values seen in the mowed plots (D. Knopp (P.Ag), personal communication, 2025). Based on this, Plot 9 was selected as the best method to maximize the nitrogen content in the soil.

Table 12. Soil nitrogen content (ppm) and estimated nitrogen release (ENR)(lbs/acre) per plot.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Baseline: Nitrate Nitrogen (ppm)	138.93	138.93	138.93	138.93	138.93	138.93	138.93	138.93	138.93	138.93
Baseline: ENR (lbs/acre)	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
Aug. 2/24: Nitrate Nitrogen (ppm)	2	16	1	1	2	1	2	1	1	1
Aug. 2/24: ENR (lbs/acre)	76	68	77	78	80	76	88	81	93	78
Oct. 5/24: Nitrate Nitrogen (ppm)	1	13	No Data	No Data	No Data	No Data	No Data	No Data	1	1
Oct. 5/24: ENR (lbs/acre)	87	82	No Data	No Data	No Data	No Data	No Data	No Data	89	91

Although no visible trends were observed between the treatments, the phosphorus, potassium, and sulfur concentrations were all deemed to be sufficient for plant growth as shown in Tables 13 through 15 (A&L Canada Laboratories 2024; D. Knopp (P.Ag), personal communication, 2025). The percent saturation of phosphorus suggests that adequate levels are available, however, for the area that the project is located in around 9% saturation of phosphorus would be considered ideal (A&L Canada Laboratories 2024; D. Knopp (P.Ag), personal communication, 2025). Similarly, the base saturation of potassium across the plots is at the low end of acceptable, however, a value between 3% to 7% would be preferable to ensure enough potassium is available for plant uptake (A&L Canada Laboratories 2024; D. Knopp (P.Ag), personal communication, 2025). The sulfur content across the plots, although the results show that it is very low, is likely sufficient and the artificially low test values are because of the shallow sampling depth (6”) not accurately representing the true availability of sulfur (Government of Manitoba (2) n.d.). As sulfur is very mobile in the soil, samples would have to be taken to 24” to cover a larger area of the soil profile and gather more data on the concentration of sulfur within a larger area of the rooting zone (D. Knopp (P.Ag), personal communication, 2025; Government of Manitoba (2) n.d.).

Table 13. Soil phosphorus content (ppm) and percent saturation of phosphorus (%P) per plot.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Baseline: Phosphorus (ppm)	10.23	10.23	10.23	10.23	10.23	10.23	10.23	10.23	10.23	10.23
Baseline: %P	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
Aug. 2/24: Phosphorus (ppm)	43	38	39	43	42	39	40	39	45	43
Aug. 2/24: %P	7	6	6	7	7	7	7	7	7	7
Oct. 5/24: Phosphorus (ppm)	29	32	No Data	No Data	No Data	No Data	No Data	No Data	31	35
Oct. 5/24: %P	7	7	No Data	No Data	No Data	No Data	No Data	No Data	7	7

Table 14. Soil potassium content (ppm) and base saturation of potassium (%K) per plot.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Baseline: Potassium (ppm)	15.06	15.06	15.06	15.06	15.06	15.06	15.06	15.06	15.06	15.06
Baseline: %K	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7
Aug. 2/24: Potassium (ppm)	207	219	210	261	350	427	402	307	314	283
Aug. 2/24: %K	2.3	2.3	2.1	2.6	3.6	4.7	3.9	3.2	3.1	2.8
Oct. 5/24: Potassium (ppm)	146	161	No Data	No Data	No Data	No Data	No Data	No Data	192	220
Oct. 5/24: %K	1.7	1.9	No Data	No Data	No Data	No Data	No Data	No Data	2.1	2.5

Table 15. Soil sulfur content (ppm) per plot.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Baseline: Sulfur (ppm)	15.09	15.09	15.09	15.09	15.09	15.09	15.09	15.09	15.09	15.09
Aug. 2/24: Sulfur (ppm)	14.0	14.0	13.0	13.0	13.0	12.0	12.0	12.0	14.0	13.0
Oct. 5/24: Sulfur (ppm)	10.0	11.0	No Data	No Data	No Data	No Data	No Data	No Data	9.0	11.0

Conclusion

Overall, both mowing and roller crimping proved effective for managing biomass to reduce tillage, as well as for influencing, and in many cases, improving the nutrient content of the vegetation and the soil profile. However, mowing was seen to be the preferable treatment as it was consistently the highest performer. As per this study, to reduce tillage while enhancing forage quality, it is recommended that the cover crop be mown three times between the beginning of June and the middle of July. However, to reduce tillage while improving the soil nutrient content, mowing once a month from June until October was seen to be the best option. Ultimately, as both of the studied methods are viable, the decision on which to select, and what frequency to utilize, belongs to the producer and is based on the management strategies that are used.

