Influence of Grazing Management Strategies on Forage Quality/Production and Animal Performance in an Ontario Cow Calf System

by

Jade St Peter

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ABSTRACT

INFLUENCE OF GRAZING MANAGEMENT STRATEGIES ON FORAGE QUALITY/PRODUCTION AND ANIMAL PERFORMANCE IN AN ONTARIO COW CALF SYSTEM

Jade St Peter
University of Guelph, 2023

Advisor(s):
Dr. Ira B. Mandell

Dr. Katherine Wood

These studies sought to develop best grazing management practices for optimizing forage growth/production and cattle performance. Cow-calf pairs grazed from May through September to evaluate the effectiveness of set stocking, rotational, strip, and continuous grazing management regimes on animal performance and forage growth. While different grazing methods did not increase forage biomass, sward height or animal performance, intensive grazing management (strip, rotational) was found to increase grazing days and dry matter intake as a percentage of body weight. A second study evaluated fall stockpile grazing using yearling heifers to evaluate grasses, alfalfa or birdsfoot trefoil effectiveness in an extended grazing system. The study found harvesting forages more than once prior to grazing may decrease available pasture during the fall and decrease grazing days. Heifer performance was not affected by pasture forage species. Considerations to forage/grazing management can directly benefit producers by lengthening the grazing season in both Spring and Fall.

DEDICATION

I would like to dedicate my thesis to my late grandfather Grant St Peter, whom I referred to as Poppa and “many” referred to as honest grant (so he would tell you anyways). My grandfather had a strong involvement in the cow-calf industry. Growing up on a farm himself and continuing to own cattle until his passing in February of 2023. Poppa is the man who ultimately started it all, I would have never had such an interest in cattle had he not passed that love to my father and thus down to me. Poppa always appreciated good Charolais cows and I can say the same love is instilled in myself. I will miss him for the rest of my life but have fond memories of growing up on a farm just across the road. His love for cattle carries on through my own involvement in the industry and I know he would be proud.

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LIST OF SYMBOLS, ABBREVIATIONS OR NOMENCLATURE

RG- Rotational grazing

SS- Set Stocking

SSM- set stocking with mowing

STG- strip grazing

CG- Continuous grazing

CP- Crude protein

ADF- Acid Detergent Fiber

NDF- Neutral Detergent Fiber

TDN- Total Digestible Nutrients

P- Phosphorus

Ca- Calcium

BW- Body weight

ADG- Average Daily Gain

DMI- Dry Matter Intake

NEp- Net Energy of Production

NEm- Net Energy of Maintenance

DMI- Dry matter intake

M&M- Minson and McDonald

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1.0 Introduction

Beef production within Canada, and certainly Ontario plays a vital role in the supply chain for local and global meat production. Beef production within Canada is primarily concentrated in the western provinces; however, Ontario beef production contributed 14.1% of beef produced in Canada (Statcan Livestock Estimates, 2020). In Canada, the structure of the beef industry starts with cow calf production, where calves from the herd will be weaned and backgrounded to gain weight prior to entering a feedlot system or marketed directly to the feedlot for finishing. In the beef production chain, cow-calf operations are generally most likely to utilize a grazing system.

A significant driver of market decisions affecting cow-calf producers result from decisions made in the backgrounding and feedlot sectors (Goddard et al., 2016). Due to the extensive range in scale for cow-calf producers, along with feedlots sourcing animals from many different operations, cow-calf producers have little influence for both market outcomes and price (Goddard et al., 2016). Based on the organization of the Canadian beef industry, backgrounders and feedlots buy animals from cow-calf producers, and therefore drive incentive for the cow-calf sector to adopt innovations (Goddard et al., 2016). However, if the cow-calf sector does not adopt innovations as the base of the value-chain, other beef industry stakeholders will not benefit from this technology (Goddard et al., 2016). Therefore, willingness to pay for technology, can be seen as a major barrier to adaption for cow-calf producers.

Most cattle within the cow-calf industry will be raised on a pasture system at some point in their life, with most beef producers maximizing the use of pasture for their breeding herd.

Managing animals on pasture provides less energy-intensive feed inputs and contribute fewer eutrophic emissions than animals managed in a feedlot system (Petellier et al., 2010). Extending pasture availability can save use of conserved forage for colder months when there is no fresh forage to graze (Janovick et al., 2004). Utilizing pasture is somewhat unpredictable compared to confined feeding systems; forage quality and availability vary with precipitation and year which may affect the length of grazing season and pasture's ability to hold a consistent number of animals without supplemental feed (Janovick et al., 2004, Myerscough et al., 2022).

Pasture typically utilizes poorer quality land that cannot be used for human food production and is able to produce a valuable protein source as beef for the human food chain. However, urban sprawl and the conversion of pasture land to grow crops in marginal areas have forced some producers to consider housing cow-calf pairs in a dry-lot management system year-round. Dry-lots provide more stable nutrition to cows, maintaining body weight and condition throughout the summer until weaning (Myerscough et al., 2022). Although dry-lot cows maintained more consistent weight through weaning and had higher body condition scores, condition scores for cows on pasture were still adequate at weaning (Myerscough et al., 2022). In contrast, Anderson et al. (2013) reported cows gained more weight on pasture than cows fed corn silage and grass hay-based diets with additional by-products in dry-lot. Cows housed in dry-lot and fed for the summer produced more milk and weaned heavier calves than cows on pasture, but pasture-raised calves had greater ADG and feed efficiency upon entering a feedlot system (Myerscough et al., 2022; Mathis et al., 2008). This previous finding negatively contrasts with Anderson et al. (2013), who found that pasture-raised calves gained more weight than dry-lot managed pairs before weaning.

Greater pasture quality potentially allows producers to save money raising calves. Anderson et al. (2013) reported overall savings of 23 cents per pound for a weaned calf for each cow-calf pair on pasture versus dry-lot management. The performance of pastured cow-calf pairs is variable based on weather conditions which largely impact pasture productivity and thus animal production; however, it may be cheaper than raising pairs in a dry lot system year-round. In addition, raising cow-calf pairs on pasture prior to weaning does not significantly affect reproduction traits (Anderson et al., 2013; Myerscough et al., 2022). Pasture use for backgrounding calves prior to feedlot finishing also saves producers money as it requires five times less feed and two times less labour in a rangeland grazing setting (Mathis et al., 2008). However, labour costs may be heightened in an intensely managed grazing setting, due to increased regular handling of cattle compared to a continuous system with minimal handling throughout the season.

Grazing is utilized to decrease the use of conserved forages (hay, silage), which are typically fed during colder months. Use of conserved forages can be decreased significantly with the use of pasture. Janovick et al. (2004) found hay use decreased on average 1701 kg DM/cow over a three-year study when cows were pastured in a year-round grazing system, supplemented with hay when required. However, pasture quantity and quality can be highly variable over a grazing season and vary with weather, specifically where low precipitation can reduce pasture biomass (Meyerscough et al., 2022; Janovick et al., 2004). Therefore, variable weather can directly affect the ability of pasture to maintain animals and the length of a grazing season.

A very popular method of grazing is continuous grazing, where animals remain in a large area for an extended period of time and potentially the entire grazing season. Continuous grazing is very well known, thus most other grazing systems are often compared to continuous grazing. Rotational grazing is becoming more popular, which consists of moving animals frequently to new a new paddock after forage has been grazed, typically after a few days. In a rotational system, animals have the potential to cycle through already grazed paddocks. Strip grazing also cycles through to new grazing areas, but cattle move every day and are only allowed to a “strip” of pasture that will adequately supply enough forage for a single day. Both rotational and strip grazing are thought to increase forage utilization and encourage more uniform grazing compared to traditional continuous grazing. Another grazing method to be further explored is set stocking, which consists of a larger grazing area in which cattle move to a new paddock on a less frequent basis.

Environmental concerns have been raised about beef production and is effect on production of greenhouse gasses, which have prompted recent studies outlining sustainability for raising beef cattle. When compared to conventional farming, animals on pasture will produce more enteric greenhouse gas emissions due to relative production of end products per kg of weight (Pelletier, 2010). This however, is not the entire story for pasture raising beef cattle, because it does not consider the potential for carbon capture within soil that is stimulated by grazing.

Cow-calf production is the sector of the industry that has the most potential to have the greatest impact on overall emissions, as it is the most greenhouse gas intensive portion of beef production on a whole farm level (Lupo et al., 2013; Beauchemin et al., 2010; Alemu et al., 2017). Cow-calf production accounted for 80% of greenhouse gas emissions in a complete life cycle assessment in Beauchemin et al. (2010). Part of the intensity of emissions associated with cow/calf production is that the maintaining breeding stock contributes a significant amount of emissions, as they are only able to produce one calf per year, but must be fed year round. Management of multiparous cows can increase emissions by as much as 8-20% compared to management of smaller framed primiparous cows for this exact reason (Legesse et al., 2011). However, these emissions may be offset by grazing systems utilization and carbon sequestration (Alemu et al., 2017).

