THE EFFECTS OF SHEEP GRAZING FOR *PISUM SATIVUM* OR *MELILOTUS OFFICINALIS* COVER CROP TERMINATION

by

Jasmine Katherine Westbrook

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DEDICATION

Dedicated to my family, Arlene Samuels, Whitney Westbrook, and Katherine Westbrook, for their emotional support throughout this and every chapter of my education. Dedicated to Phillip Brassington, who recovered crucial data from a broken USB, without which, the project would have been lost, and provided endless support and encouragement. Finally, dedicated to Kahlan, who kept me together.

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ABSTRACT

Integration of sheep grazing into crop rotation systems has been proposed as an alternative to conventional cover crop management techniques. However, the effectiveness of this approach and its impact on subsequent crops has not been evaluated in Montana. This study assessed the use of sheep (*Ovis aries*) grazing to terminate field pea (*Pisum sativum*) and yellow sweetclover (*Melilotus officinalis)* cover crops used in rotation with winter wheat. Cover crops were terminated using either rotational or continuous grazing treatments and their effects on cover crop termination, sheep live weight gains, and winter wheat emergence and yield were quantified. Sheep grazing for cover crop termination was also compared to chemical termination and mechanical tillage.

In 2013, yearlings grazed the winter pea cover crop for 32 days. Sheep grazing was an effective termination method (77% dead, 1% live, 22% bare ground). Average daily gains (ADGs) did not differ between grazing treatments with sheep exhibiting ADGs of 0.181 kg day^{-1} for rotational (230 sheep ha^{-1})and 0.154 kg day^{-1} for continuous (57 sheep ha^{-1}) treatments (P = 0.12). Winter wheat seedling emergence post grazing was higher under the continuous grazing treatment (P = 0.017), however winter wheat yield did not differ between treatments (P = 0.91). Results indicated grazing was a viable method for terminating a pea cover crop.

In 2014, yearlings grazed the sweetclover cover crop for 40 days. Sheep grazing at stocking densities of 44 and 178 sheep ha^{-1} did not provide effective termination (40% dead, 34% live, 9% bare groundcover). Average daily gains did not differ between grazing treatments with sheep exhibiting ADGs of 0.177 kg day^{-1} for rotational and 0.172 kg day^{-1} for continuous treatments (p = 0.79). Termination was achieved using a second group of sheep at stocking densities of 119 and 477 sheep ha^{-1}. Winter wheat seedling emergence did not differ between grazing treatments (p = 0.95). Winter wheat yield was lower in grazed plots than tilled and chemically terminated plots. Grazing has the potential for effective cover crop termination comparable to tillage or herbicide, but results may vary with cover crop species.

INTRODUCTION

Livestock grazing and cropping systems have been successfully integrated internationally (Greenall, 1958; Mulholland et al., 1976; Allden and Geytenbeek, 1980; Hepworth, 1998), with research and interest growing in the United States (Franzluebbers and Stuedemann 2007; Franzluebbers and Stuedemann 2008; Lenssen et al. 2013; Miller et al. 2015). Integration provides a beneficial exchange of services in which livestock grazing is used as a crop residue, weed, or fallow management tool. Livestock (e.g. sheep) graze vegetation that would conventionally constitute a tillage or herbicide-based management cost, while livestock waste produces valuable nutrients for the cropping system (Franzluebbers and Stuedemann 2007). The potential for integration in Montana is high as both crop and sheep production enterprises are present. Most conventional crop producers in Montana have adopted no tillage systems in response to rising concerns over the detrimental effects of tillage on soil properties (Azooz and Arshad 1996;Rühlemann and Schmidtke 2015) and the use of cover crops to provide weed management and soil protection may be an alternative to tillage or herbicide use. Cover crops have the potential to provide high quality forage sources for livestock production (Franzluebbers and Stuedemann 2007), while livestock grazing may be an effective tool for cover crop termination.

Integration of crop and livestock production has the potential to improve agricultural sustainability through reduced dependence upon tillage and herbicide application and through potential diversification of agricultural enterprises

(Franzluebbers and Stuedemann 2007). This study built upon previous integration efforts (Lenssen et al. 2013; Miller et al. 2015) by using sheep grazing to terminate cover crops in a five year rotational cropping system. Sheep have previously been used for fallow (Miller et al. 2015) and crop residue (Goosey et al. 2005; Hatfield et al. 2007a; Hatfield et al. 2007b; Lenssen et al. 2013) management, but further research was necessary to evaluate the potential to use sheep for cover crop termination. The cover crops used in this study, field pea and yellow sweetclover, have the potential to provide agroecosystem services (Schlegel and Havlin 1997; Blackshaw et al. 2001; Blackshaw et al. 2010) and quality forage for sheep (Allden and Geytenbeek 1980; Hepworth 1998). Sheep grazing may provide a viable biological method for cover crop termination in an organic system. My study sought to determine 1) the efficacy of grazing for termination in either continuous or rotational systems, and 2) if grazing was comparable to two of the most common termination methods, tillage and herbicide. If successful, grazing for cover crop termination could reduce mechanical tillage and soil disturbance during cover crop termination in organic systems and reduce herbicide use in conventional systems. Sheep grazing may provide organic farmers with the opportunity to adopt no-till practices which have proven beneficial to conventional producers, thereby improving the sustainability of organic cropping systems.

LITERATURE REVIEW

Grazing Systems

Continuous grazing refers to year- or season-long grazing of the same pasture every year and is one of the most common grazing systems globally (Owensby 1991). Continuous grazing generally allows for the most selectivity by livestock, as livestock are allowed free choice of the entire pasture for the whole grazing period (Heitschmidt and Stuth 1991; Launchbaugh et al. 1978; Launchbaugh and Howery 2005; Owensby 1991). Many studies have shown that this high degree of selective freedom results in increased individual animal performance, measured as individual animal weight gains (Launchbaugh et al. 1978; Holecheck 1989; Owensby 1991; Glindemann et al. 2009; Hao et al. 2013). However, this system can result in uneven grazing distribution, as animals are free to return to and regraze preferred plants while ignoring others (Launchbaugh and Howery 2005; Owensby 1991).

Owensby (1991) defined rotational grazing as a multiple pasture system in which all pastures are grazed periodically and more than twice in any given year or grazing season. Rotational grazing has also been described as “a grazing method that utilizes recurring periods of grazing and rest among two or more paddocks in a grazing management unit throughout the period when grazing is allowed” (SRM 1998). Rotational grazing utilizes a short grazing period followed by a relatively longer rest period in order to give the preferred forage time to recover from the first grazing period before grazing pressure is reapplied (Holecheck 1989; Owensby 1991). Rotational grazing increases uniformity of utilization, forcing animals to graze non-preferred species by concentrating grazing pressure into smaller pastures and increasing stocking density (Launchbaugh et al. 1978; Owensby 1991).

Stocking density, the number of animals per unit area, and stocking rate, the number of animals per unit area over time, are important factors in livestock grazing which can affect livestock gains, vegetation response, and economic outcomes. Increasing the stocking density can increase economic yield by increasing the animal weight gains per unit area grazed (Launchbaugh et al. 1978; Holecheck et al. 1989; Owensby 1991). Increased revenue from higher gains per unit area is the main impetus behind grazing systems that increase stocking density or stocking rate (Owensby 1991). However, increasing the number of animals in an area also increases the intraspecific competition, which can cause individual animal performance to decline (Holecheck et al. 1989).

Stocking density can also be increased in attempt to improve distribution; however, there are many biotic and abiotic factors that affect livestock movements and forage utilization (Holecheck et al. 1989). Livestock habitually select preferred areas, often based upon forage composition and distance from water or supplements, which receive the highest grazing pressure in the pasture. Even at light to moderate stocking densities, these preferred areas, or patches, can be overgrazed, leaving other areas underutilized (Holecheck et al. 1989). Livestock distribution can be improved through placement of water and supplements, herding, or fencing. The larger and more heterogeneous the pasture, the more likely patch grazing is to occur. Increasing the stocking rate alone is unlikely to alleviate patch grazing in a large or heterogeneous pasture (Holecheck et al. 1989).

Gains per unit area can be increased in rotational grazing systems compared to continuous grazing, largely due to increases in stocking density (animals per unit area) (Briske et al. 2008; Hao et al. 2013; Launchbaugh et al. 1978; Owensby 1991). Livestock in rotational grazing treatments may be under additional stress due to handling and movement inherent in rotational grazing, which may cause decreased gains per individual (Launchbaugh et al. 1978; Holecheck et al. 1989). However, increased stocking density may also account for declines in weight gain. Hao et al. (2013) observed that sheep in a rotational grazing treatment exhibited lower live weight gains and organic matter intake than those in a continuous grazing system. The two treatments had similar stocking rates, but the rotational grazing treatments had higher stocking density , so the authors concluded that stocking density was the most important factor in determining animal performance and that individual animal performance declined with increased stocking density (Hao et al. 2013).

Briske et al. (2008) performed a meta-analysis on the results from studies that compared continuous and rotational grazing and ultimately concluded that there are no inherent benefits of one method over the other but that stocking rates are important. There was no difference in plant production/standing crop between continuous grazing and rotational grazing systems. The results of the studies Briske et al. (2008) analyzed were inconclusive for animal performance, both in terms of animal production per head and animal production per unit land area. Individual animal performance did not differ between grazing treatments when stocking rates were similar, but was higher in continuous systems when continuous systems had lower stocking rates. When stocking rates were lower for continuous systems, animal production per unit area was higher in rotational systems than continuous (Briske et al. 2008). Briske et al. (2008) cited numerous sources of ecological and managerial variables (e.g. commitment, goals, abilities and opportunities) which have confounded direct comparison between these two common grazing systems.

Organic Crop Production

Organic crop production is a rapidly expanding sector of agriculture in the United States, with the land area under organic cultivation doubling between 1992 and 1997 (Dimitri and Greene 2002) and again from 2002 to 2011(McBride et al. 2015). Organic food sales increased from $3.6 billion in 1997 to $21.1 billion in 2008 (Greene et al. 2009). The National Organic Standards Program prohibits the use of synthetic agrichemicals, genetically modified organisms, and sewage sludge in organically certified crop production.

Increasing public demand for organic products has created potentially lucrative markets for organic agriculture (Pimentel et al. 2005; McBride et al. 2015). However, several economic and environmental barriers deter the transition into dryland organic agriculture. Although a successful organic enterprise may pay dividends in the long term, the conversion process includes a three-year organic certification transition period. During this transition period, which typically affects two harvested crops, producers must practice organic agriculture but cannot market their products under the organic label.

Although price premiums for organic produce can offset and even exceed the higher production costs (Pimentel et al. 2005; McBride et al. 2015), these price premiums cannot be obtained during the transition period.

Weeds are a major source of yield reduction and economic loss in organic cropping systems (Pimentel et al. 2005; Kolb et al., 2010). Although conventional producers have access to biological, mechanical, and chemical control methods, organic producers are generally limited to biological or mechanical control of weeds (Pimentel et al. 2005). Biological control may include the use of diverse crop rotations, including cover crops (Pimentel et al. 2005; McBride et al. 2015). Organic cash crops may not be grown as frequently over time as their conventional counterparts due to the utilization of cover crops and crop rotations (Pimentel et al. 2005). McBride et al. (2015) reported that organic wheat farms harvested fewer acres of wheat in a given year, although organic and conventional farms were similar in size.

Disrupting weed life cycles with tillage is one of the most commonly used weed management practices in an organic system (McBride et al. 2015), however, tillage can spread weed seeds through the soil, and decrease soil productivity and reduce soil water (Azooz and Arshad 1996). Tillage reduces soil carbon, alters soil structure, and causes declines in soil microorganisms (Trewavas 2004). Peigné et al. (2007) asserted that reducing tillage should enhance microbial activity and carbon sequestration while reducing nutrient leaching, erosion, and fuel use.

Conservation tillage can be broadly defined as any management practices that reduce soil and water loss compared to using tillage that inverts the soil, or as any set of practices that maintain a minimum of 30% crop residue cover after seeding (Lal et al. 1994). No-till (also referred to as zero tillage, direct seeding, or direct drilling) systems limit soil disturbance to that which occurs during seeding (Lal et al. 1994). Conservation tillage would be beneficial for organic agroecosystems, as it increases soil organic carbon, soil microbial biomass and earthworm abundance, enzyme activity, select plant nutrients, and nitrogen mineralization potential (Carr et al. 2013).