Appendices

Appendix A – GANTT Chart

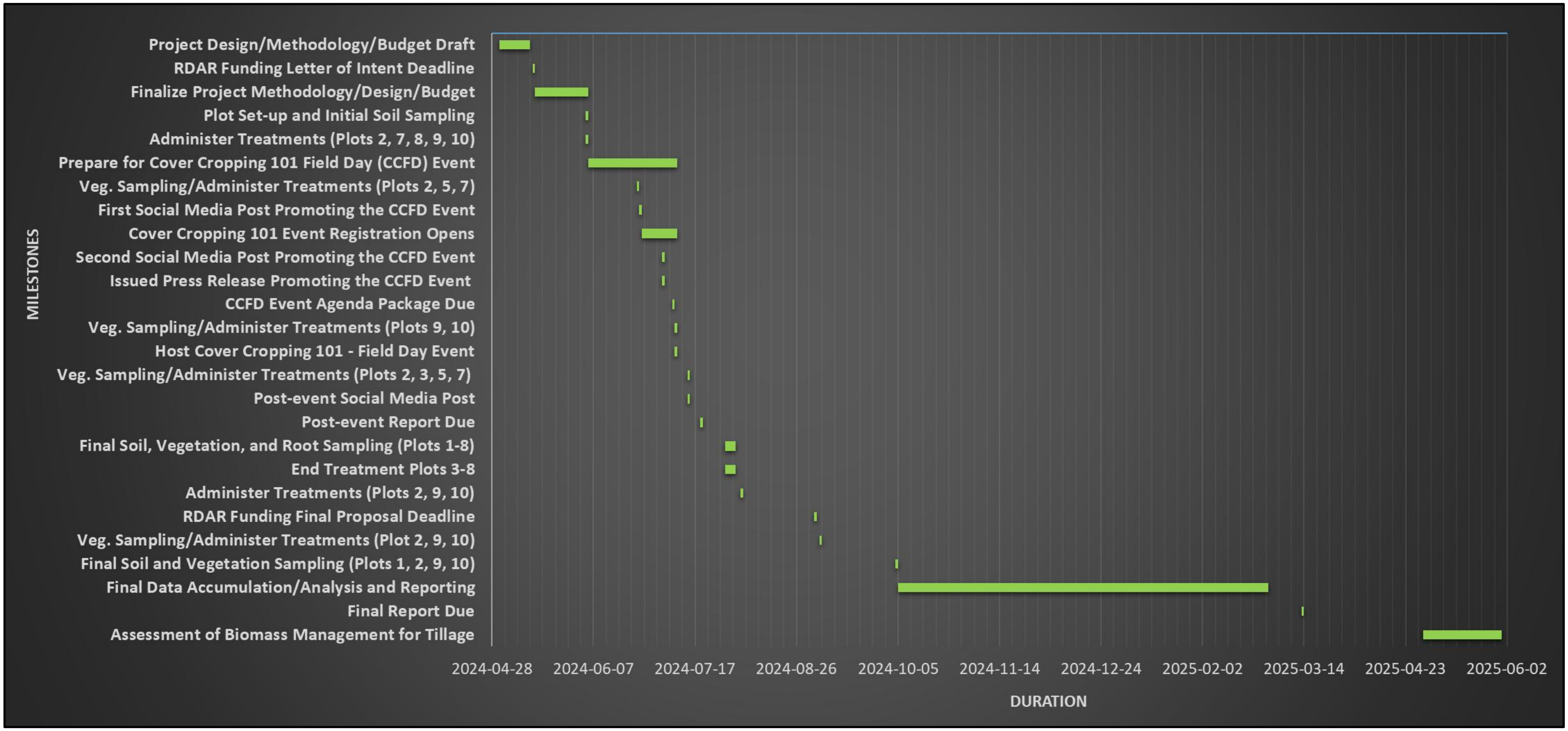

Figure A1. GANTT chart detailing the timeline for the Evaluation of Termination Methods for Cover Crops Project.