Grazing of cattle can encompass animal production goals, such as weaned calf weights and environmental goals such as reducing carbon emissions by carbon sequestration (Alemu et al., 2017). Plants can take atmospheric carbon and store it within their root structures for re-growth through the carbon cycle and process of photosynthesis (Ontle and Schlute, 2012). This process is increased by grazing events, forcing the plant to re-grow and develop more root carbon stores (Ontle and Schlute, 2012).

Farms in the lower quartile for emissions reported increased use of perennial forage and increased productivity of these lands by 25% compared to farms in the upper 3 quartiles of recorded carbon emissions (Legesse et al., 2011). Use of pasture systems generally benefit producers in one way or another.

Some intensive grazing methods are thought to be more efficient for using the land, producing more animal weight per land area, and potentially increasing carbon sequestration due to repeated controlled defoliation. Rotational grazing is considered to be an intensive grazing method where animals are moved through a series of small paddocks and potentially re-graze paddocks after a period of rest. Rotational grazing is becoming more popular with producers as a way to increase stocking density and produce more animal weight per land unit (Bertelsen et al., 1993; Beck et al., 2016).

Although stocking rate may be increased by utilizing rotational grazing, a balance between high and low stocking rates based on land availability is needed. Some studies have shown greater body condition for calves on a medium stocked continuous grazing system vs. a medium stocked rotational grazing system, due to differences in protein content in forages between grazing systems (Wyatt et al., 2012, 2013). Wyatt et al. (2012) stated that lower stocking rates on pasture could result in less time on conserved forages such as hay when there is not enough pasture to sustain animals. Haan et al. (2007) found no differences in forage biomass between rotational and continuous grazing systems, indicating there may not be notable increases in forage production in all cases, but likely better forage utilization with higher carrying capacity versus the lower stocked treatments.

Carbon dioxide uptake of plants are reported to be lower in rotational grazing fields compared to continuous grazing, but increase during the rest period prior to re-grazing, when plants are trying to recover (Gourlez De La Motte et al., 2018). This indicates a potential for carbon storage, if grazed plants uptake more carbon from the atmosphere during re-growth. However, when looking at carbon deposition, Sanderman et al. (2015) showed no difference in soil organic carbon levels within soils subjected to continuous and rotational grazing due to slow accumulation of carbon.

Strip grazing is another method of intensive grazing where animals are given enough forage for only one day of grazing, moving to a new area daily. Gregorini et al.

(2007) found that allowing cattle only enough forage for one day and moving them in the morning resulted in longer and heavier grazing bouts in the afternoon after a period of fasting. When animals are only grazing during the day, they graze forages undergoing photosynthesis, which are more digestible, higher in metabolizable energy and lower in fibre concentrations (Gregorini et al., 2007). Other studies have shown similar body weights, body condition and time grazing when comparing strip grazing to a continuous grazing system (Gadberry et al., 2014; Verdon et al., 2018). Strip grazing has the potential to encourage more uniform grazing and result in better forage utilization due to restriction of animals which cannot be selective if they are required to eat everything in a given area to meet their needs (Gadberry et al., 2014).

A less intensive method of grazing is set stocking, where animals are allowed a larger area to graze over an extended period of time and are moved very infrequently. Set stocking is usually carried out with a set number of animals that a pasture is thought to hold for the entirety of the season. Little et al. (2015) found that set stocking and strip grazing methods were similar in terms of calf weight gain. Set stocking is more common in European regions, and needs further investigation under Canadian conditions.

A possible way to further sequester carbon is through extending the grazing season later into fall. This can be done by resting forages after cutting during the spring/summer and grazing after the critical frost period has ended when plants become dormant. It has been reported that fall grazing is an effective way to remove plant litter from a forage stand, while also returning feces and urine directly to the forage ecosystem, stimulating plant growth (Baker et al., 1988). Typically grass mixes are used in a stockpile grazing system because they better retain forage biomass through colder temperatures. In addition, heifers grazing stockpiled forages gained more weight than animals managed on just conventional pasture (Baron et al., 2004; Lyons et al., 2016). McFarlane et al. (2018) reported heifers enter a period of compensatory gain following extended fall grazing. Utilizing legumes in an extended grazing system may better meet protein requirements for heifers while maintaining weight for fetal development (Lyons et al., 2016).

In addition to the environmental benefits of pasture utilization as a net greenhouse gas mitigation strategy, increasing pasture usage may overall benefit producers economically, as pasture is generally considered a cost-effective way to manage animals during the warmer season. McCartney et al., (2004) found that winter feeding strategies utilizing swath grazing costed $70 less per cow for the first 100 days compared to a typical confinement feeding system feeding barley silage and ad lib straw. Funston and Larson (2011) also found similar findings with a cost reduction of $45 USD per pregnant heifer when grazed on either corn crop residue or dormant rangeland in separate years compared to dry lot feeding of a common diet consisting of corn gluten feed, corn silage and hay.

Use of pasture can not only benefit the environment through carbon sequestration but also producers by managing animals in a cost-effective way that does not compromise performance. Further discussion of current research surrounding management of breeding stock, grazing management practices for increased animal and pasture efficiency, benefits and challenges of pasture production, and environmental impacts of pasture will be further discussed within this literature review.

2.0 Literature Review

2.1 Use of pasture systems to manage breeding stock in cow calf production

The Canadian beef industry plays a significant role in the global beef supply chain. At the start of 2020, there were 11.2 million beef cattle on Canadian farms (Statcan Livestock Estimates, 2020). Beef production in Canada is concentrated mainly in the western provinces, with Alberta and Saskatchewan leading in production; however, Ontario beef production ranks third in the country, making up 14.1% of Canadian beef production (Statcan Livestock Estimates, 2020). Canada's beef industry functions with three main stages of production, usually on separate operations. These include cow-calf production, backgrounding calves for the feedlot, finishing cattle in the feedlot. In cow-calf production, breeding animals are managed to produce a calf per cow per year to enter meat production or serve as breeding replacements. Calves are then backgrounded after weaning to grow muscle and frame before entering a feedlot to be finished, or some calves go directly to a feedlot to be finished. Finally, feedlot cattle are finished and then enter the food chain. Grazing is primarily utilized for feeding cattle on cow-calf operations with approximately 66,160 beef and dairy farms in Canada currently grazing cattle; 22.4% of these cattle utilized for grazing are within Ontario (Statistics Canada, Grazing Management in Canada, 2004).

Canadian beef farmers, particularly cow-calf producers, typically utilize pasture in the spring/summer months, from early spring to late fall, but typically utilizes forages throughout the entire production period. Pasture is typically a low-cost way to manage fed a high forage diet, without needing to rely on conserved forages all year round. Continuous and rotational grazing are among the most popular methods of grazing. Continuous grazing is typically carried out on a larger area of land that cattle will remain on for the entirety of the grazing season. In rotational grazing systems, land is split up into smaller paddocks and cattle are placed into one paddock and remain there until the quantitative/qualitative amounts of the available forage in the paddock compromise meeting nutrient requirements for cattle or longevity of the paddock. The cattle are then cycled through to the other paddocks, thereby allowing previously grazed paddocks to be re-grazed once forage grows back. Within Canada, 69% of farms with over $500 thousand gross farm receipts report utilizing rotational grazing (Statistics Canada, Grazing Management in Canada, 2004). In general, larger farms in Canada manage pasture more closely with sward height and density in mind, as per statistics by Canada Grazing Management (2004). The primary grazing method utilized by Canadian beef farms is continuous grazing. However, this seems to be shifting in recent years. Reseeding pastures every 5-10 years is the most common practice used by 30% of cattle farms (Statistics Canada, Grazing Management in Canada, 2004). Beneficial grazing management practices are being promoted to safeguard or enhance the environment, prevent over-grazing, and protect riparian areas and surface water areas. Increased use of beneficial grazing management practices such as rotational grazing and management of pasture species increased with farm size (Statistics Canada, Grazing Management in Canada, 2004) as Canadian beef farmers adapt to new information to graze animals better to benefit production and the environment.

2.2 Environmental benefits for pasture use and increased efficiency of forages in grazing systems

Recent studies have outlined the sustainability of raising beef cattle. When comparing conventional farming methods, pasture-raised animals release more emissions relative to their output of products by weight (Pelletier, 2010). This high output of emissions relative to product weight is especially apparent in cow-calf production, where one calf is produced per cow fed per year. Additionally, the cow-calf industry is the most greenhouse gas intensive portion of beef production (Lupo et al., 2013; Beauchemin et al., 2010; Alemu et al., 2017). Cow-calf production accounts for 80% of emissions in the Beauchemin et al. (2010) model for life cycle assessment of beef production, and the maintenance of multiparous cows may attribute 8-20% more emissions compared with primiparous cows due to maintaining multiparous cows for long periods between calving, attributing to higher total emissions (Legesse et al., 2011). Since the cow must be fed year-round to produce only a single calf for the food chain, management of breeding animals is very greenhouse gas intensive, accounting for 79% of emissions compared to finishers at 9%, backgrounders at 7%, bulls at 3% and calves at 2% of emissions from beef cattle (Beauchemin et al., 2010; Petellier et al., 2010). A large part of the energy and emissions inefficiency is due to winter feeding and production of forage, as production of conserved forage may have similar fuel inputs to production of crops (Petellier et al., 2010; Galyean et al., 2011). Pasture is utilized in warmer months, allowing low input systems for grazing that encourage both adequate animal production and rearing of calves and reduction in carbon emissions by utilizing carbon storage within the soil, resulting in a net carbon sink (Alemu et al., 2017).