Pollnac et al. (2008) compared weed presence and distribution between conventional no-till systems using herbicides and organic cropping systems that relied upon tillage. Conventional fields were largely weed-free with concentrated patches of weed populations that Pollnac et al. (2008) speculated could be economically treated with herbicide directly applied to those specific areas. Organic fields had higher and more continuous weed cover and species richness than conventional no-till fields in both years of this study. Higher weed cover in the organic system can result in reduced yields due to competition and contamination from weeds (Miller et al. 2015).

Carr et al. (2011) referred to weed control as, “the greatest obstacle for successful adoption of zero till methods among organic farmers.” Organic weed management approaches include the use of higher seeding rates to increase crop competitiveness, decreasing row spacing to limit inter-row space available to weeds, or inter-row cultivation (Pollnac et al., 2008; Kolb et al. 2010). However, the impacts of varying seeding rate and row spacing on yields have been inconsistent and it is unclear whether or not these techniques are cost-effective (Kolb et al. 2010).

The use of a competitive cover crop can reduce weeds in conventional and organic systems. A cover crop consists of “herbaceous plants established for seasonal cover and conservation purposes” (NRCS 2013) which can be used to compete with weeds directly for resources (e.g. nutrients and water) and indirectly if cover crop residues are used as mulch. Organic producers remain limited to biological and mechanical management options to terminate cover crops, and tillage is the most common method (McBride et al. 2015). Although the ecological and economic benefits of no-till systems have been widely realized, they are generally coupled with chemical weed prevention in conventional systems (Miller et al. 2015b). As such, no-till options for cover crop termination in organic systems are an important area of research.

No-till cover crop termination has been accomplished mechanically through the use of roller-crimpers (Carr et al. 2013). A roller–crimper consists of a rolling drum to which dull blades have been affixed. The roller-crimper is designed to crush rather than cutting the cover crop, and the blades do not penetrate the soil surface (Carr et al. 2013). The effectiveness of roller-crimping is highly correlated to the growth stage of the cover crop, with higher percent kill as plants mature (Ashford and Reeves 2003; Carr et al. 2011; Carr et al. 2013). Carr et al. (2013) asserted that cover crop termination method must be “consistent and effective” if vegetative mulch is to be relied upon for weed suppression. While roller-crimping has been shown to effectively terminate cover crops, Carr et al. (2013) surmised that effective termination using this approach requires cover crops to reach reproductive maturity. In some cases, delaying termination to meet cover crop maturity can delay seeding of the subsequent crop, which can negatively impact yield. Delaying termination also increases the chance that the cover crop will produce viable seed which may produce volunteer cover crop seedlings that compete for resources with the subsequent cash crop (Carr et al. 2011; Carr et al. 2013).

Cover Crops

Cover crops are used within cropping systems for a variety of agroecological benefits, largely focusing on soil protection and enhancement (Zentner et al. 2003; Cupina et al. 2013; Alonso-Ayuso et al. 2014). Cover crops may enhance soil aggregate stability, water retention, and soil nutrients compared to traditional fallow systems (Zentner et al. 2003; Snapp et al. 2005; Cherr et al, 2006; Alonso-Ayuso et al. 2014). Cover crop residues that are retained on the soil surface as mulch have the potential to reduce evaporation from the soil surface compared to bare (e.g. fallowed) soils, and provide protection from erosion (Snapp et al. 2005; Cherr et al, 2006; Alonso-Ayuso et al. 2014). Cover crop mulch, or green manure, can be used for weed suppression (Biederbeck et al. 1993; Blackshaw et al. 2010; Carr et al. 2013) such that Carr et al. (2013) asserted that the primary purpose of cover crops in organic no-till systems was the creation of vegetative mulch for weed suppression.

Cover crops can also have important effects upon soil nutrients (Blackshaw et al. 2001; Zentner et al. 2003; Blackshaw et al. 2010). Zentner et al. (2003) found that plots using a legume cover crop (*Indianhead* black lentil, *Lens culinaris* Medik) needed lower fertilizer additions over the course of their 12 year study, and that the grain protein content of the succeeding spring wheat cash crop was gradually increasing. Blackshaw et al. (2010) observed 16 to 56 kg ha^{-1} higher available soil nitrogen following a sweetclover cover crop compared to fallow (measured April following termination).

Cover crops are terminated before planting of the subsequent crop, with termination timing essential to maximizing the benefits of cover crops (Zentner et al. 2003; Krueger et al. 2011; Alonso-Ayuso et al. 2014). Terminating the cover crop earlier in the growing season results in greater soil water and higher subsequent crop yields (Zentner et al. 2003; Krueger et al. 2011; Alonso-Ayuso et al. 2014). Miller et al. (2011) observed that terminating a pea cover crop near first bloom resulted in similar soil water content to tilled summer fallow. Using cover crops can be beneficial, but the agronomic application needs to reflect the requirements of specific agroecosystems (Krueger et al. 2011; Alonso-Ayuso et al. 2014). Termination timing can be a powerful management tool to regulate the effects of cover crops in a given agroecosystem. As Alonso-Ayuso et al. (2014) described, early termination can be beneficial to reduce preemptive competition for nitrogen and soil water, but later termination can be useful in areas in which nitrogen leaching down the soil profile is a concern.

Cover Crop: Winter Pea

Winter pea is a cool season, leguminous annual forb. Peas have relatively shallow roots compared to wheat and other cereal crops, such that plants are unable to utilize soil water below the first 60 cm of soil, which makes them an ideal cover crop capable of conserving water while providing soil protection and producing N and soil organic carbon (Miller and Holmes 2012).

Peas have been successfully integrated into cropping rotations as a pulse crop in Australia, Canada, Europe, New Zealand, and many regions of the US, where the benefits include N production, water conservation, disease and pest cycle disruption, and weed prevention (Mulholland et al., 1976; Allden and Geytenbeek, 1980; Biederbeck et al. 1993; Hepworth, 1998; McDonald 2003; Miller et al. 2015a; Clark, 2007; Moore et al., 2010; Rühlemnn and Schmidtke, 2015). Field pea can be harvested and sold for human or livestock consumption, hayed, grazed, or retained as an effective green manure (Mulholland et al. 1976; Clark 2007; Moore et al. 2010; Miller et al. 2011). Winter pea has a long history of human cultivation resulting in many varieties, which show variation in yield, competitive ability, and plant characteristics (e. g. plant height, lodging, crude protein, acid detergent fiber and neutral detergent fiber) (McDonald 2003; Rondahl et al. 2011; Tan et al. 2013).

Peas can provide valuable livestock forage. In an Australian study, 6 - month - old Merino wethers grazing on field pea gained160 g day^{-1} for the first 6 weeks, which was the highest daily gain reported for eleven forage species (Allden and Geytenbeek, 1980). Field pea was 4th in wool production with 8 g of wool day^{-1} (Allden and Geytenbeek, 1980). Hepworth (1998) found that lambs gained 186 g day^{-1} on field peas at 30 lambs ha^{-1}, and that lambs finished on pea had higher dressing percentages than those finished on faba beans (*Vicia faba* L.) or lupine (*Lupinus* spp.).

Cover Crop: Sweetclover

Sweetclover is a biennial, leguminous herb. Native to Eurasia, it is now established worldwide (Lesica and DeLuca 2000; Pacanoski 2010). Sweetclover commonly colonizes disturbed sites (García-Palacios et al. 2012) and is now found in disturbed areas throughout the Unites States and Canada, where it is highly invasive in the northern Great Plains (Lesica and DeLuca 2000; Schlegel and Halvin 1997; Pacanoski 2010). Sweetclover establishes a long tap root during the first year of growth, utilizes biological nitrogen fixation, propagates through high seed production, and has a long growing season (Wolf et al. 2003). Sweetclover is a successful cover crop in agroecosystems because of its competitive ability, nitrogen fixation, and high biomass yield (Schlegel and Havlin 1997; Blackshaw et al. 2001; Blackshaw et al. 2010).

In integrated cropping systems, sweetclover has been used as a cover crop, after which it was mowed or harvested for hay (Blackshaw et al. 2001; Blackshaw et al. 2010). In a cover crop context, tillage and mowing have been used to terminate sweetclover. Mowing sweetclover at the 80% flowering stage in the second year of its growth to a height of 30 cm was sufficient to cause mortality in two field experiments in Alberta, Canada (Blackshaw et al. 2010). Termination was also achieved at 80% flowering through disking, cultivating, or mowing, although Blackshaw et al. (2001) could not terminate sweetclover through any of those methods at 10 to 20% bloom stage.

Integration Potential

Franzluebbers and Stuedemann (2007) assessed the integration of cattle into cropping systems in Georgia, and found that grazed cover crops returned higher net returns over variable costs than ungrazed cover crops. While livestock grazing of cover crops had variable effects on subsequent crop production in their study, the added value of livestock production increased economic return and diversity overall (Franzluebbers and Stuedemann 2007).

A series of experiments to examine the potential roles of sheep in dryland grain production systems in Montana examined the effects of sheep grazing wheat residue. Sheep grazing on wheat residues reduced wheat stem sawfly larvae survival (Goosey et al. 2005; Hatfield et al. 2007a) and reduced weed biomass. Soil bulk density did not differ consistently between treatments, suggesting no discernable impacts due to grazing (Goosey et al. 2005; Hatfield et al. 2007b). In a review of studies featuring sheep grazing to manage wheat and alfalfa residues, grazing increased soil nutrient cycling and soil carbon, provided an alternative to herbicides and pesticides, and decreased reliance on fossil fuels required in mechanical tilling and chemical application (Hatfield et al. 2011).

In a recently published study, Lenssen et al. (2013) compared grazing, mechanical tillage, and herbicide as weed control mechanisms in two conventional wheat-fallow systems. Wheat yield and protein concentration, the determinant factors affecting gross income for wheat farmers, were not significantly influenced by residue management method (Lenssen et al. 2013). Miller et al. (2015b) examined the effects of sheep grazing for fallow management on spring wheat yields and weed communities by comparing grazing to minimum and conventional tillage practices in continuous spring wheat and wheat-fallow rotation cropping systems. Miller et al. (2015b) observed similar spring wheat yield and grain quality between grazing managed and tillage managed plots and suggested that grazing-based management could reduce tillage and herbicide use while maintaining similar yields to conventional management.

Cover crops provide valuable soil protection, increase soil carbon, and compete with weeds (Kolb et al. 2010). Field pea cover crops have been shown to reduce weed invasion and to contribute to soil nitrogen, reducing the need for chemical fertilization, without depleting soil water (Clark 2007; Miller et al. 2015; Moore et al. 2010; Mulholland et al. 1976). Mechanical and chemical termination have adverse environmental impacts due to decreased infiltration rates and increased erosion risk (Azooz and Arshad, 1996). As Hatfield et al. (2011) reported in their review, the amount of litter left standing as an erosion preventative is easily controlled with grazing through manipulation of stocking rate or stocking density.

RESEARCH QUESTIONS

My study sought to determine whether using sheep grazing in either continuous or rotational systems was an effective method of termination. In order to be a viable termination method, sheep grazing would need to meet termination goals while generating sheep weight gains and without detrimental impacts on the subsequent winter wheat crop. The following questions were used to assess the potential for using sheep grazing for cover crop termination:

1) whether or not one method of grazing (continuous or rotational) was more successful in achieving termination (e.g., more uniform grazing, more complete cover crop mortality). I expected that there would be no difference in cover crop termination between the two grazing treatments (continuous and rotational) because the total stocking rates were the same and because both treatments were designed for complete utilization of the cover crop.

2) whether or not one method of grazing (continuous or rotational) was more successful in achieving sheep weight gains. I expected no difference in sheep average daily gains as any benefit to sheep in the rotational treatment from cover crop regrowth was expected to be counterbalanced by the increased selectivity that continuous grazing allows and by the decrease in individual performance associated with higher stocking density (Hao et al. 2013).

3) whether grazing termination was comparable to tillage and herbicide based termination. It was expected that grazing could result in similar vegetation cover at the

time of termination and that termination via sheep would not affect subsequent crop yields.

METHODS

Study Area

Research was conducted at the Montana State University Fort Ellis Experiment Station, located at 45º 40’N, 111º 2’W, approximately 3 km east of Bozeman, Montana. The elevation of the site is 1,468 m above sea level. The mean maximum and minimum temperature are 18.9 ˚C and -5.7 ˚C, respectively, with a mean annual precipitation of 490 mm (Miller et al. 2015b). The soil is a Blackmore silt loam (a fine-silty, mixed, superactive, frigid Typic Argiustoll), with 0-4% (Miller et al. 2015b).