Appendix B – Aboveground Biomass Analysis

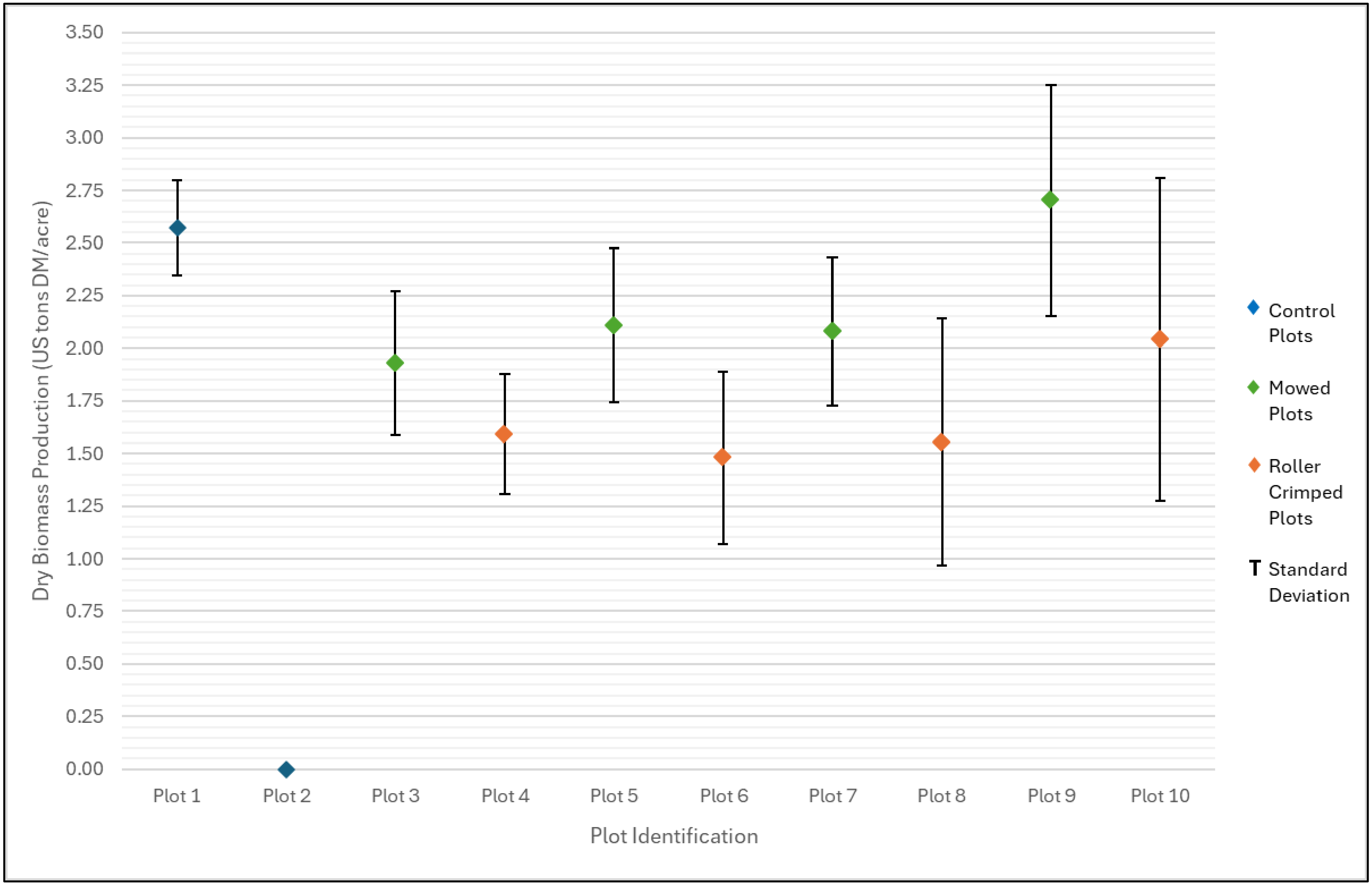

Figure B1. Annual dry biomass production of red clover above 6" (aboveground biomass).

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