Although public perception of beef production and greenhouse gasses is generally poor, agriculture only accounts for a total of 8.2% of greenhouse gas emissions, and enteric fermentation is only 2% of total greenhouse gas emissions (Canada.ca, 2022). However, this picture of methane emissions does not depict the livestock industry's benefits through carbon sequestration. Apart from utilizing poor quality land not suitable for crop production, grazing livestock helps restore atmospheric carbon to the soil through carbon sequestering and plant carbon storage within the root rhizosphere. Plants store atmospheric carbon, carbon dioxide in their root structures through photosynthesis and deposit it as soil organic carbon (Ontle and Schlute, 2012). This process of storing carbon is specifically vital regarding global warming. Unfortunately, many soils are depleted in soil organic carbon from release of carbon into the atmosphere, caused by the breakdown of carbon by soil microbial communities and the lack of carbon deposited back into the soil by plant communities due to land-use change (Ontle and Schlute, 2012). This depletion of soil organic carbon, although negative, leaves room for the deposit of carbon back into the soil.

Soil that has been previously depleted of carbon has the greatest potential for soil organic carbon to be once again stored. Conversion of natural grasslands into airable crop land releases carbon from soil aggregates and therefore leaves potential for re-accumulation of carbon within the soil. Conversely, conversion of airable crop land back into airable pasture creates a potential for rapid accumulation of carbon stores within the soil (Alemu et al., 2004; Poeplau et al., 2011; Jones and Donnelly, 2004). Soil organic carbon is accumulated at an exponential rate following land use change from cropland to grasslands with the use of perennial pastures (Poeplau et al., 2011). The farms in the lower quartile for greenhouse gas emissions have a greater amount of land devoted to perennial forages and 25% greater land productivity (Legesse et al., 2011). Carbon sequestration varies with moisture and temperature of the soil and atmosphere; warmer temperatures sequester more carbon into the soil (Chaivegato et al., 2015; Poeplau et al., 2011). Studies conducted in different climates are helpful for understanding carbon flux in a grazing system; however, carbon sequestration will vary within a climate zone based on seasonal temperatures in a climate zone. While the amount of carbon sequestered by managed grazing varies based on climate, soil type, rainfall, and type of vegetation, there are also large amounts of variability on the farm level (Chaivegato et al., 2015). The variation in soil organic carbon levels by site is likely why many studies use models to depict carbon fluxes with management strategies. While this creates a valuable depiction of soil carbon levels, more research is needed to understand variations in soil organic carbon levels by site with different management practices.

Managed grasslands are an important factor for managing sward characteristics which affects soil organic carbon levels and need to be extensively considered for examining the environmental impacts of beef cattle. Managed grasslands can sequester more carbon on converted cropland than natural pastures that are naturally allowed to re-establish due to already depleted carbon stores from practices associated with conventional cropping such as cultivating (Li et al., 2018). The harvest of plant biomass mechanically or by grazing encourages plant re-growth, thus encouraging photosynthesis and carbon sequestration within root systems (SCCC, 2001). Soil organic carbon will continue to accumulate in soils until an equilibrium is met, where no more carbon can be stored (Lal., 2004). Sources are generally in agreement that a managed grassland converted from airable cropland will take over 100 years for soil organic levels to reach equilibrium (Soussana et al., 2004; Poplau et al., 2011). However, these sources differ in the number of years it will take before this equilibrium is attained (Li et al., 2018; Pouplau et al., 2011). The amount and rate of carbon stored in soil is heavily influenced by management of grasslands (Soussana et al., 2004; Chiavegato et al., 2015b). Increasing stocking rate will decrease soil organic carbon storage and increase total system greenhouse gas intensity within a pasture system (Sousanna et al., 2004; Li et al., 2018; Alemu et al., 2017). Alemu et al (2017) claimed this is due to the concentration of many animals on a smaller area of land, thus decreasing potential for carbon sequestration. Increased stocking rate is also negatively correlated with animal performance if grass is unable to support a larger number of animals (Wyatt et al., 2012b, Wyatt et al., 2013, Derner et al., 2008).

In order to add carbon to the soil, carbon inputs into the grazing system must be greater than those lost by herbivory (De Mazancourt et al., 1998). Grazing by animals not only encourages photosynthesis by re-growth of plants but adds limiting nutrients auch as nitrogen and phosphorus to the soil with manure (De Mazancourt et al., 1998; SCCC, 2001). Pasture grazing increases decomposition of plant litter and returns more digestible carbon to the nutrient system in manure (Semmartin & Garbialdi., 2004; SCCC, 2001). Cattle return as much as 25-60% of ingested carbon back to the system via manure (SCCC, 2001). Past grazing sites had increased soil nitrogen availability over ungrazed sites for an extended period of time, even after 45 days post grazing (Semmartin & Garbialdi., 2004). Grazing increases the decomposition of leaf and shoot mass with little effects to the roots (Semmartin & Garbialdi., 2004).

Grazing management also plays a large role in the productivity and carbon cycle in managed grasslands. Improving forage quality can significantly decrease greenhouse gas emissions by altering the rumen environment to produce more propionate and consequently less acetate, and slightly less butyrate as a result of less fibrous feedstuffs. The reported decrease in greenhouse gas emissions with intensively managed grassland varies. Beauchemin et al. (2011) reported a 5% reduction in emissions in a cow-calf herd with increased forage quality through harvest of winter fed hay at an earlier stage of growth, while Deramus et al. (2003) reported a 22% reduction in emissions with increased forage quality from best management practices for grazed pastures compared with continuous grazing. Although increasing forage quality through earlier harvest and more intense grazing decreases greenhouse gas emissions overall from beef cattle by reducing dry matter intake, increased crude protein content in high-quality forages may subsequently increase manure NO_2 emissions due to increased N secretion (Deramus et al., 2003, Beauchemin et al., 2011).

Type of forage grazed can also increase greenhouse gas emissions; alfalfa-grass pastures had lower emissions compared to grass only pastures due to an increase in protein content, which is negatively correlated with fibre content of forages (McCaughey et al., 1999). Increasing alfalfa content in pastures increased dry matter intake in cattle, which is largely correlated with higher greenhouse gas emissions; however, pastures with increased protein content had lower emissions due to increased digestibility of forages containing legumes because they contain more hemicellulose than cellulose, which is more easily digestible (McCaughey et al., 1999). Increasing digestibility of forages fed to beef cattle will decrease the amount of enteric methane production by decreasing energy lost through digestion and decreasing intakes in a limit fed scenario (McCaughey et al., 1999; Moraes et al., 2014; Lupo et al., 2013).

The specific forage species mix may also affect the rate of soil organic carbon storage within the soil; Alemu et al. (2019b) reported a higher rate of carbon sequestration with a 12-species pasture mix compared to a 7-species mix. In addition, the grazing method may affect species diversity in managed pastures. Chaivegato et al. (2015) found that paddocks with a shorter rest period had a higher legume fraction due to frequent defoliation of taller grasses, allowing shorter legumes to reach sunlight.

Forage quality can be controlled by management factors such as utilizing intensively managed grazing, mowing, and control of stocking rate. Heitschmidt et al. (1990) found that moderately stocked pastures produced calves with heavier weaning weights, and thus provided more productivity per cow in these systems. Increases in weaned calf weight per land unit will increase with increased stocking rate; however annual stocking stability may decrease with stocking rate (Heitschmidt, 1990). In the latter study, deferred rotational grazing with an extended rest period of 16-weeks was the most productive per cow for weaned calf weight. It was concluded that moderate stocking rates produced the most calf weight per cow (Heitschmidt,1990). Alemu et al. (2019) found that deferred rotational grazing had a greater average dry matter yield and greater number of grazing days per unit area compared to continuous grazing. Continuous grazing had a higher digestible nutrient fraction and thus greater weight gain per day (Alemu et al., 2019). Highly stocked continuous grazing can produce higher quality forages with higher crude protein and lower neutral detergent fiber contents due to decreased availability for selective grazing (Alemu et al., 2017). A shorter rest period in a rotationally grazed system produced better quality forages with more protein and lower fiber content (Chaivetago et al., 2015). Crude protein and neutral detergent fiber fractions in forages play a large role in methane emissions through production of acetic acid by fibre digesting bacteria within the rumen which is a major precursor for methane production in ruminants (Lupo et al., 2013). Management of forages through intensively managed grazing systems can help maximize forage quality and maintain cow-calf pairs.

2.3 Grazing methods for increased efficiency of forage use in extended grazing, roational, strip, set stocking and continuous grazing.