This research was conducted on a subset of plots within a larger crop rotation study that consists of three replicates of 15 plots in a split-plot arrangement (Figure 1). Three management systems (Organic Tilled, Organic Grazed, and Conventional No-till) were randomly assigned to five of the 15 plots in each replication, and within each of the five plots, one cropping treatment was applied as the start of a 5-yr crop rotation system (safflower - legume cover crop - winter wheat - lentil - winter wheat). All five phases of the rotation were present within a management system and replicate every year. My study took place on the cover crop phase during the transition period prior to organic certification for the tilled and grazed systems.

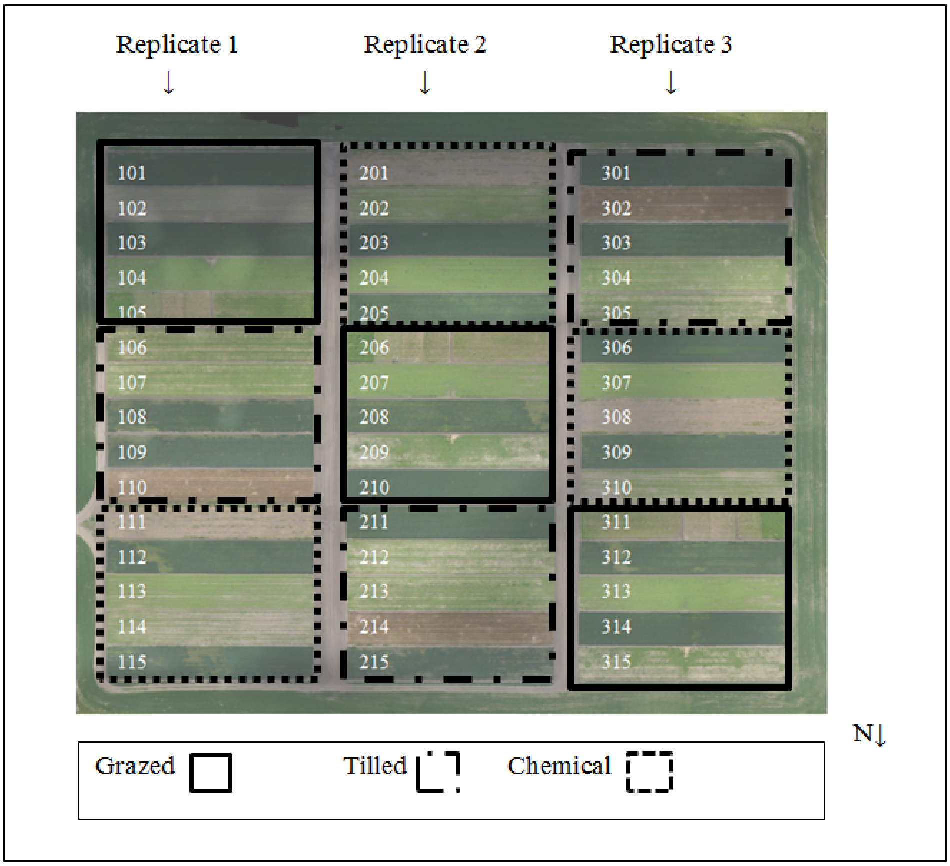

Figure 1: Aerial image of Fort Ellis plots with plot numbers labeled (Photo courtesy of Ian Johnson, Aerie Works 2014)

4	3 Rotational	2	1	Continuous

Figure 2: Diagram of a grazed plot illustrating the division into rotational and continuous treatments. Rotational grazing began at the central dividing line, with the sheep moving outward through rotational subplots, numbered one through four, above.

Each cover crop plot in the Organic Grazing system was divided in half laterally and a grazing system was randomly assigned to each half (Figure 2). In 2013, the plots were 90 x 15 m in dimension, providing 45 x 15 m per grazing treatment, and in 2014 the plots were 88 x 15 m, or 44 x 14 per grazing treatment. The rotational grazing treatment was divided into quarters and grazed sequentially with sheep moving outward from the central divider between rotational and continuous treatments.

Cover Crops

Two cover crops were used in this study, winter pea and yellow sweetclover. *Melrose* Austrian winter pea was seeded 18 September 2012 at 190 kg ha^{-1} with 0.13 m row spacing for organic plots and 95 kg ha^{-1} and 0.25 m row spacing for conventional plots, with a goal of 160 plants and 80 plants m^{-2}, respectively. Field pea was the cover crop for summer 2013 and grazed from 16 June 2013 to 18 July 2013.

Sweetclover (‘VNS yellow blossom’ certified organic and inoculated with rhizobium; Ore-Vail, INTX Microbials) was seeded at 6.7 kg ha^{-1} as an understory to a safflower nurse crop 20 April 2013. In spring 2014, the sweetclover cover was patchy due to winter vole (*Microtus* spp.) damage. This damage was present in all plots, but was not evenly distributed among plots or within grazing treatments. Sweetclover was the cover crop for summer 2014 and was grazed from 12 June 2014 to 13 August 2014.

Sheep

Groups of sheep with similar average weights were randomly assigned to grazing treatments and plots (Average group weight = 46.6 kg, SD = 0.64 kg, Table 1). Although selection controlled for variation in sheep weights, selection of sheep was not random and inferences to a larger population should be made with caution.

Table 1: Average group weights and standard deviations of sheep grazing cover crops in 2013 and 2014

Cover crop	Treatment	Plot	Avg. wt. (kg)	SD
Winter pea 2013	Continuous	101	47.8	8.5
Winter pea 2013	Continuous	210	46.4	1.9
Winter pea 2013	Continuous	314	46.3	1.3
Winter pea 2013	Rotational	101	46.8	5.2
Winter pea 2013	Rotational	210	46.4	3.7
Winter pea 2013	Rotational	314	45.9	0.6
Sweetclover 2014	Continuous	105	48.2	2.8
Sweetclover 2014	Continuous	206	48.8	4.2
Sweetclover 2014	Continuous	311	48.2	7.8
Sweetclover 2014	Rotational	105	48.5	3.5
Sweetclover 2014	Rotational	206	48.5	4.8
Sweetclover 2014	Rotational	311	49.4	6.6

The length of the grazing period and the rotational interval for the rotational grazing system were determined based upon estimates of cover crop productivity and livestock demand, see Appendix B for calculations. Twelve - hour fasted weights were taken immediately prior to the start of the study and again upon conclusion and individual average daily gains were calculated as the difference between the final and initial weights per individual sheep, divided by the number of grazing days.

Male Rambouillet yearlings were used to terminate the winter pea cover crop. The yearlings were a non-traditional livestock class, all having only one testicle removed. Twenty four yearlings were used, resulting in four sheep per treatment replication. The rotation interval for moving sheep in the rotational treatment was four days. Sheep grazing began 16 June 2013 and was scheduled to continue until 3 August 2013 based upon an estimated 48 days of available forage (3138 kg winter pea ha^{-1}). However, grazing ended 18 July 2013, after 32 days of grazing, as the termination goals had been met. Grazing was initiated when approximately 50% of the pea plants had at least one open flower.

Rambouillet yearling wethers were used to terminate the sweetclover cover crop. Allocation methods were consistent with those used on the winter pea cover crop study, except that only three sheep were allotted per treatment per replicate, with a total of 18 sheep in the grazing study. The rotation interval for moving sheep in the rotational treatment was five days. Sheep grazing began on 12 June 2014, once sweetclover had initiated bloom, and was estimated to last 40 days based upon average production of 3155 kg ha^{-1}. The first full rotation through the rotational subplots was completed on 2 July 2014, with the second and final rotation finished on 22 July 2014. Sweetclover regrowth was much higher than expected, such that on the estimated day of grazing completion, there remained too much clover to consider the cover crop terminated.

Yearling ewes that had been previously grazing on rangelands were introduced on 24 July 2014 and were allocated to plots and treatments using the same methods described previously, with the exception that the ewes did not undergo 12-hr fasts before weighing. The ewes were rotated through the rotational subplots in the same sequence as the wethers, but with a four day rotation interval and with eight ewes per group. The variable nature of this cover crop resulted in some subplots that had more clover than others, so after the first full rotation through all four subplots, they were grazed with varying duration in an attempt to fully terminate the clover. As a result, the grazing periods for ewes varied, ranging from 8 to 20 days of grazing (Table 2).

Table 2: Number of days yearling ewes regrazed sweetclover cover crop by plot and by treatment

Plot	Treatment	Days
105	Continuous	20
105	Rotational	14
206	Continuous	8
206	Rotational	18
311	Continuous	14
311	Rotational	20

Termination

Plant cover was used to quantify termination. Our goal for termination was 80% or greater dead cover crop cover, 0% live cover crop cover, and 20% or less bare ground cover. This termination goal was designed to maintain adequate ground cover to prevent erosion and provide a mulching effect, and was based upon Natural Resource Conservation Service recommendations (NRCS 2010; NRCS 2013). Cover was measured using the Line Point Intercept (LPI) method (Herrick et al. 2005) measured along transects that were established prior to the start of the grazing season.

Transect lines, oriented at a 45 ° angle to the seed rows, were established from a random starting point selected from the first 5 meters of a baseline running down the center of the plot (Figure 3). Continuous plots had a total of six transects per plot spaced at 6 m intervals while rotational sub-plots had four transects at 3 meter intervals. The number of points sampled in each plot differed in accordance with the variability in cover crop and was determined through pilot sampling.

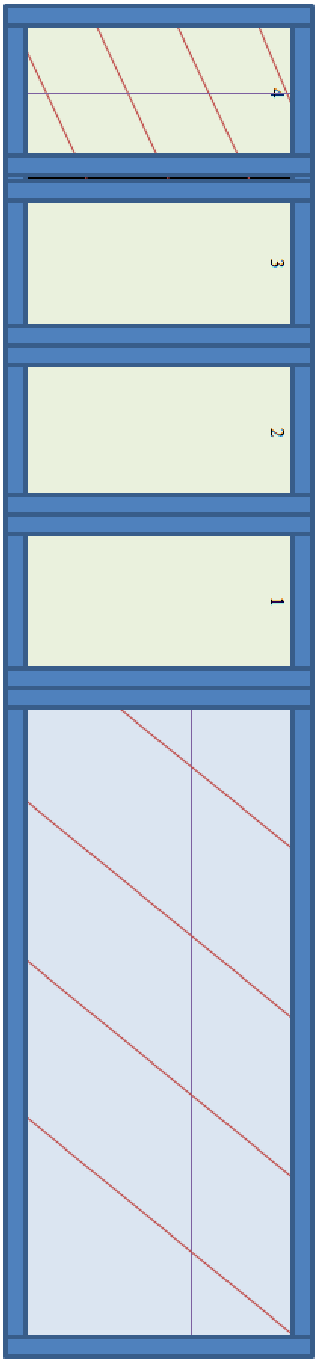

Figure 3: Diagram of grazed plots including 1 m buffer zones around each grazing sub-plot. Permanent transect lines (solid lines), and the baselines used to generate transect lines (dotted lines) are shown in the 4th rotational grazing sub-plot and the continuous plot.

Vegetation cover was measured on the morning when grazing was initiated, halfway through the grazing period, and at the end of the grazing period. In Rotational plots, cover measurements were taken for each sub-plot immediately prior to sheep introduction and immediately after sheep removal. Cover data consisted of plant species as well as the designation of live or dead to monitor plant mortality. Plants were only counted as dead if they were completely desiccated or decadent, with no regrowth potential or ongoing photosynthesis. This strict definition was an effort to eliminate the possibility of overestimating termination by counting as dead any plants that could recover and set seed or that were still utilizing water.

The chemically terminated winter pea plots were sprayed 18 June 2013 using a mixture of glyphosate (840 g ai ha^{-1}) and dicamba (140 g ai ha^{-1}) with a 0.5% by volume *HellFire* adjuvant. The herbicide mixture was applied at 187 L ha^{-1} at 0.21 MPa with a 7.62-m wide shielded boom sprayer. The chemically treated plots received a second glyphosate treatment via backpack sprayer on 24 June 2013 to treat remaining live plants. Termination of the tilled plots occurred 19 June 2013. Termination by sheep grazing was concluded 18 July 2013. Cover was measured on 19 July 2013 to determine termination success for all three termination methods. Six transect lines were established in chemically treated and tilled plots following the protocols outlined for the grazed treatments.