Stockpiling forages consist of resting pasture late summer with no cutting or grazing, allowing forage biomass and nutrient accumulation; with the onset of cooler temperatures in the fall and be grazed while forage can no longer accumulate. Resting forages from July to mid-September allows for the maximum accumulation of forage biomass by mid-September; the amount of forage biomass in the field remains constant until below freezing temperatures shift plants into storing carbon in their roots to survive over winter (Baron et al., 2004). Janovick et al. (2004) used stockpiled forage to graze cows throughout winter and found total hay use decreased on average by 1701 kg DM/cow over three years. While this study was carried out in a warmer region than Canada, stockpiling success depends on the weather in any scenario. During the Janovick et al. (2004) study, cows were supplemented with hay during cold weather and excessive snowfall; however, no hay was supplemented on pasture during winter in mild years. Although Canada's climate may be harsher, there is an opportunity to reduce hay use during the fall with stockpile grazing before heavy snowfall and freezing temperatures develop preventing cattle access to forage.

Forage species used for stockpiling is highly variable throughout previously reported studies. Cool-season grasses are preferred for their ability to maintain biomass in cold temperatures and quick regrowth in the spring (Baron et al., 2004, Riesterer et al., 2000). Tall fescue is commonly used in stockpiling systems due to its biomass stability in cold weather (Riesterer et al., 2000). Cool-season perennial grasses such as early maturing orchard grass, timothy, and meadow bromegrass are also all well suited for stockpile grazing, although they are more susceptible to biomass changes with varying rainfall (Baron et al., 2004, Riesterer et al., 2000). Meadow bromegrass may be more suitable for use in stockpile grazing in climates with highly variable rainfall. Baron et al. (2004) found that meadow brome was stable for stockpiling in both dry and wet years making it suitable for areas with variation in rainfall.

Baron et al. (2004) evaluated the use of alfalfa in a stockpiled system, showing high losses of 43% in cold weather, compared to only 3-35% losses with grasses depending on species. Although legumes tend to experience more significant biomass losses in winter, their use for increasing protein content in pastures/conserved forage diets and nitrogen-fixing within the rhizosphere are apparent (Noviandi et al., 2014). Alfalfa mixes containing 25% legume with 75% tall fescue contained 12.1% crude protein, increasing legume content to 50% increased protein up to 13.7% and increasing legume content to 75% of the mix increased protein content to 17.0 %, mixes with birdsfoot trefoil and cicer milkvetch showed similar trends with increasing legumes (Noviandi et al., 2014). The use of birdsfoot trefoil (*Lotus cornicalatus* L.) within a grass mixture for grazing increases protein content in pastures/ conserved forage diets and decreases methane emissions (Novandi et al., 2014). Grass pastures using trefoil as a legume are higher in protein but may not persist well through colder weather, losing biomass faster than alfalfa (Moore et al., 2004; Baron et al., 2004). Alfalfa lost 520 kg ha^{-1} from mid-September to mid-October, with species deemed more suitable for stockpile grazing such as meadow bromegrass losing only 50 kg ha^{-1} and a mix losing 90 kg ha^{-1} in the same time period (Baron et al., 2004). Legumes in a pasture system can alter rumen fermentation by supplying more protein and thus less fiber to rumen microbes, producing more propionate while decreasing acetate and butyrate production (Noviandi et al., 2014). With the reduction in acetate and butyrate, methane emissions due to the release of hydrogen ions in the rumen are reduced (Noviandi et al., 2014). Lyons et al. (2016) examined the use of protein supplementation for heifers grazing stockpiled tall fescue and found heifers supplied with protein supplementation by a molasses and urea-based lick tub consumed at 0.36kg hd^{-1}day^{-1} gained 0.15kg day^{-1} in the normal forage allocation treatment and 0.08 kg day^{-1} more weight in the extra forage treatment and lost less body condition than animals fed only pasture. Pastures under seeded with trefoil resulted in lower live weight gains for cattle grazed from the spring until fall than cattle managed on a control grass or alfalfa pasture (Moore et al. 2004). These studies suggest that added legumes in a stockpiled forage system can increase protein supply in the feed compared to commonly used grass pastures, and also can decrease methane production as forage fiber content increases with cold weather**.**

The nutrient composition for stockpiled forages are sufficient to maintain heifer and cow body weights without compromising reproduction, allowing animals to wean calves yearly (Curtis et al., 2008, Lyons et al., 2016). Following fall grazing of stockpiled endophyte infected tall fescue, Indiangrass and big bluestem mix or switchgrass heifers entered a period of compensatory gain and maintained weight effectively for pregnancy development after removal from pasture (McFarlane et al., 2018). Heifers in McFarlane et al. (2018) were bred following removal from stockpiled pastures, and were successfully bred following grazing. The use of legumes in a stockpile grazing system can better meet bred heifers' protein requirements; however, legume pastures may undergo extensive leaf loss with cold weather (Baron et al., 2004). Janovick et al. (2004) evaluated April calving cows in a year-round grazing system which included use of stockpiled smooth bromegrass with red clover; these cows had lower body weights in March at weaning and breeding, but otherwise were able to maintain similar body weights to April calving cows managed in dry lot (Janovick et al., 2004). Pre-weaning weights of April born calves in the same study were 67kg lower in a year-round grazing scenario compared to a dry lot feeding system (Janovick et al., 2004). During these times, the decrease in body weight had no effects on the re-breeding of cows or birth weights and weaning weights for calves, but cows consumed much less hay (Janovick et al., 2004). Curtis et al. (2008) demonstrated the use of stockpile grazing tall fescue at different allocations of 2.25, 3.00, 3.75 and 4.00% of cow-calf BW, concluding that limit feeding of stockpiled forages does not necessarily affect reproduction negatively. This study used fall calving cows at an adequate body condition score (BCS) and weight for breeding when they started fall grazing. The authors noted body condition for reproductive performance may not be adequate at breeding for cows entering grazing at a lower body weight (Curtis et al., 2008). Overall, the literature has found that stockpiled forages provide adequate nutrition for reproductive success in cows of adequate or well-conditioned cow-calf system.

Stockpile grazing can be a useful method for lengthening the grazing season; however, in stockpile grazing, the actual grazing event takes place when forage becomes dormant. Studies using this grazing system have shown grass species maintain more constant biomass than legumes when temperatures are below freezing (Baron et al., 2004). Grass yield in a stockpiled grazing system may be more stable than legumes; however, yield is highly dependent on the amount of precipitation in a given year. Hall et al (1998) concluded that prairie grass is not suitable for cultivation in regions with colder temperatures due to declining persistence in a grazing system; the authors concluded tall fescue and perennial ryegrass will persist better throughout the four grazing seasons. Grasses average 25% DM losses from mid-September to mid-October (Baron et al., 2004). However, Alfalfa can lose up to 43% of dry matter due to high leaf losses in late fall, due to cold weather encouraging dormancy (Baron et al., 2004). Robinson et al (2007) concluded that in 2003, alfalfa noticeably declined in biomass between September 30th and October 14th, but brome, fescue, orchard grass and birdsfoot trefoil all remained constant or biomass declined slightly. In the following year of the study, trefoil, tall fescue and orchard grass all weathered better than the other forage species (Robinson et al, 2007). Species with rapid growth such as bromegrass are less useful as extended grazing species; their rapid regrowth is not advantageous in the accumulation phase (Baron et al., 2004).

Baker et al. (1988) concluded that greater spring hay yields resulted from when the past season hay was harvested once and then grazed in the late fall vs cutting the forage for hay twice. It was concluded that grazing the forage in the fall removed more plant litter than harvesting mechanically, and returned feces and urine to the grazing system, which possibly stimulated plant productivity (Baker at al. 1988). Hall et al. (1998) tested the effectiveness of stockpile grazing prairie grass, tall fescue and perennial ryegrass compared to intensive grazing before the critical frost date on a 30 d rotation and grazing once before fall. Stockpiled grazing resulted in lower fall yields than the intensive grazing treatments and had lower spring yields than the treatment grazed once before fall (Hall et al., 1998). Although yield data from this study were lower for the stockpiled system compared to intensive fall grazing by 1973, 1524 and 3679 kg ha^{-1} the authors noted the effectiveness of extending grazing into late fall/early winter with potential for combination with other grazing methods throughout the year to increase overall yield from the grazing system. This study was conducted using sheep, which could have been a factor in the lower spring yield after stockpile grazing, due to the ability of sheep to graze to shorter sward heights than cattle.

Strip grazing is commonly used in stockpile grazing, where cattle are allowed only enough forage for a single day. In a strip grazing system, fencing must be moved daily to allow only enough forage for a day; this can limit feeding activity throughout the day, depending on the time fences are moved to allow access to new forage. Limiting feeding activity can lead to animals being fasted, without access to feed for a length of time until fences are moved. Gregorini et al. (2007) demonstrated that fasting cattle for the morning on a strip grazing system did not affect animal performance. Grazing during the day results in animals consuming forages at higher digestibility with greater concentrations of metabolizable energy and non-structural carbohydrates, and lower concentrations of neutral detergent fiber (Gregorini et al., 2007). This improvement in nutritional quality is due to increased photosynthesis activity during the day, and therefore this difference in nutritive value helps fasted animals account for lost grazing time during the day (Gregorini et al., 2007). Fasted animals graze for longer and more heavily in the afternoon and evening due to morning fasting, and will compensate for missed grazing time with increased grazing intensity and greater consumption of biomass per bite (Gregorini et al., 2007; Kennedy et al., 2009). Verdon et al. (2018) found that dairy cows grazing strips consumed the same amount of forage, had similar body weights, and similar time feeding to cattle on one continuous grazed pasture. Gadberry et al (2014) also saw similar results for body weight and condition in beef cattle grazed on strip grazing or continuous grazing.

The benefit of strip grazing is pasture utilization; Gadberry et al (2014) saw pasture utilization of 93% for strip and only 69% for continuous treatments during the grazing season. However, seasonality may play a roll, as this study showed no significant differences in forage utilization by the end of season at 85% utilization in strip grazing and 88% utilization in continuous**.** Initial utilization of pasture may be more uniform in a strip grazing system, allowing for more precise control of the grazing area, which could be useful in managing complex ecosystems to prevent patch grazing; however overall forage utilization for the season may not differ. Verdon et al. (2018) and Dalley et al. (2001) both concluded there were few animal production benefits in strip grazing treatments moved multiple times daily. Cattle herbage intakes and milk production overall did not increase with 6 and 7 moves per day vs 1move/day, and rumination time decreased with many moves per day (Dalley et al., 2001; Verdon et al., 2018; Kennedy et al., 2009). In Kennedy et al. (2009), the amount of grazing time with two 4.5 h grazing bouts resulted in more ruminating time, more boluses in a rumination period and longer ruminating bouts, versus the other grazing treatments including: 22 h of constant grazing, three 3 h grazing bouts, and 9 h of constant grazing. While these studies are extreme in the number of moves per day, they provide insight to the effects of moving daily in a strip grazing treatment and the benefits of only moving once daily and suggest that high intensity strip grazing is not necessary to maximize animal performance.

Some data suggests that strip grazing is comparable for biomass production and cattle performance to rotational grazing as the grazing methods can be considered similar depending on length of time in a paddock, the closer rotational grazing gets to a 1d rotation the more similar to strip grazing. Strip grazing was comparable to set stocking treatments in Little et al. (2015) with strip grazed calves gaining more weight than calves raised on a feed pad or strip grazed oats. Set stocking involved grazing animals on a set amount of land with infrequent moving of pastures or rest. In another study, the use of intensive, continuous grazing resulted in lower biomass production and lower root mass in the first 10 cm of soil for the month of June, with numerically lower values overall in contrast to strip grazing **(**Hoekstra et al., 2019). Lower root mass in the first 10 cm of soil is an indication of heavily defoliated pasture and is thought to represent lower sugar storage within the root structure at a time of above ground re-growth (Hoekstra et al., 2019). Warner et al (1984) found that lambs grazing on rotationally managed pastures had 16.7% higher average daily gains and ewes 5.7% heavier by the end of the grazing season than set stocked lambs and ewes. Optimally managed pastures can increase animal production per acre by increasing stocking density, as seen predominantly in comparing rotationally and continuously grazed pastures (Bertelsen et al., 1993). Although these studies have investigated rotational grazing systems compared to continuous, more data are needed on the comparison of strip grazing to other grazing methods within the Canadian climate, and its impact on animal performance, soil health, and forage yields.

Increased use of forage through improved grazing management can increase biomass yields with consistent management of sward heights (Haan et al., 2007). Pastures grazed to a lower sward height of 5 cm are associated with increased amounts of bare soil due to decreased forage coverage (Haan et al., 2007). Haan et al., (2007) noted that continuous grazing system managed to the same sward heights as improved gazing systems had mean sward heights below 5 cm for most of the grazing season and was below 3 cm in November. This resulted in more significant bare soil in the continuous grazing treatment (Haan et al., 2007). Hirata et al. (2011) demonstrated that cattle graze more in areas that have a higher pre-grazing forage biomass leaving a proportionate amount of forage regardless of higher biomass consumption from these areas. Biomass production was higher in hilly rangeland areas of Turkey using rotational grazing compared to set stocking, and thus produced heavier animals (Bozkurt and Kaya, 2011). This suggests that managed grazing systems manage pastures to a more consistent height and biomass to encourage uniform grazing and thus potential increases in biomass.

The carbon sequestering potential of rotational grazing may not significantly differ from continuous grazing. Rotational grazing had lower uptake of carbon dioxide into soils compared to continuously grazed pastures; however higher uptake of carbon dioxide occurred during rest periods, when photosynthesis was increased during the growing periods for forages (Gourlez De La Motte et al., 2018). Sanderman et al. (2015) also concluded that no differences in soil organic carbon arise when comparing rotational and continuous grazing. This was attributed to slow accumulation of carbon within the soil. Paddocks in this study were selected from farms that had previously used rotational grazing for at least 7 years and compared to a continuously grazed paddock nearby. However, within farms that practiced rotational grazing, there were varying management practices by landowners, which may affect consistency of results (Sanderman et al., 2015).

Rotational grazing allows producers to stock cattle at a greater density than continuous grazing, resulting in a greater gain per pound for a unit of land (Bertelsen et al., 1993, Beck et al., 2016). Wyatt et al. (2012, 2013) found that calves and cows both had greater daily gains, while calves had greater body condition scores at weaning on a medium stocked continuous grazing treatment, compared to the medium stocked rotational grazing treatment. This was attributed to higher protein content on continuous fields in early spring and summer; however, the finishing weights were similar between grazing treatments. Overall stocking density had the greatest effects on success of the grazing system; lower stocking rates resulted in less dry lot days for both rotational and continuous treatments (Wyatt et al., 2012). With low forage sward heights of 5 cm in a continuous grazing system, cattle forage intakes can be reduced, negatively affecting performance (Haan et al., 2007). In this study mean forage biomass for continuous grazing treatments were lower than rotationally grazed systems in June, July, September, October, and November and remained the same for August; however, forage biomass did not differ in any paddocks, regardless of grazing technique (rotational or continuous grazing and sward height management), with forage harvested in April and May (Haan et al., 2007). Beck et al. (2016) reported higher biomass measures for rotationally grazed pastures in early summer, and higher biomass for rotationally grazed pastures under a higher stocking rate of 0.4 ha/cow than the rotational grazing treatment stocked at 0.8 ha/cow, and continuous grazing. This study also showed a 5% decrease in cow body weight at weaning in October and a lower calf weaning weight under the high stocking rate rotational grazing, with no differences between medium stocked rotational and continuous grazing. However, there were no differences in BCS or pregnancy rate between the grazing treatments (Beck et al., 2016).

Stockpile grazing can be a useful way for producers to minimize use of conserved forages, while minimizing costs without compromising reproductivity of heifers. Intensive grazing such as rotational and strip grazing can better maximize forage use and possibly increase animal performance. Less intensive grazing methods such as continuous grazing and set stocking do have a place in the cattle industry as they generally require less labour input and can still maintain animals for a period of time.

2.4 Conclusion

Further studies are needed regarding pasture production, specifically in Ontario. Many studies outline effectiveness of certain grazing methods, but few are based in Ontario, where forage species and growing conditions may differ drastically than in Western Canada. Forage production is highly reliant on weather; therefore, data specific to Ontario conditions will be useful to better understand impacts on Ontario cow-calf producers.

Overall management of pastures can clearly affect forage species composition within a pasture stand and efficiency of biomass composition. Intensively managed grassland may provide more production per acre but store less organic carbon within the soil. Research is needed to understand the balance between animal performance and greenhouse gas emissions.

2.5 Hypothesis and Objectives

When evaluating summer grazing conditions, continuous grazing will have the best animal performance, based on nutritive value of the pasture and ability for selection. Forage yield will be increased with rotational grazing by stimulating shoot regrowth in controlled bouts and allowing for root biomass accumulation during periods of rest. Set stocking will also see an increase in forage usage; however, this grazing method lower forage yields, and thus decrease animal performance. Set stocking should have increased forage yields compared to continuous grazing with lower nutritive value than rotational or strip grazing due to increased rest time. Strip grazing is predicted to provide the best forage utilization of the grazing treatments; however, it will result in the lowest animal performance because animals cannot select highest quality forages within the grazing area and must consume the allocated forage that is available.

For the extended grazing portion of this research, it is predicted that the native grass mix will perform best under temperatures below zero, holding biomass consistently throughout the season. Animals on the grass pasture will maintain condition better, and pastures will better maintain forage yields in colder weather. Alfalfa will perform the poorest in comparison to trefoil due to large leaf losses after the growth of the plant ceases, and lower protein content of the legume compared to trefoil.

The objectives of this study is to evaluate best grazing practices for animal performance, forage growth, and potential for carbon sequestration. The study should provide more in-depth insights to beef farmers on sustainable practices within the industry on various grazing practices not commonly studied. This research hopes to encourage more sustainable pasture production for beef cattle and lower GHG emissions. The ultimate goal is to reduce the beef industry’s environmental footprint, energy use, and cost of production for an improved industry image and end product.