Sweetclover in chemically treated plots was sprayed with Sharpen ® at 49.86 g ha^{-1} tank mixed with Gly Star ® at 1123 g ha^{-1}, 1120 g ha^{-1} AMS, and MSO at 53 g ha^{-1} on 16 June 2014. Sweetclover was resprayed 16 July 2014 to kill remaining live sweetclover using 0.146 L ha^{-1} 1.81 kg Gly Star and 0.073 L ha^{-1} Sharpen and 0.680 kg per 37.9 L of spray grade ammonium sulfate and methylated seed oil 1% v/v in 187 liters per hectare volume. Tilled sweetclover plots were terminated on 13 June 2014 using two passes of a 1.3 m -wide tandem disk. Tilled plots were tilled again on 3 July 2014 using multiple passes of a chisel plow. Termination cover readings on all plots were conducted on 23 July 2014, at the end of the predicted 40 day grazing period. Termination cover goals were not met in grazed plots so grazing was continued with yearling ewes.

Winter Wheat

Winter wheat was seeded following termination of field pea on 23 September 2013 in conventional, no-till (herbicide terminated) plots and 24 September 2013 for both transitioning organic tilled and grazed plots. The seeding rate targeted 220-230 plants m^{-2} with 0.30 m row spacing for the chemically treated plots and 440-460 plants m^{-2} and 0.15 m row spacing for the organic tilled and grazed plots. Both the grazed and chemically treated plots were seeded directly into the cover crop residue as they were both in no-till systems. The tilled plots used a chisel plow followed by a spring-tine cultivator to prepare the seed bed. Lambs were used to remove weeds from the grazed plots on 29 Aug 2013, by grazing for 24 hr. Herbicide was applied to the chemical treatment plots to remove weeds on 16 September, with a mixture of 3.51 L ha^{-1} of 1.81 kg glyphosate with 0.177 L per 37.9L^{-1} *Hellfire* adjuvant and 0.680 kg ammonium sulfate per 37.85 L^{-1} sprayed in 93.5 L ha^{-1} of water. Winter wheat emergence rates were determined by counting the number of seedlings within 32 0.2 x 0.5 m randomly placed quadrats (16 per treatment per plot) one month after seeding. Quadrats were positioned perpendicular to the crop rows and the number of winter wheat seedlings and rows were recorded (Figure 1, Appendix D).

After sweetclover termination, winter wheat was seeded into the organic grazed and tilled plots on 17 September 2014, and into the conventional chemically treated plots on 23 September 2014. The seeding rate targeted 220-230 plants m^{-2} with 30.5 cm row spacing for the chemically treated plots and double that rate, and half the row spacing, for the organic tilled and grazed plots.

Winter wheat yield was sampled using two techniques. Once heads were dry, wheat was hand-clipped within 1.0 x 0.5 m frames, with eight frames per plot in the tilled and chemical treatments, and 8 frames per subplot (16 frames per plot) in the grazed treatments (Figure 2, Appendix D). Each frame contained eight rows of winter wheat. In grazed plots, two frames were placed in each quarter subplot, one on the north edge and one on the south edge. Tilled and conventional chemical plots were roughly divided into quarters, with one frame on the north and south edges of each quarter. Wheat was clipped down to the soil surface in each frame to sample the aboveground biomass. Samples were threshed and kernels were collected and weighed. Center strips from each plot were harvested using a single pass of a field-scale combine with a 4.2-m cutting width. The resultant wheat was weighed in the field directly off the combine.

Data Analysis

Statistical Procedures

The mosaic (Pruim et al. 2015), and car (Fox and Weisberg 2011) packages for the statistical software R (R Foundation for Statistical Computing, R Core Team 2015) were used for analyses. Before initiating any tests, data were plotted and visually assessed for obvious deviations from normality and to identify potential outliers.

Sheep. Analysis of variance (ANOVA) was used to test for differences in sheep ADG associated with grazing treatment. Grazing treatment and replication were included as explanatory variables in the model and, to account for the differences in grazing period associated with the ewes grazing the sweetclover cover crop, grazing end date was also included for this response. Average daily gain data were aggregated by treatment within plot, giving six experimental units for each cover crop type. This model was then assessed using a Type II ANOVA.

Termination. Analysis of variance was used to test for differences in cover crop termination associated with grazing treatment. Grazing treatment and replication were incorporated as explanatory variables for three separate analyses of the response variables live cover crop cover, dead cover crop cover, and bare ground cover. (Type II ANOVA). Grazing was compared to the other termination methods using termination cover as the response variable and termination method as the explanatory variable (a categorical variable with three levels: grazed, tilled, or chemically terminated). As no differences in termination cover in response to grazing treatment was observed for either cover crop, grazed termination data were combined for these analyses. Analyses to compare termination methods were conducted using a linear mixed effect model which included treatment as the main effect and replicate as a random effect to account for variability between plots. Separate analyses were performed for the responses of percent dead cover crop, percent live cover crop, and percent bare ground. Multiple pairwise comparisons among termination treatments were performed on least squares means using a Tukey correction for family-wise error rate. These methods were consistent between cover crop species.

Winter Wheat. Analysis of variance was used to test for differences in winter wheat seedling emergence based on grazing treatment. Seedling emergence counts served as the response variable while grazing treatment was the explanatory variable and replicate was a blocking factor. Analysis of variance was used to test for differences in wheat yield based on grazing treatment. Grazing treatment was used as the explanatory variable, replicate was used as a blocking factor, and wheat yield from the hand-clipped frames was used as the response variable. As there was no difference in wheat yield between grazing treatments, grazed plot yields were combined. Analysis of variance was used to compare the effects of grazing termination to tillage and chemical treatment on wheat yield, with termination method as the explanatory variable, replicate was used as a blocking factor, and yield harvested from the center strip as the response.

Scope of Inference

Although the plots were assigned randomly, in field-based studies such as this, it is important to remember that differences in soil and climate can significantly alter results.

Even variations in timing and amount of rain from one year to the next can result in different plant response to the same treatment in the same field. As such, it should be noted that the population to which inferences could be drawn would be limited to areas with similar soils, slopes, and climactic regimes.

RESULTS

Sheep

Average daily gains of sheep grazing winter pea did not differ between grazing treatments in 2013 (*P* = 0.12; Figure 4).

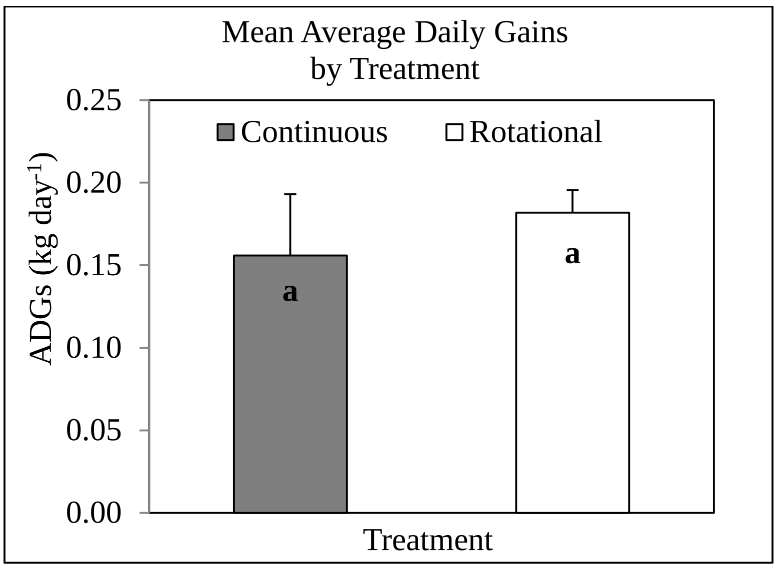

Figure 4: Mean average daily gains of yearling sheep grazing the 2013 winter pea cover crop over a 32 day grazing period (error bars = SD, letter codes represent statistical differences (α = 0.05) between treatments

Average daily gains did not differ between grazing treatments for the original group of wethers used to initiate sweetclover termination in 2014 (*P* = 0.79; Figure 5).

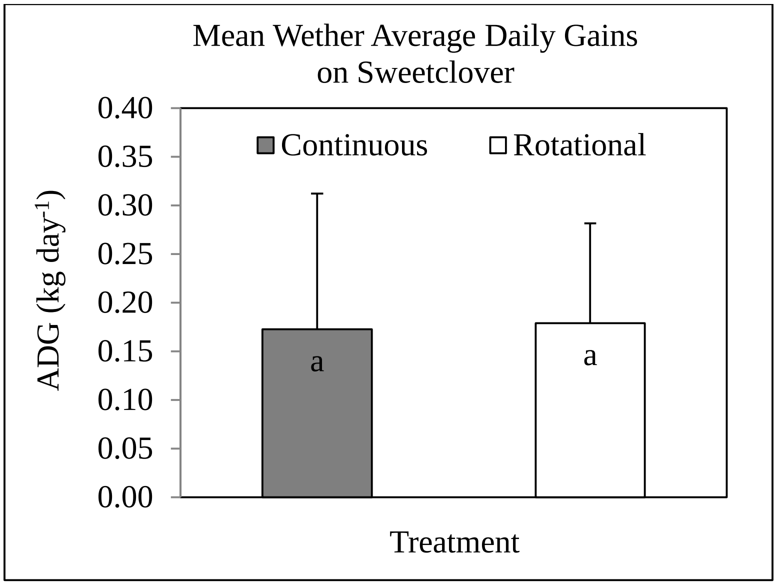

Figure 5: Mean average daily gains of yearling wethers grazing the 2014 sweetclover cover crop over a 40 day grazing period (error bars = SD, letter codes represent statistical differences (α = 0.05) between treatments).

The yearling ewes that were brought in to finish termination universally lost weight on the sweetclover (Figure 6). However, this difference was not significant by treatment (P = 0.456) when the number of days grazed was taken into account. Rate of ewe weight loss decreased with increasing time grazing the mature sweetclover.

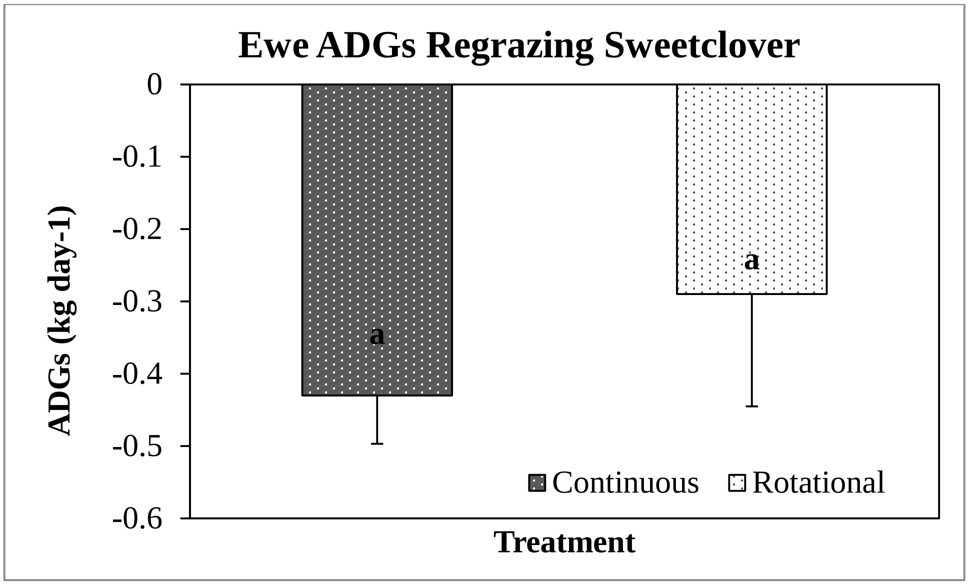

Figure 6: Mean average daily gains of yearling ewes regrazing the 2014 sweetclover cover crop to finish termination (error bars = SD, letter codes represent statistical differences (α = 0.05) between treatments).

Termination

Both grazing treatments were equally effective at terminating the winter pea cover crop (P = 0.86 for dead pea, P = 0.82 for live pea, and P = 0.95 for bare ground, Figure 7).