3.0 Materials and Methods for Summer Grazing Methods to Enhance Animal and Forage Production

The study was initially designed as a randomized complete block design with three replicates of five grazing management technique treatments including 2 set stocked treatments (with/without mowing of paddocks after cow-calf pairs were moved to a new paddock). As the study proceeded, the rate of growth for the pasture necessitated mowing previously grazed strips and paddocks for all treatments besides continuous grazing to ensure uniform regrowth and limit the amount of trampled down forage that limited pasture regrowth. No mowing was ever conducted for the Continuous grazed paddocks.

3.1 Pre-grazing Field Preparation and Treatment Description

In 2019, a 47.3 ha parcel of land previously used in conventional crop production (corn, hay/silage) at the Ontario Beef Research Station-Elora was seeded with a mixture of diverse grasses and legumes at varying seeding rates: Will Ladino Clover (*Trifolium repens*) at 6.55 kg ha^{-1}, OAC Bruce Trefoil (*Lotus cornicalatus L.)* at 26.19 kg ha^{-1}, Paradus Meadow Fescue (*Festuca pratensis*) at 7.66 kg ha^{-1}, Fleet Meadow Brome (*Bromopsis bierbersteinii*) at 7.66 kg ha^{-1}, Ginger Kentucky Bluegrass (*Poa pratensis*) at 6.87 kg ha^{-1}, Cowgirl Tall Fescue (*Festuca arundinacea*) at 7.66 kg ha^{-1} and Lofa Festulolium at 7.66 kg ha^{-1}. The seeded parcel of land was then divided into 15 pasture fields which includes thirteen 3.23 ha fields (with eight 0.41 ha paddocks), one 3.64 ha field (with nine 0.41 ha paddocks), and one 1.62 ha field (with six paddocks varying is size; Figure 1). The pasture fields were grazed in 2019 in another rotational grazing trial.

Soil samples were collected from each field in spring of 2021 and submitted to the University of Guelph's Agriculture and Food Laboratory for analysis of pH, extractable P, K, and Mg (Guelph, Ontario). Soil samples were taken based on four diagonal soil samples across each paddock with the samples composited to make a representative sample. Representative samples were taken for half of each field, split between the north and south groups of paddocks.

Phosphorus fertilizer was not required for the south group of fields 1, 3, 4, 5, 15 and the north group for field 6 (Figure 1 for field numbers). Phosphate was applied at a rate of 20 kg ha^{-1} to fields 2, south 14 and north 15. A rate of 30 kg ha^{-1} of phosphate was applied to 8 and 12 south. A rate of 40 kg ha^{-1} of phosphate was applied to North 4, 5, 12 and south 11 and 13. South 6, 9 and 10 and north 9 and 11 received 50 kg ha-1 of phosphate. A rate of 70 kg ha^{-1} of phosphate to the north of fields 3, 10, 13 and 14. Phosphate was applied at 90 kg ha^{-1} to south 7 and north 7, 1 and 8. Potash was not applied to south 1, south 5, south 8, south 11, south 15, north 1, north 6, and north 15. A rate of 20 kg ha^{-1} of potash was applied to all of fields 2, 3, 4, 9, 10, 12, 13, and 14; north 8, north 11, south 6, and south 7. A rate of 30 kg ha^{-1} of potash was applied to north 5 and north 7. No nitrogen fertilizer was applied to any fields.

The 15 pasture fields were assigned to 5 grazing management technique treatments with 3 replicate fields for each grazing management technique. The study evaluated: continuous grazing, rotational grazing, strip grazing, set stocking, and set stocking plus mowing. For continuous grazing (Fields 10, 12, 15), cattle were able to graze anywhere in the field at any time. For rotational grazing (Fields 1, 5, 9), cattle were restricted to one 0.41 ha paddock until the pasture was grazed to an average sward height of 10 cm with cattle then moved to another 0.41 ha paddock. For Strip grazing (Fields 2, 3, 6), cattle were restricted to one ~ 0.14 ha strip for 1 day and then moved to another ~ 0.14 ha strip the next day, and back-fenced. For set stocking (Fields 4, 7, 11), cattle were restricted to one 0.82 ha paddock until the pasture was grazed to an average sward height of 10 cm and then cattle moved to another 0.82 ha paddock. For set stocking plus mowing (Fields 8, 13, 14), cattle were managed as previously described for set stocked cattle and then afterwards the 0.82 ha was mowed to a uniform sward height. All fields contained a small area at the front of the field where cattle had ad libitum access to water, salt, and mineral. All moves of cattle on pasture were carried out by Ontario Beef Research Centre (OBRC) staff based on specified sward height and specific grazing management treatment.

Continuously grazed fields were sampled a few days prior to cattle being turned out for grazing, which was staggered for each of the fields. Each 8-9 acre continuous grazing field was sampled for a minimum of 27 quadrats prior to grazing and a minimum of 100 sward heights. Continuous grazing fields were equipped with a grazing cage measuring 4.55 m^2 to measure the progression of forage quality throughout the season without forage in the cage being grazed by animals. Standing forage in grazing cages was completely clipped to approximately 3 cm above ground height once per month. All clipped forage was then removed to be weighed back and sampled for dry matter determination and botanical composition with the procedures to be described later in the Materials and Methods.

Rotationally grazed fields were sampled 1 to 2 days pre-grazing prior to cattle (cow-calf pairs) turn out. Each one-acre paddock was sampled using 16 quadrats and approximately 60 sward heights before and after grazing. Cattle were to be moved to the next paddock when the average sward height was approximately 10 cm in height, and the next paddock was at least 20 cm in height. Botanical composition was also measured for entry into each paddock.

Strip grazing fields were sampled 1 to 2 days pre-grazing prior to cattle turn out. Strip grazing fields were sampled two times weekly using sward height, botanical composition and quadrats as described above. The use of 8 quadrats per grazing strip was used to determine dry matter yield. Approximately 30 sward heights were gathered per strip to get an average sward height. Pre-grazing sampling was completed for cycle one, and post-grazing sward height and quadrat sampling were also included from cycle two throughout the rest of the grazing season. Botanical composition was also determined two times weekly for pre-grazing sampling. Grazing strip length was allocated based on forage consumption so area given varied daily depending on forage availability. If cattle grazed the strip and left forage that was greater than a 10 cm average sward height, the length of the strip was reduced by two meters until they grazed to leave no more than a 10 cm average sward height. A back fence was in place to inhibit back grazing and allow forages adequate time to recover. If cattle grazed the strip and left forage that was less than a 10 cm average sward height, the length of the strip was increased by two meters until the animals grazed pastures to leave no more than a 10 cm average sward height. Each daily move was changed daily based on how well the last strip was grazed and determined by OBRC staff upon moving.

Set stocked grazed fields were sampled were sampled 1 to 2 days pre-grazing prior to cattle turn out. For all set stocking treatments, 24 quadrats were collected in a 0.82 ha paddock pre- and post-grazing. Each paddock was sampled for roughly 100 sward height measurements to determine the average sward height for the paddock. Botanical composition was analyzed two times for each paddock upon entry. Field 14 was allocated as a set stocking treatment but only had a total grazing area of .67 ha with 6 paddocks averaging 0.27 ha per paddock. There were only 4 cow-calf pairs assigned to Field 14 in contrast to 8 to 9 cow-calf pairs assigned to the other paddocks. Each paddock was sampled using ten quadrats, except paddock 4, which was larger, so 12 quadrats were sampled pre- and post-grazing. Each paddock also had approximately 60 sward heights recorded pre- and post-grazing. Botanical composition was also determined for each paddock prior to grazing. Fields 8, 12 and 14 were set stocking with mowing treatments, which were to be mowed after cattle left each 0.82 ha paddock. With heavy rainfall in June, pasture growth exceeded expectations and mowing was required for all treatments to ensure adequate re-growth and to avoid damage to pasture ground cover due to trampling of tall forage.

Once all paddocks or strips were grazed in each field, cattle will then begin the next grazing cycle around the field. Data were recorded by cycle and paddock to track forage progression throughout the season.

3.2 Forage Sampling and Analysis

Forage sampling was conducted according to each specific grazing management treatment. Sward height (the height of the standing forage) for each field was measured by the same person each time using a meter stick. Specifically, sward height was measured by pacing the meterstick in intended area measuring every five paces on a diagonal. Number of measurements in a large paddock such for continuous grazing was targeted for 200 sward heights with 100 sward height measurements for set stocked, 80 sward height measurements for rotational and 50 sward height measurements for strip grazing. The numerical measurement for sward height was determined by placing the sward stick into the forage resting on the ground and measuring the forage height at the thickest part of the forage, not counting any abnormally long or short forage heights. Measurements for each field were orally recorded using a Sony IC recorder ICD-BX140 stating the date, field number, cycle number, paddock number, entry/exit, and each sward height for the given area. Sward height was measured prior to grazing and after grazing for all grazing management treatments except continuous, which was measured just prior to grazing at the start of the season. The forage heights were then transcribed from the tape recorder to an Excel file with a sheet for each field. Each entry into the Excel file was then averaged to get one representative sward height for a given field. In case of technology failure, the average sward heights for each paddock were also recorded with pasture moves and dates as a hard copy in the summer 2021 grazing binder. Pre-grazing average sward height was targeted for 25 cm, although sward heights during extreme growing periods often exceeded 25 cm. Extreme growing periods were times when forage grew rapidly due to an increase in temperature and precipitation, which animals were unable to keep up with by grazing. Post-grazing average sward height for each paddock was targeted for 10 cm, such that the cattle would be moved to another paddock/strip as applicable.

Each field was assessed to determine dry matter yield (amount of forage biomass) and quality (botanical and nutrient composition) using randomized quadrat sampling. Polyvinyl chloride (PVC) piping was used to construct quadrats measuring 0.25 m x 1.0 m in a rectangular format to provide a surface sampling area of 0.25 m^2. Pasture sampling using the quadrats was conducted by pacing out the area for sampling at equal sections across the paddock, walking lengthwise and tossing the quadrat approximately 2 m away to ensure random sampling of forage patches and avoiding biases. Once the quadrat landed, the researcher pulled all forage from underneath the quadrat to the respective side that the forage originated from. If the forage stem is outside the quadrat, but the quadrat lands on the shoot, the forage would be pulled out of the quadrat and vice versa for any stems within the quadrat area. This ensures quadrat sampling was only conducted within the random 0.25 m^2 area that the quadrat landed on. All forage within the quadrat was then clipped to approximately 3 cm above ground height using STIHL HSA 26 Battery Shrub Shears (Vincent Lawn &

Garden Equipment Cambridge, ON). Clipped forage was placed into 12 lb plastic bags labelled with a black sharpie permanent marker by field number, entry or exit, and date.

Bagged quadrat samples were then taken from the pasture and weighed individually, recording each weight. Once individual weights were recorded, a representative sample was taken from each field (two for continuous and set stocking treatments due to greater sampling areas) weighing approximately 300-500 g for subsequent determination of dry matter (DM) and nutrient composition.

For samples used for DM determination, samples were placed in a pre-weighed brown paper bag with the weight of the bag and sample recorded. These samples were dried for a minimum of 48 hours at 65 °C in Hotpack Tru-temp forced air oven (Hotpack Canada LTD, Waterloo, ON, CAN). After drying, samples were re-weighed with weights recorded, and DM content was determined (Equation 1). This DM content value was used as a representative dry matter value for each sampling date; each of the forage weights with bag weight subtracted were used to calculate dry matter (Equation 1). Dry matter values for the paddock were then calculated by using the total weight of all wet quadrats and the dry matter percent found in equation 1 (Equation 2). This value was then converted to Kg and used to calculate DM kg/m^2 (Equation 3) and converted to DM kg/ha by multiplying by 10000. Post-grazing quadrats were used to determine the quantity of forage remaining post-grazing.

Equation 1:

Dry matter of forage sample % = (dry sample weight (g)/ Wet sample weight (g)) x 100

Equation 2:

Dry matter for paddock (g)= Total wet weight of quadrats x (dry matter of sample/100.

Equation 3:

DM kg/m^2= dry matter for paddock (g)/(0.25 m^2 quadrat x number of quadrats)

[z]The value for the number of quadrats used in the equation dependent on the specific grazing method used in the field

Number of quadrats =

24 for continuously grazed fields

16 for rotationally grazed fields

24 for set stocked grazed fields

8 for strip grazed fields

From the combined quadrat samples in a field, another representative sample was taken for analysis of botanical composition, similar in size to the sample used for dry matter determination. One sample per paddock was collected for determination of botanical composition, except for continuous and set stocking treatments in which two representative samples were collected. Samples were then manually sorted by each collected stem into legume, weeds, grasses, or dead fractions. Each fraction was observed for the predominant species it contained and weighed out separately. The botanical composition for each field was then recorded as a percent of the sample in each paddock, to later determine the % of individual fractions in the forage sample. Botanical composition was determined once for each paddock upon entry for each cycle; the exception was for strip grazing where two botanical compositions were performed per week upon sampling.

The sample used for dry matter determination was then ground small enough to pass through a 1 mm screen using a Thomas Wiley feed grinder (Wiley Mill, Arthur H. Thomas, Philadelphia, PA, USA). Samples were numbered by trial, field, cycle, entry/exit and bag number and placed into a Whirlpak bag for later compositing. These samples were later composited into representative samples for each field by cycle and paddock. Samples were composited by the number of days in a cycle into two replicates of each field per cycle. This was done by dividing the number of days in a cycle by two; any sampling dates before the number of days at the halfway point were in replicate one while any sampling dates after the half-day was placed into replicate two. Each composited sample contained ~ 60 g total. Samples were sent to A&L Canada Laboratories INC (London, Ontario, Canada) for analysis. Briefly, net energy for maintenance (NE_m), net energy for production (NE_p), and TDN values were estimated using the NRC beef model (NASEM 2016). Forage nitrogen concentration was measured using a LECO FP628 nitrogen analyzer (Leco Corporation, St. Joseph, MI; AOAC, 2006 method 968.06) and crude protein (CP) content was determined by multiplying 6.25 by percent feed N. Neutral detergent fibre and ADF were determined according to methods of Van Soest et al. (1991) using an Ankom 2000 Fibre analyzer (Ankom Technology, Macedon, Fairport, NY, USA) with sodium sulfite and amylase being used in the NDF analysis. Determination of major minerals (Ca, P, K, Mg) and trace minerals (Cu, Fe, Zn) was conducted based on inductively coupled plasma optical emission spectrometry (PerkinElmer, Woodbridge, ON), (AOAC 2006; Method, 985.01).

3.3 Climate and Weather Conditions for the Grazing Season

Average temperatures (°C) for May, June, July, August, and September 2021 were 11.3, 19.1, 18.9, 20.7 and 14.7 respectively for Elora, ON. Total precipitation (mm) for May, June, July, August, and September 2021 was 10.6, 32.3, 45.0, 13.9, and 56.8 respectively. Average maximum temperature °C, Average minimum temperature °C, average mean temperature °C and average precipitation (mm) for each month of grazing are listed below in Table 2.

3.4 Animal Management

The spring/summer grazing trial utilized 162 cow-calf pairs that were predominantly Angus crossbreds. The study was completed under the approval of the University of Guelph’s Animal Care Committee based on the submission and approval of Animal Utilization Protocol (#4423). Animals were managed and cared for at the

Ontario Beef Research Centre (OBRC) in Elora, ON. All animals were cared for in accordance with the guidelines presented by the Canadian Council on Animal Care (1993). The cattle were sorted into three replicates for each of the five grazing management technique treatments, balanced by weight, body condition, calf sex, cow age, and previous experimental treatment from a previously conducted nutritional trial (Croft, 2022). Cow weights upon entry on pasture ranged from 456 to 986 kg. All cow-calf pairs were turned out over a three-week period. Each week, one of the three replicates per grazing management technique treatment was placed on the pasture based on their availability for the trial. Cow availability was based on (Croft, 2022) which used February-April calving cows until approximately d 67 after calving. Cow-calf pairs were weighed on consecutive days, the day before turnout and morning of turn out to pasture on the following dates: May 5th, May 12th and May 19th of 2021. The number of cow-calf pairs per paddock along with changes in numbers of cow-calf pairs per paddock are presented in Table 1. Calves and cows were weighed bi-weekly during the trial period. Weaning took place after the trial was completed starting in late September until mid-October. Weaning was done in groups with the use of easy wean nose tags, placed a week before calves were removed from dams (EasyWean®, Australia). Weights for calves were recorded at the start date for the beginning of the weaning process; at the same time the cows were also weighed, and body condition scored.

Dry matter intakes were calculated using forage biomass measures taken prior to and post-grazing, with the calculated difference representing the total amount of forage consumed. The calculated difference was then divided by the number of cow-calf pairs on each pasture, multiplied by the number of days on a pasture to estimate dry matter intake (Equation 5). Dry matter intake was also estimated using Equation 6 and inputting each cow's body weight and ADG data (Minson and McDonald., 1987). For both methods of DMI calculation, calf intake was considered negligible.

Equation 5: *Dry matter intake (kg/d) for cattle on pasture using pre- and post-grazing herbage biomass measurements, stocking density, and grazing days.*

$$DMI = (Average\ pre\ grazing\ herbage\ biomass - Average\ post\ grazing\ herbage\ biomass) / (\#\ cow\ calf\ pairs\ x\ \#\ days\ spent\ grazing\ the\ pasture)$$

In addition to quadrat estimates for pasture intake, an additional method was used to calculate estimated pasture DMI. The Minson and McDonald (1987) equation estimates DMI on an individual basis using cow BW and ADG and is outlined below (Equation 6).

Equation 6: *Dry matter intake (kg/d) for cattle on pasture using body weight (BW, kg) and average daily gain (ADG, kg/d) for individual cows.*

$$DMI = (1.185 + 0.00454BW - 0.0000026BW^2 + 0.315ADG)^2$$

Average daily gain (ADG) was calculated using PROC Reg in SAS OnDemand for Academics, (SAS Studio edition, Cary, NC). Body weights from each cow were recorded on a biweekly basis and recorded into a spread sheet by day, with average of the two entry weights being 0 and week two weights being 14 days. Weights were then calculated by linear regression. This method was used to better capture weight fluctuations throughout the grazing season rather than just entry and exit weights.