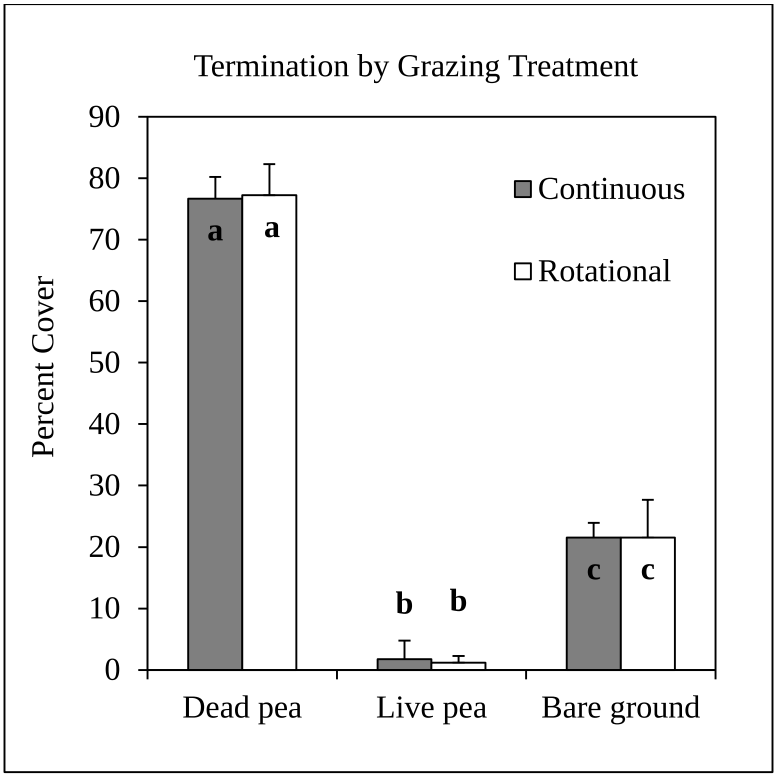

Figure 7: Mean Percent cover by grazing treatment and cover type (error bars = SD, letter codes represent statistical differences (α = 0.05) within cover types).

Sheep grazing was effective at terminating winter pea. Dead pea cover differed between the three termination treatments ($P > 0.05$) with grazed plots having the highest percent dead pea cover, followed by tilled and chemically treated plots. Percent live pea cover was highest in the chemically terminated plots (Figure 8). Grazed and tilled plots did not differ in percent live pea cover ($P = 0.71$). Percent bare ground cover differed among all termination methods ($P > 0.05$). Tilled plots had the highest percent bare ground cover, followed by grazed and chemically treated plots (Figure 8). Although the herbicide treatment retained excellent soil cover, at the time of sampling for termination the herbicide mixture did not appear very effective on the pea, leaving 73% live pea cover (Figure 8). It is important to note that the pea growth was no longer vigorous; nonetheless it remained green and therefore alive.

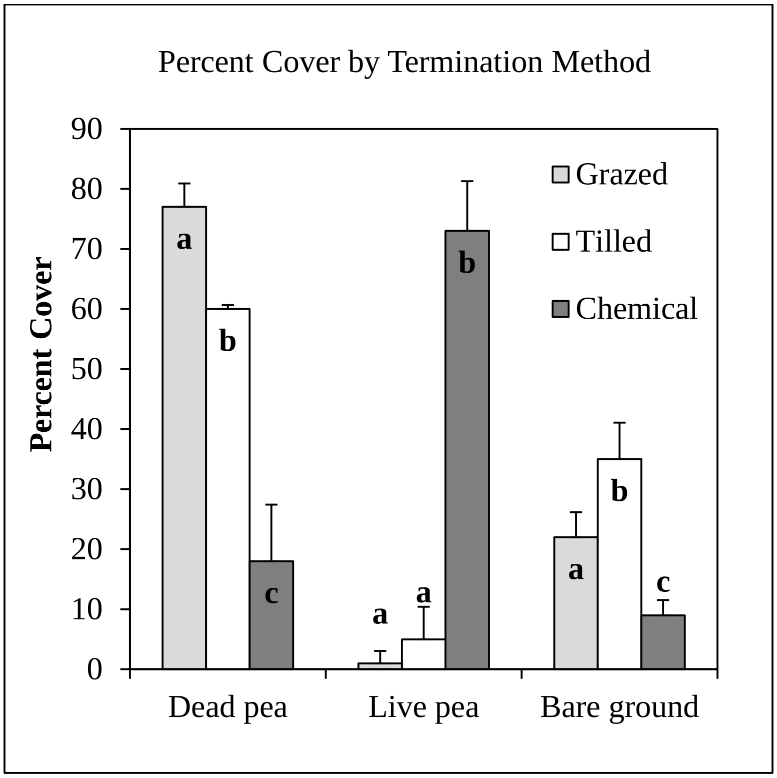

Figure 8: Mean percent cover by termination treatment and cover type (error bars = SD, letter codes represent statistical differences ($\alpha = 0.05$) within cover types).

Cover at time of sweetclover termination did not differ between continuous and rotational grazing treatments (P = 0.12, 0.32, and 0.89 for live sweetclover, dead sweetclover, and bare ground, respectively; Figure 9).

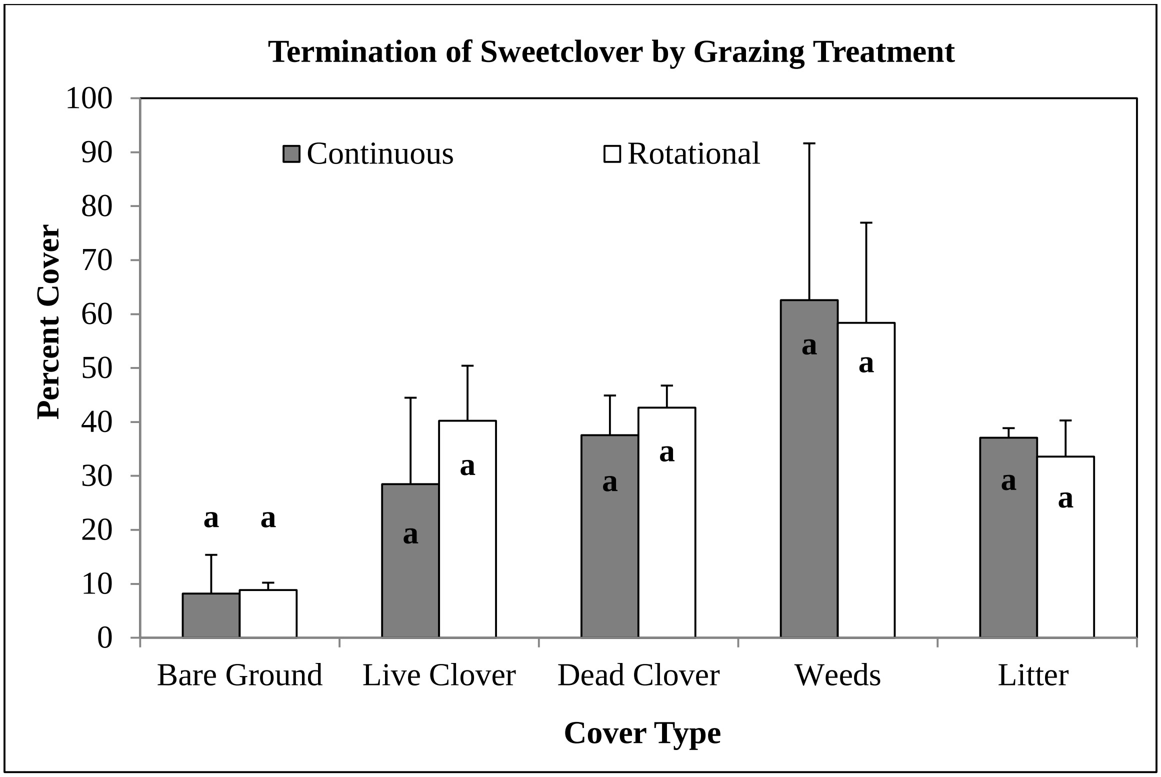

Figure 9: Mean Percent cover by grazing treatment and cover type (error bars = SD, letter codes represent statistical differences (α = 0.05) within cover types)

The initial sheep grazing treatments used were not effective at terminating a sweetclover cover crop (Figure 10). As Figure 16 illustrates, the chemically terminated plots had more dead clover cover than the tilled (P = 0.0003) or the grazed plots (P = 0.0011). Grazed and tilled plots did not differ in dead sweetclover cover (P = 0.603). Grazed plots had more live sweetclover cover on July 23, 2014 than chemically terminated (P < 0.0001) or tillage terminated plots (P < 0.0001). Tilled and chemically terminated plots did not differ in live sweetclover cover (P = 0.997). Grazed and chemically treated plots did not differ in bare ground cover (P = 0.996), while tillage resulted in higher bare ground percent cover than grazing and chemical termination (P< 0.0001).

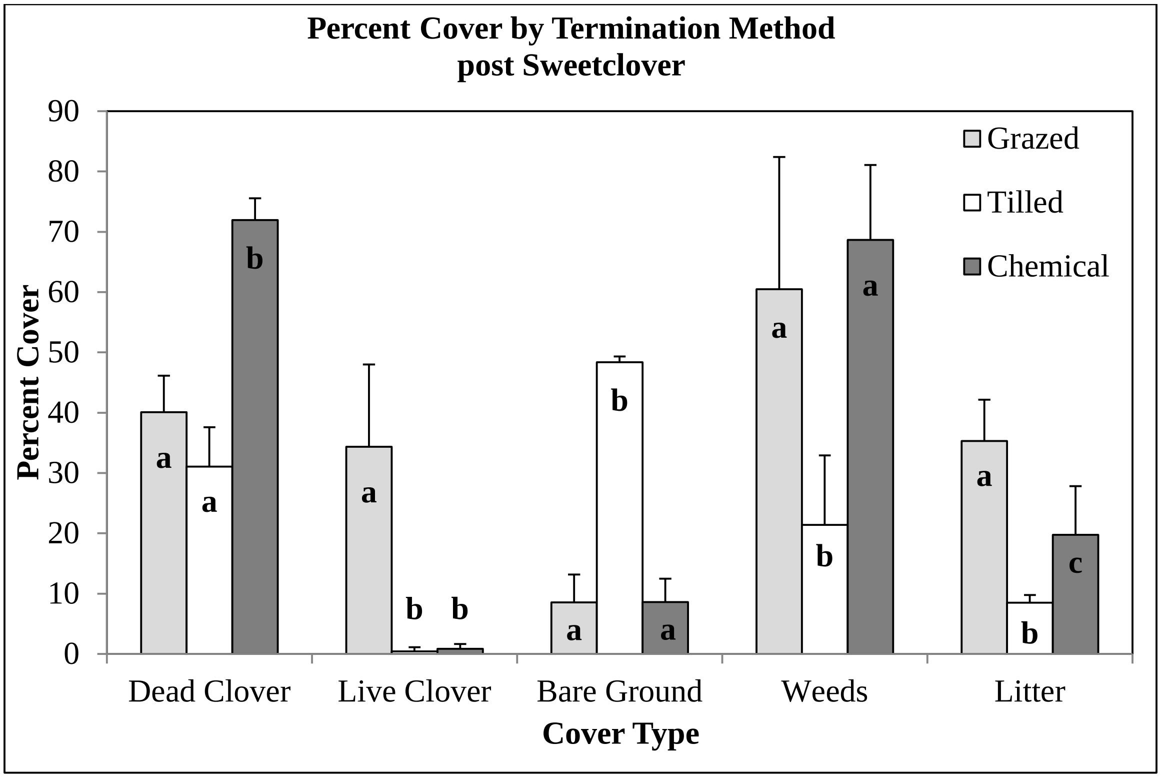

Figure 10: Mean percent cover by termination treatment and cover type (error bars = SD, letter codes represent statistical differences (α = 0.05) within cover types).

<u>Winter Wheat</u>

Winter wheat seedling emergence one month after seeding into post grazed winter pea plots was higher under the continuous than rotational grazing treatment (P = 0.017, Figure 11), although both treatments had seedling densities within the target range (440-460 seedlings m^{-2}). However, there was no difference in wheat yield between the two grazing treatments, (P = 0.924) when measured as kernels from clipped frames (Figure 12). There was no difference in wheat yield between the three termination methods regardless of method used to estimate yield (P = 0.92, Figure 13).

After sweetclover termination, there was no difference in winter wheat seedling emergence numbers between the rotational (434 seedlings m^{-2}) and the continuous (435 seedlings m^{-2}) treatments (*P*= 0.95, Figure 14). Winter wheat yield after sweetclover did not differ between tillage and chemical termination, but was lower in grazing terminated plots (Figure 15).

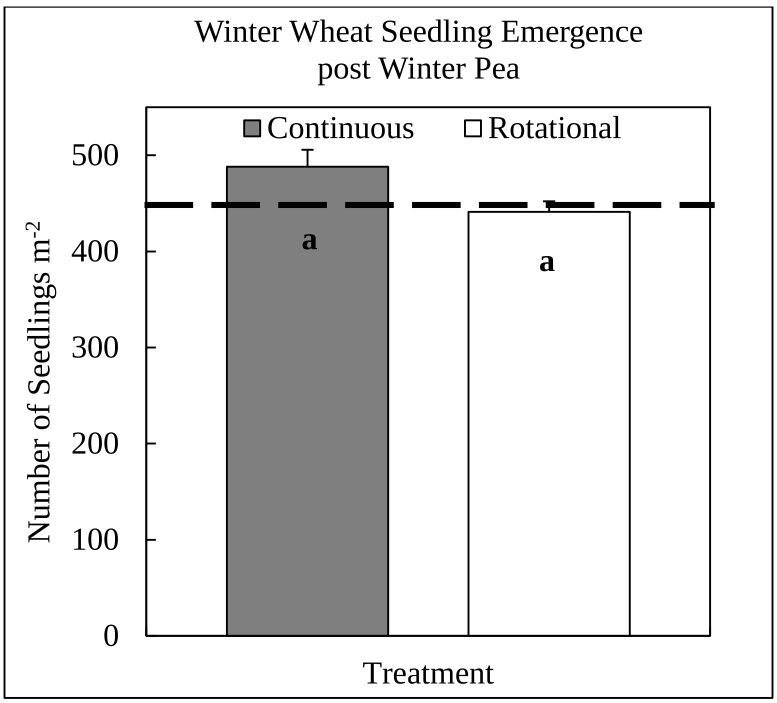

Figure 11: Winter wheat seedling emergence in grazed plots after winter pea cover crop termination. Dashed line shows target seedling density (error bars = SD, letter codes represent statistical differences (α = 0.05) between treatments).

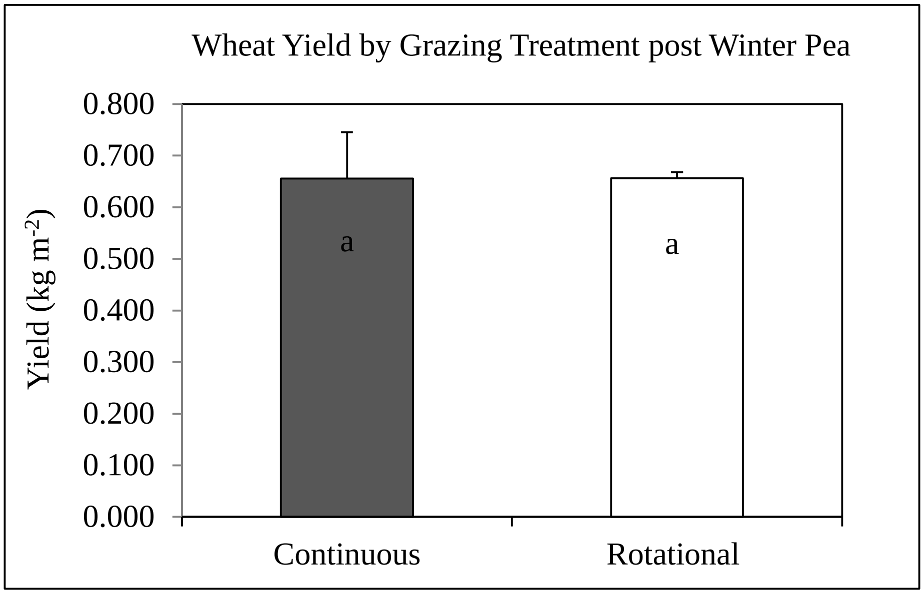

Figure 12: Winter wheat yield (kernels) by grazing treatment following winter pea cover crop termination (error bars = SD, letter codes represent statistical differences (α = 0.05) between treatments).

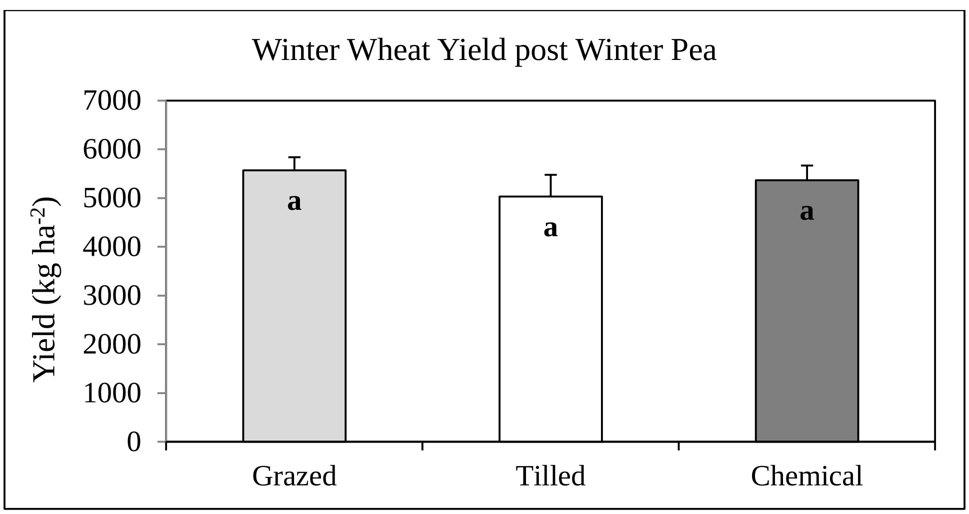

Figure 13: Winter wheat yield after pea cover crop by termination method (error bars = SD, letter codes represent statistical differences (α = 0.05)). Wheat yield evaluated at 12% moisture through center strip method.

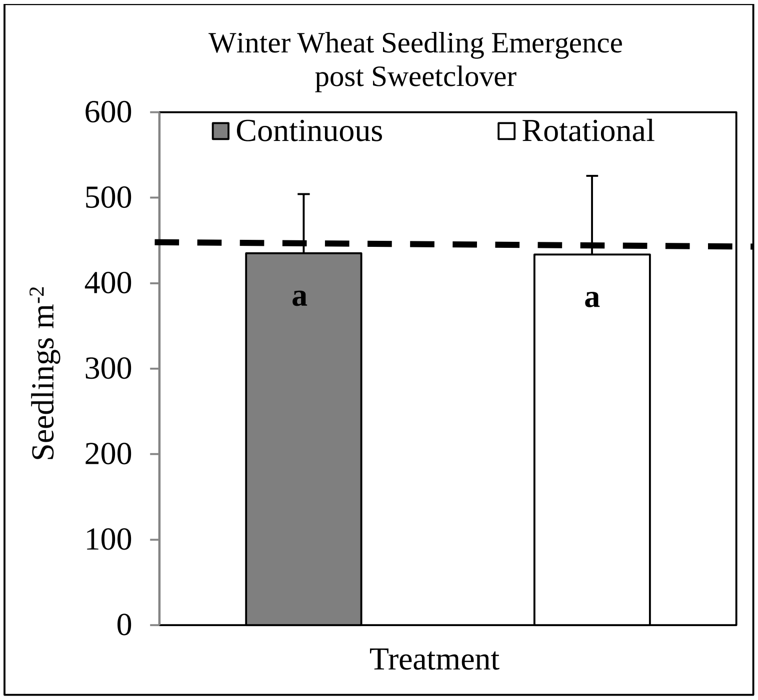

Figure 14: Winter wheat seedling emergence in grazed plots after sweetclover cover crop termination. Dashed line shows target seedling density (error bars = SD, letter codes represent statistical differences (α = 0.05) within cover types).

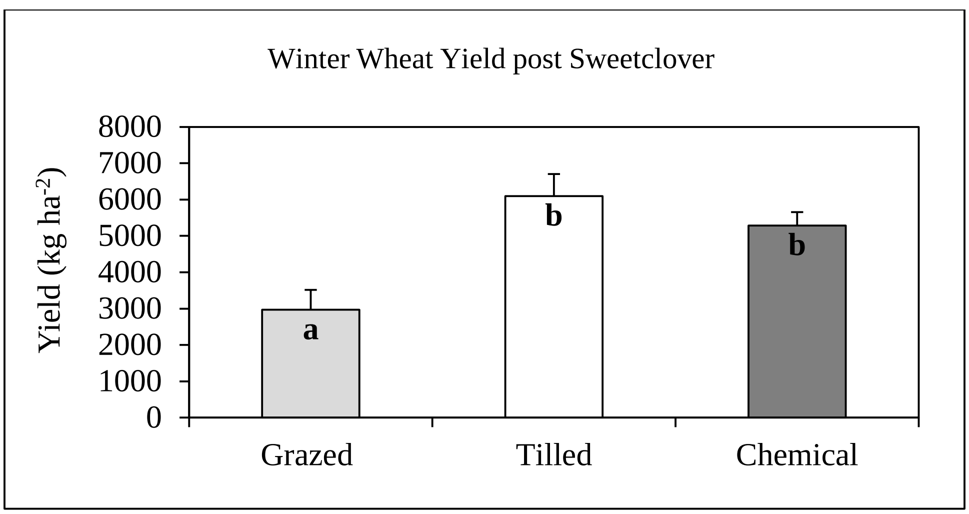

Figure 15: Winter wheat yield after sweetclover cover crop by termination method (error bars = SD, letter codes represent statistical differences (α = 0.05)). Wheat yield evaluated at 12% moisture through center strip method.

DISCUSSION

Sheep

Grazing for cover crop termination has the potential to generate sheep weight gains. There was no difference in ADGs between continuous and rotational grazing treatments in any of our grazing trials, suggesting that either grazing method may be used to terminate cover crops. Sheep weight gains were observed from both grazing treatments while grazing winter pea, however net gains or losses from grazing sweetclover were not easily assessed as two different groups of sheep were used. Wethers grazing sweetclover for 40 days averaged gains of 0.177 kg day^{-1}, while ewes grazing mature sweetclover residue for 8 to 20 days averaged losses of 0.36 kg day^{-1}. Replacement ewes that were brought in to finish sweetclover grazing uniformly lost weight. However, strong conclusions cannot be drawn from these data as the short grazing times (8 to 20 days) were not suitable for monitoring meaningful weight change (Obernier and Baldwin 2006). Increasing length of grazing period seemed to correlate to decreasing rate of weight loss, such that sheep grazed for 8 days averaged weight losses of 0.544 kg day^{-1} while those sheep grazed for 20 days averaged losses of 0.286 kg day^{-1}. Declining rates of weight loss with longer grazing periods may indicate that the initial heavy losses seen in the sheep grazing only 8 days were due to the stress of transportation, handling, and the lack of acclimatization period required to adapt to a new feed and environment (Obernier and Baldwin 2006) rather than a reflection on the treatments or the forage. Sweetclover forage quality was lower at the time that the ewes began grazing than it was when the wethers began grazing (Appendix E), which may also have contributed to weight losses observed in the ewes.

While some studies have shown that continuous grazing optimizes individual animal performance over rotational grazing (Hao et al. 2013), this study does not support the use of either grazing treatment over the other, as both were equally effective at generating sheep gains. These results support the findings of Briske et al. (2008), in that neither grazing system resulted in higher gains. Briske et al. (2008) concluded that continuous and rotational grazing strategies are both potentially effective, and that neither has unique properties that give it an advantage over the other, and they stipulated that management is actually the most important factor in a grazing system. Data from this study support this contention as both the rotational and continuous grazing treatments were managed by the same individual with the same resources and were equally effective at generating sheep live weight gains.

This study compared a continuous grazing and rotational grazing treatment in which the stocking rates were equal across treatments, but the stocking density of the rotational grazing treatment was much higher than that of the continuous grazing treatment. Hao et al. (2013) also had the same stocking rate for their continuous and rotational treatments but higher stocking density for the rotational treatment. In the context of the current study, continuous grazing should have provided for the highest animal performance (Hao et al. 2013), but it had the potential to result in less uniformity in cover crop termination (Launchbaugh and Howery 2005; Owensby 1991). Although poor livestock distribution is often an issue leading to low uniformity of grazing in a rangeland setting (Heitschmidt and Stuth 1991; Owensby 1991), lack of grazing uniformity was not observed in this study, likely due to the small size of the plots and the uniform vegetation. Rotational grazing did not result in reduced individual animal performance, which contrasts with the findings of Glindemann et al. (2009) and Hao et al. (2013). This suggests that the stocking densities in my rotational treatments were not so high as to limit individual animal performance.

Termination

Winter pea was successfully terminated using either continuous or rotational grazing systems, both of which allowed for direct seeding of winter wheat through crop residue. Termination, based upon cover, occurred more quickly than expected, which could have resulted from overestimation of available forage, underestimation of animal demands, or underestimation of wastage. Based on observations of trampling and sheep behavior, underestimation of wastage seemed most likely. Sheep trampling appeared to break pea stems and broken stems were not consumed, rather, sheep selected vegetation that was still standing. At time of termination, most of the dead winter pea cover was in the form of stems and leaves that appeared to have been broken off but not consumed.

Sweetclover termination was not possible within 40 days at the low stocking rate used with the wethers. Sweetclover growth was slow initially, possibly due to cool spring 2014 temperatures. As such, the initial forage availability estimates taken in June 2014 likely underestimated the total forage. After temperatures increased in July, sweetclover growth appeared to accelerate beyond what the wethers could consume. As sweetclover matured, total digestible nutrients decreased (Appendix E) and the main stems appeared to be less palatable than the sweetclover leaves and the weeds. It seems that our stocking rates were low enough that sheep in all treatments were able to graze selectively. The wethers were observed to strip the leaves from the stems, but sweetclover would regrow. Blackshaw et al (2001) observed that termination of sweetclover through disking, cultivating, and mowing was not successful at 10 to 20% bloom stage, although all of those methods were successful at the 80% flowering stage. It is possible that termination of sweetclover could have been more rapidly achieved if grazing had begun at a later stage of sweetclover maturity. On the date we set for the termination goal, there were too many erect sweetclover stems with the possibility of regrowth and seed production to consider the cover crop terminated. I also had concerns that tall, stiff stems might impede the seeding equipment needed for planting winter wheat. Unlike the pea, sweetclover stems did not appear to be broken by trampling. After 40 days of grazing, the wethers were removed for the other project in which they were being used, and we were able to bring in yearling ewes at stocking rates more fitting to the available forage. After grazing periods ranging from 8 to 20 days at stocking densities of 119 and 477 sheep ha^{-1}, it was possible to seed winter wheat into the sweetclover residue.

The herbicide mixture used did not result in winter pea mortality as quickly as was expected. At the time of termination readings, 31 days after the initial application of herbicide, 73% of the cover in chemically treated winter pea plots were still considered live. Winter pea plants were chlorotic and visibly yellowed, however, chemically treated winter peas were not desiccated, which suggested that the plants could have been respiring and using water even 31 days after herbicide treatment. It is likely that more prompt and obvious mortality could be achieved with herbicide, but it was not observed in our study. A similar problem with glyphosate failing to effectively terminate pea, and other legume plants (i.e. common vetch), occurred in other studies in Montana (P. Miller pers. comm.). Cover crop mortality was achieved in time for the subsequent winter wheat crop to be directly seeded into winter pea residue on the chemically terminated plots.

Tillage resulted in high winter pea mortality, but resulted in higher bare ground cover than was desired, 35% bare ground observed compared to the goal of ≤20% bare ground (Figure 8). Tilled plots had the highest percent bare ground over of all of the treatments and placed tilled plots at elevated risk to erosion compared to grazed and chemically treated plots. Similarly, tillage terminated sweetclover, but left 48% bare ground, which was more than twice the goal of 20% bare ground (Figure 10). The additional disturbance represented by multiple tillage passes and the amount of bare ground may have long term detrimental effects upon the soil (Azooz and Arshad, 1996).

Weeds were prevalent in the sweetclover plots (Figure10), which could have been due in part to overwinter vole (*Microtus* spp.) damage (Hobbs and Mooney 1985; Hobbs and Mooney 1991). Conclusions cannot be drawn as to whether or not the higher percentage of weed cover was related to the difference in cover crop species. Winter pea had a more prostrate growth habit and formed a denser canopy than sweetclover, which had an erect growth habit. There was no bare ground in the pre-grazed winter pea plots, whereas bare ground was present in pre-grazed sweetclover plots. Vole damage was observed in the sweetclover plots, which resulted in open areas that could have reduced the competitive ability of sweetclover against weeds in vole disturbed areas (Hobbs and

Mooney 1985; Hobbs and Mooney 1991). In previous research at Fort Ellis Experiment Station (Miller et al. 2015b), spring wheat yield was decreased by 0.14 Mg for every percentage increase in weed cover. Although our study focused on winter wheat in a different rotational cropping system, the presence of weedy species may have adverse effects on subsequent wheat yields.

Winter Wheat

Winter wheat yields following winter pea cover crop did not differ between sheep grazing treatments. As such, the yields garnered from the center strip method, which by necessity must combine the rotational and continuous grazing treatments, should not have been affected by the presence of different grazing treatments. Winter wheat yield did not differ among winter pea cover crop termination methods. This indicates that sheep grazing has the potential to be used for cover crop termination without impacting wheat yields, which could reduce tillage and herbicide use. Our results are in keeping with the findings of Miller et al. (2015), who applied sheep grazing in a spring wheat production system. Previous research from Miller et al. (2015) encompassed a longer period of study (7 years), and also demonstrated positive benefits from integrating sheep and crop production.

Winter wheat yield was lower following sweetclover termination by sheep grazing, compared to tilled and chemically terminated plots. This yield reduction could have been related to the difference in termination timing between the three treatments (Zentner et al. 1996; Zentner et al. 2003). The grazed plots were terminated more slowly, with sheep grazing continuing into August 2014 while the tilled and chemically treated plots were terminated in June (Appendix A).

Zentner et al. (2003) found that delaying cover crop termination until late July or early August lead to depleted soil water and reduced yields in the subsequent wheat crop. When Zentner et al. (2003) changed their termination timing to early July, subsequent wheat yields after cover crop use were similar to those following fallow. Yield reductions could also have been related to soil compaction. Soil compaction may occur from livestock grazing in integrated crop production systems (Tracy and Yang 2008; Krenzer et al. 2013) and can reduce subsequent crop yields. Tracy and Yang (2008) observed compaction from cattle grazing in an integrated corn production system, but the compaction had inconsistent impacts upon crop yields. Soil is more likely to become compacted when it is moist (Tracy and Yang 2008), and sheep grazing occurred through several significant precipitation events in summer 2014. The soil surface in the grazed plots appeared compacted at the time of winter wheat seeding in September 2014 (Perry Miller, personal communication). Soil compaction has been shown to alter root growth and distribution (Oussible et al. 1992; Khan et al. 2012). Oussible et al. (1992) observed that wheat plants in compacted soils developed rooting systems that were denser, finer, and shallower than plants in the control plots. Oussible et al. (1992) also observed reduced numbers of shoots per unit area in compacted treatments. These differences in the rooting system and the wheat emergence were accompanied in a 12 to 23% decrease in grain yield (Oussible et al. 1992). In a greenhouse study, compaction was demonstrated to increase soil bulk density and reduce porosity, which in turn restricted root growth, resulting in decreased root length and root mass and ultimately decreased yield (Khan et al. 2012).

The current study was limited to only one year per cover crop and took place before organic certification was achieved. Ongoing research from the Organic Transition Project at MSU should provide further insights into the effects of sheep grazing in a five year rotational cropping system.

MANAGEMENT IMPLICATIONS

As there were no differences between continuous and rotational grazing for winter pea termination, sheep weight gains, or subsequent winter wheat yields, there was no benefit to using labor intensive rotational grazing over continuous grazing in this setting. However, it is important to note that these were relatively small, uniform pastures. Application at larger scales and with greater pasture heterogeneity may alter the results. This may be especially true for patch grazing in a continuous system as patch grazing is more likely to occur with increasing size and heterogeneity of an area

Flexibility and adaptive management are important to using targeted sheep grazing for cover crop management. The winter pea study successfully met the termination goals while achieving sheep weight gains. However, that success relied upon having the flexibility to remove the sheep after 32 days of grazing, compared to the originally estimated 48 day grazing period. After 32 days, the cover crop was dead, and average bare ground was 22%. Leaving the sheep on the plots an additional 16 days would have increased bare ground as sheep were forced to eat dead pea litter. This could have resulted in weight loss, as the forage quality of dead pea is greatly reduced (Appendix E; Abd El Moneim et al, 1990, Arzani et al. 2010). Adhering to a rigid grazing program would have decreased the benefits to both crop and sheep production systems.

Grazing for sweetclover termination would have been improved with more flexibility in management. The sheep used in this project were also involved in another study (Butler et al. unpublished data). As such, the number of animals used was predetermined and the wethers had to be removed after 40 days, before termination could be completed. The initial stocking rate was too low for the amount of forage present, and the plants grew more rapidly than the sheep could graze. This delayed termination, which can be detrimental to subsequent crop yields (Krueger et al. 2011; Carr et al. 2011; Carr et al. 2013; Alonso-Ayuso et al. 2014). Ideally, managers would be able to adjust the number of grazing animals to the forage availability. Managers should be cognizant of weather variations and have the flexibility to change stocking to reflect how weather is affecting cover crop growth. Careful monitoring of the system and adaptive management is recommended to maximize benefits.

Termination timing and cover crop species selection appear important for successful integration. Blackshaw et al. (2001) observed that termination of sweetclover was more successful at the 80% flowering stage whether termination used an offset-disk, a cultivator, or mowing to 30 cm height. However, delaying termination to meet cover crop maturity can negatively impact subsequent crop yield and increases the chance that the cover crop will produce viable seed (Carr et al. 2011; Carr et al. 2013), which could prove costly with a species like sweetclover, which can produce over 10,000 seeds per individual plant (Pacanoski 2010). Cover crop species should be selected to complement management strategies and goals. If early termination is necessary for the crop rotation, a plant that requires maturity for some termination methods may be less desirable.

RESEARCH SUGGESTIONS

As this study has shown, winter pea and sweetclover responded differently to the termination treatments used. Based on these observations, further research with sweetclover could focus on higher stocking densities, faster rotations, and .on pairing termination timing with plant maturity. In this study, sweetclover was initially very difficult to terminate, but termination was possible later in the growing season and with higher stocking densities. As such, it is inconclusive whether stocking density or plant growth stage was more important for termination, and both areas would benefit from further research. In previous studies, mowing sweetclover was reported to result in termination (Blackshaw et al. 2010), and grazing of windrowed forages has been utilized (Miller et al. 2015a). As such, mowing and windrowing sweetclover before grazing may be an alternative approach. Other cover crop species and crop rotations should be considered as well.

The ultimate test for integrating sheep into cropping systems will be utilizing sheep grazing on an agricultural production scale. The power of my study was limited by its small sample size and relatively short duration. Production-scale experiments involving larger plots and higher numbers of sheep will be necessary to bridge the gap between small scale studies and producer application of integrated sheep and crop production systems.

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APPENDICES

APPENDIX A

TIMELINE

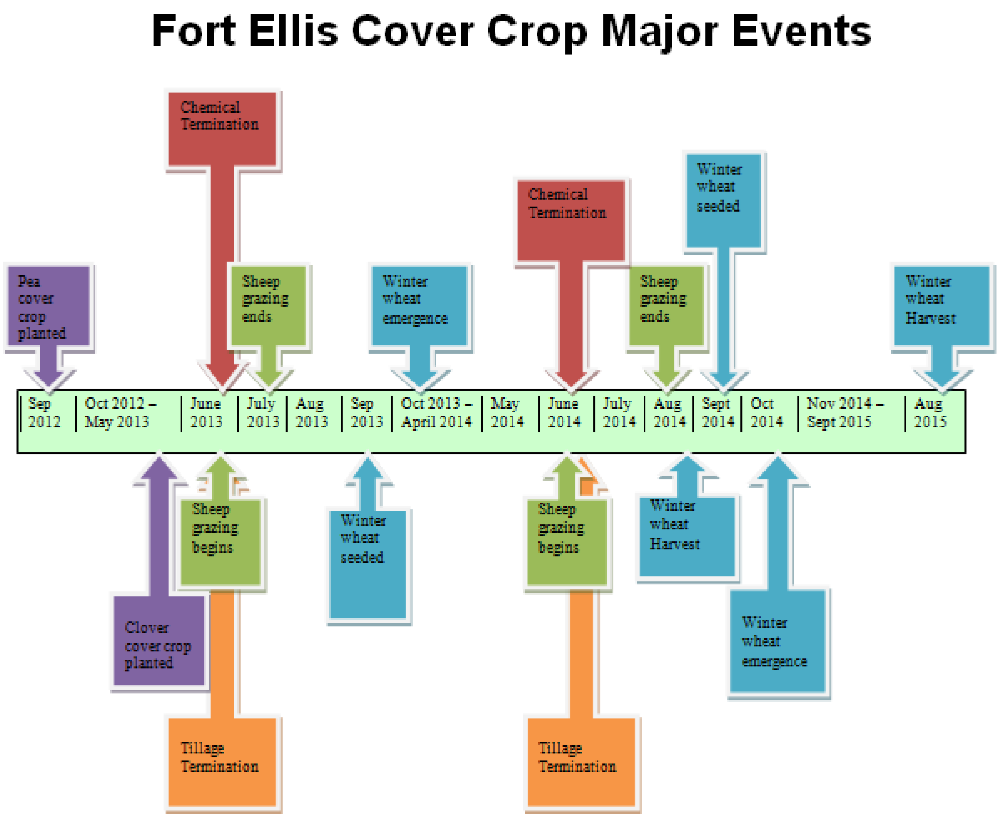

Figure 1: Timeline of major management events at Fort Ellis Research Farm from September 2012 to August 2015

APPENDIX B

STOCKING DENSITY CALCULATIONS

<u>Winter pea – 2013 Grazing Season</u>

Wastage was estimated as 20% Based upon Greenall (1958).

$$Treatment\ pasture\ size = 150\ ft\ x\ 50\ ft = 7{,}500\ ft^2$$

$$Treatment\ pasture\ production$$
$$= \ 7{,}500\ ft^2 \left(\frac{1\ acre}{43{,}560\ ft^2}\right)\left(\frac{1.4\ tons\ DM}{1\ acre}\right)\left(\frac{2{,}000\ lbs}{1\ ton}\right) = 482\ lbs\ DM$$

$$Available\ forage - wastage = 482 - (482 \times\ .20)$$
$$= 386\ lbs\ \ DM/treatment\ pasture$$

$$Amount\ of\ forage\ needed/\ \frac{sheep}{day} = \ (100\ lb\ sheep\ \times\ 2\%\ daily\ gain)$$
$$= 2\ \ lbs/sheep\ day$$

$$Number\ of\ sheep\ days = 386\ lbs\ DM\ \left(\frac{1\ sheep\ day}{2\ lbs}\right)$$
$$= 193\ sheep\ days\ \left(\frac{1\ pasture}{4\ sheep}\right)$$
$$= 48\ days\ for\ each\ pasture\ with\ 4\ sheep$$

$$High\ density\ rotation = \left(\frac{48\ days}{total\ pasture}\right)\left(\frac{total\ pasture}{4\ paddocks}\right)$$
$$= 12\ \ days/paddock\left(\frac{1\ rotation}{4\ days}\right) = 3\ \ rotations/paddock$$

$$High\ density\ paddock\ size = (37.5\ ft\ \ \times 50\ ft) = 1{,}875\ ft^2$$

$$High\ Density\ SD = \left(\frac{4\ sheep}{1{,}875\ ft^2}\right)\left(\frac{43{,}560\ ft^2}{acre}\right)$$
$$= \ 93\ \ sheep/acre\ or\ 230\ sheep/hectare$$

Sweetclover – 2014 Grazing Season

Calculations of stocking density were conducted as above, with the exceptions that plot size was reduced and wastage estimate was increase. Plot size was 88 m by 15 m (0.33 acres). Based upon 2816 lbs. $acre^{-1}$ and plot sizes of 0.33 acres, I calculated an available 918 lbs. of forage $plot^{-1}$. If the each sheep weighed 100 lbs. and consumed 2 lbs. day^{-1}, with 50% wastage, each sheep would need 24 lbs. day^{-1}. With six sheep per plot, calculations showed around 40 days of available forage.

APPENDIX C

AVERAGE DAILY GAINS BY COVER CROP AND TREATMENT

Table 1 Average daily gains (ADGs) for yearlings grazing winter pea cover crop over a 32 day period

Treatment	Plot	ADG (lbs. day^{-1})	ADG (kg day-1)
Continuous	101	0.5	0.23
Continuous	101	0.2	0.09
Continuous	101	0.36	0.16
Continuous	101	0.41	0.19
Continuous	210	0.27	0.12
Continuous	210	0.42	0.19
Continuous	210	0.48	0.22
Continuous	210	0.28	0.13
Continuous	314	0.19	0.09
Continuous	314	0.42	0.19
Continuous	314	0.3	0.14
Continuous	314	0.3	0.14
Rotational	101	0.44	0.20
Rotational	101	0.41	0.19
Rotational	101	0.3	0.14
Rotational	101	0.41	0.19
Rotational	210	0.44	0.20
Rotational	210	0.39	0.18
Rotational	210	0.41	0.19
Rotational	210	0.42	0.19
Rotational	314	0.27	0.12
Rotational	314	0.48	0.22
Table 1 Continued			
Rotational	314	0.47	0.21
Rotational	314	0.39	0.18

Table 2 Average daily gains for yearling wethers grazing sweetclover cover crop over a 40 day period

Treatment	Plot	ADG (kg day^{-1})
Continuous	105	0.25
Continuous	105	0.22
Continuous	105	0.16
Continuous	206	0.11
Continuous	206	0.18
Continuous	206	0.18
Continuous	311	0.18
Continuous	311	0.05
Continuous	311	0.17
Rotational	105	0.24
Rotational	105	0.23
Rotational	105	0.20
Rotational	206	0.17
Rotational	206	0.19
Rotational	206	0.16
Rotational	311	0.16
Rotational	311	0.08
Rotational	311	0.18

Table 3: Average daily gains for the yearling ewes finishing grazing termination of sweetclover. Average daily gains (ADGs) reflect the number of days the specific individual grazed.

Treatment	Plot	Days of grazing	ADG (kg day^{-1})
Continuous	206	8	-0.57
Continuous	206	8	-0.34
Continuous	206	8	-0.63
Continuous	206	8	-0.17
Continuous	206	8	-0.29
Continuous	206	8	-1.08
Continuous	206	8	-0.74
Continuous	206	8	-0.57
Continuous	311	14	-0.26
Continuous	311	14	-0.29
Continuous	311	14	-0.62
Table 3 Continued			
Continuous	311	14	-0.55
Continuous	311	14	-0.74
Continuous	311	14	-0.49
Continuous	311	14	-0.59
Continuous	311	14	-0.42
Continuous	105	20	-0.27
Continuous	105	20	-0.07
Continuous	105	20	-0.23
Continuous	105	20	-0.34
Continuous	105	20	-0.11
Continuous	105	20	-0.20
Continuous	105	20	-0.36
Continuous	105	20	-0.45
Rotational	105	14	-0.39
Rotational	105	14	-0.49
Rotational	105	14	-0.45
Rotational	105	14	-0.03
Rotational	105	14	-0.32
Rotational	105	14	-0.42
Rotational	105	14	-0.13
Rotational	105	14	-0.49
Rotational	206	18	-0.08
Rotational	206	18	-0.28
Rotational	206	18	-0.55
Rotational	206	18	-0.15
Rotational	206	18	-0.18
Rotational	206	18	0.03
Rotational	206	18	-0.18

Rotational	206	18	-0.30
Rotational	311	20	-0.36
Rotational	311	20	-0.14
Rotational	311	20	-0.20
Rotational	311	20	-0.29
Rotational	311	20	-0.29
Rotational	311	20	-0.27
Rotational	311	20	-0.50
Rotational	311	20	-0.43

APPENDIX D

FIGURES REPRESENTING SAMPLING METHODS

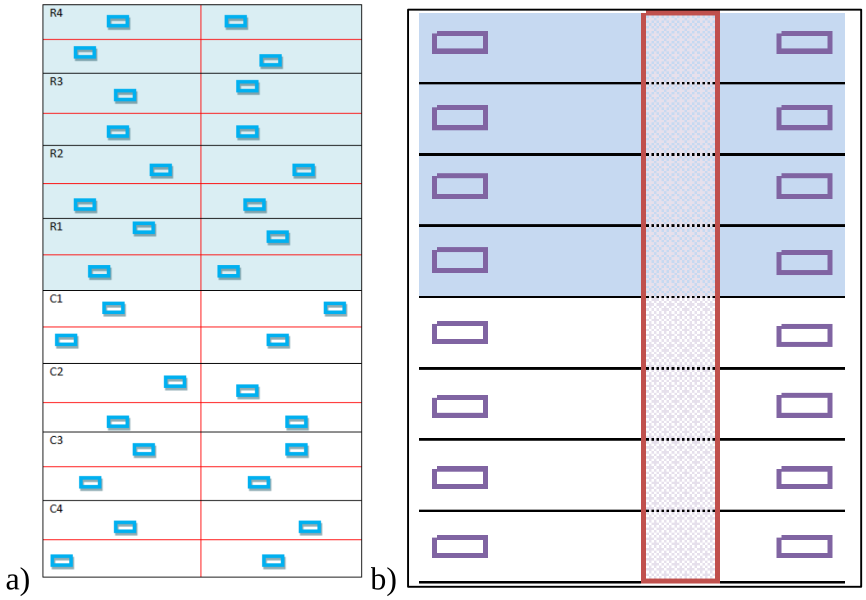

Figure 1: a) Representation of a single whole plot (90 x15 m), which has been divided for wheat emergence sampling. The shaded section differentiates the Rotational from the Continuous treatment. 20 x 50 cm frames are represented by the small rectangles. b) Diagram of winter wheat yield sampling in a grazed plot. Frames for hand clipping are represented by small rectangles. The center harvested swath is represented as the large, vertical rectangle. Shading represents the presence of two grazing treatments.

APPENDIX E

FORAGE QUALITY INFORMATION

Forage quality samples were taken concurrently with cover measurements. Every five points along the established transect lines, a pin was dropped approximately 0.5 m from the transect line, and all of the plants that intersected the pin were collected. If weedy species intersected the pin, they were taken as part of the forage sample. Forage quality samples were oven dried at 68 ˚C to a constant weight and ground in a Wiley Mill to 1 mm diameter particle size. Samples from the first and final days of grazing were sent to Midwest Laboratories, Inc. (13611 B Street, Omaha, NE 68144) for analysis of crude protein, acid and neutral detergent fiber, and total digestible nutrients. Samples were combined across replicates but grazing treatments and dates were maintained separately. Forage quality samples were collected and processed using the same methods for both cover crops.

Winter pea forage quality samples were similar between grazing treatments (Appendix F, Table 1). After 32 days of grazing, crude protein and total digestible nutrients decreased while acid and neutral detergent fiber content appeared to increase in both continuously and rotationally grazed plots (Appendix F, Table 1).

Table 1: Winter pea forage quality parameters by grazing treatment and sampling time

Treatment	Timing	Crude Protein	ADF	NDF	TDN
Continuous	Pregraze	28%	31%	35%	67%
Rotational	Pregraze	29%	30%	35%	68%
Continuous	Postgraze	13%	52%	63%	51%
Rotational	Postgraze	13%	51%	61%	52%

Initial forage quality for sweetclover was high in all grazed plots (Appendix F, Table 2) sweetclover forage quality decreased over the 40 day initial grazing period as plants matured and became more fibrous. Continuous plots averaged 7% CP, a third of the pregrazed value and rotational plots averaged 8% CP. Forage quality was similar between grazing treatments.

Table 2: Sweetclover forage quality parameters by grazing treatment and sampling time.

Treatment	Timing	Crude Protein	ADF	NDF	TDN
Continuous	Pregraze	21%	28%	34%	71%
Rotational	Pregraze	21%	29%	35%	69%
Continuous	Postgraze	7%	60%	71%	46%
Rotational	Postgraze	8%	58%	70%	47%

Forage quality averages for crude protein, ADF, NDF, or TDN were similar between rotational and continuous treatments after 32 and 40 days of grazing for winter pea and sweetclover, respectively. Forage quality was more closely linked with plant phenology, with digestibility and crude protein decreasing as plants matured and increased in fiber. This finding supports the assertion made by Arzani et al. (2010) that stage of growth is the most important factor determining nutritional value of forage.

As plants mature, CP and digestibility decrease as NDF and ADF increase (Abd El Moneim et al, 1990, Arzani et al. 2010). Our findings are supported by Abd El Moneim et al., 1990, who saw a similar trend of decreasing CP and increasing fiber as plants matured. Both NDF and ADF increased gradually over time as plants matured, more than doubling over the course of the study (Abd El Moneim et al. 1990). Abd El

Moneim et al. (1990) also measured the ratio of leaf to stem on a dry matter basis, and found that leafiness began to decline sharply 102 to 115 days after germination. Declining leaf to stem ratio and increasing fibrousness over time could explain why the forage quality declined so sharply in the cover crops. Although leafy regrowth was observed, the overall leaf to stem ratio was probably declining as plants matured. It is possible that animal selectivity could improve the effective forage quality, as sheep were observed to strip the leaves from the stems rather than uniformly consuming the entire plant. However, regrowth due to grazing did not appear to increase the forage quality of either cover crop based upon my sampling methods. I cannot determine if grazing affected the leaf to stem ratio, as I sampled whole plants, including maturing stems and I did not separate leaves from stems when processing my samples, whereas sheep would have browsed the leaves and left less palatable stems.