3.4.1 Use of Body Condition Scoring to Estimate Cattle Body Composition and Ultrasound to Quantitatively Measure Fat Accumulation or Mobilization

Cows were body condition scored bi-weekly throughout the grazing season to assess fat coverage over the ribs and tail head by palpation. Body condition scoring was conducted on a scale of 1.0 to 5.0 in 0.25 increments based on the Code of Practice for the Care and Handling of Beef Cattle (NFACC, 2013). Cows with a body condition score (BCS) of 1.0 are considered extremely thin, a BCS score of 2.0 is considered thin with some muscle, a BCS score of 3.0 is considered in good condition, a BCS score of 4.0 is considered fat, and a BCS score of 5.0 is considered extremely fat.

Ultrasound evaluation was used to objectively measure body condition by determining rib and rump fat thickness. Cows were measured by ultrasound before turning out to pasture at the time of weighing and at the end of the grazing season. Ultrasound images were taken by a trained technician using an EXAGO ultrasound (Universal Imaging, Bedford Hills, NY, USA) using an L3180B 18cm bovine transducer (Universal Imaging, Bedford Hills, NY, USA). Cows were first brushed to remove any debris in targeted areas, and was coated in vegetable oil to ensure a clear image when transducer was placed on the hide. Ultrasound images for rib fat thickness (mm) were taken at the 12-13th rib interface in the direction of the ribs, three-quarters from the medial end of the longissimus dorsi. Rump fat thickness (mm) was measured using the ultrasound by placing the transducer horizontally between the hooks and pins to measure the fat depth between the *gluteus medius* and *biceps femoris* muscles. Images were recorded along with the identification number of each animal for later analysis. Captured rib and rump fat images were measured using ImageJ (MacBiophotonics, Canada) by the same person to ensure consistency. Measurements were recorded and analyzed based on the changes in rib and rump fat thickness from the beginning to the finish of the grazing season. These numbers were determined by subtracting the initial measurement of fat thickness at each body location from the final measurement of fat thickness for each cow.

3.5 Statistical Analysis

Data for the study were statistically analyzed as a randomized complete block design with three replicates of two grazing management technique treatments, four replicates of rotational grazing and five replicates for set stocking. Data were statistically analyzed to assess animal performance based on cow BCS, cow body weights throughout the study, calf weight, calf weaning weight, cow weaning weight, cow weaning BCS, and calculation of average daily gain and calculation of dry matter intakes (DMI). Forage growth and progress were analyzed for forage quality, botanical composition, overall yield, and time on pasture throughout the season. Data were analyzed using SAS OnDemand for Academics, SAS Studio edition (SAS Institute, Cary, NC). The Proc Glimmix procedure was used to analyze data for fixed treatment effects, with the experimental effect using cow as experimental unit for cattle data and field for forage data. Fixed effects for the model were grazing management treatment. Tukey-Kramer post hoc test for separation of means. A P-value ≤ 0.05 were considered significant, while a trend was noted when $P \leq 0.10$.

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Table 1. Numbers of Cow-Calf Pairs Per Field Throughout the Grazing Season				
Field Number	**Grazing Management Technique**	**Number of cow-calf pairs per field**	**Date for change in cow-calf numbers and numbers of cow-calf pairs added/subtracted**	**Date for change in cow-calf numbers and numbers of cow-calf pairs added(+)/subtracted(-)**
15	Continuous	9	(+) 2 pairs June 29	(-) 5 pairs Aug 12
12	Continuous	8	(+) 2 pairs June 29	
10	Continuous	8	(+) 2 pairs June 29	(-) 5 pairs Aug 12
5	Rotational	8	No change	
9	Rotational	8	No change	
1	Rotational	8	No change	
11*	Set stocked	8	(+) 2 pairs July 7	(-) 1 pair July 28
7	Set stocked	8	(+) 2 pairs July 7	
4	Set stocked	8	(+) 2 pairs July 7	
13	Set stocked	8	(+) 2 pairs July 7	
8	Set stocked	8	(+) 2 pairs July 7	
14	Set stocked	4	No change	
6	Strip	8	No change	
2	Strip	8	No change	
3	Strip	8	No change	

* One cow-calf pair removed due to injury only 2 weeks prior to complete removal of all cow-calf pairs from field. All other removal of cow-calf pairs for health reasons were substituted with another pair.

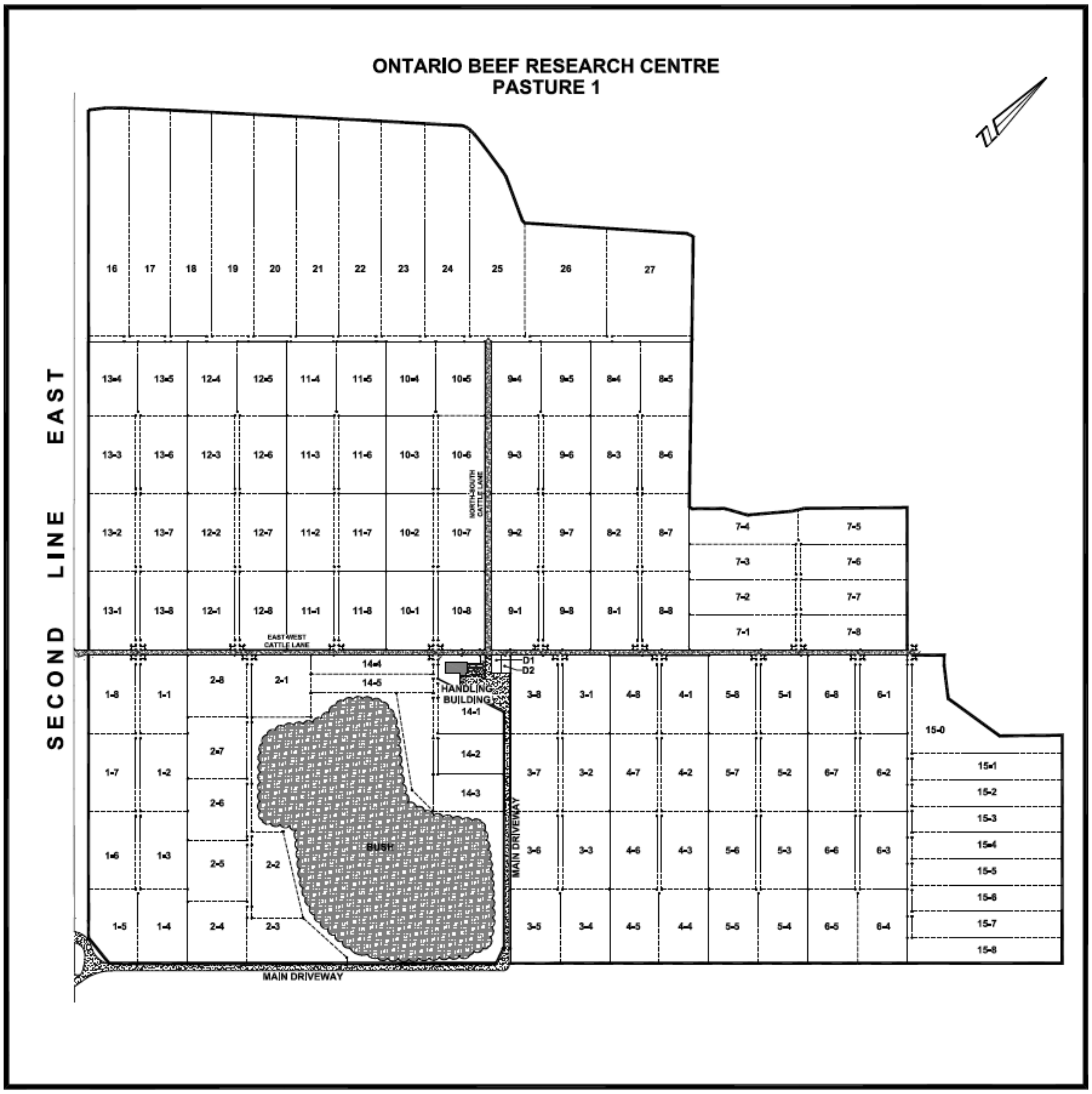

Figure 1. Pasture Field Layout for Fields Used for Grazing in the Spring/Summer

4.0 Results and Discussion Summer Grazing

The study aimed to explore effectiveness of different grazing methods within the Ontario climate for animal performance, forage quantity and quality. Continuous, rotational, set stocking, and strip grazing were tested with cow-calf pairs from May-September.

4.1 Climate Measures During Pasture

For the present study, there was below average precipitation for the overall grazing season based on monthly averages from May to September. Average rainfall in 2021 decreased by 81 mm in May and 49 mm in August compared to monthly averages based on data compiled from 1991-2021 (Table 2, Climate.weather.gc.ca. Rainfall in June and July (106 and 89 mm respectively) were almost the same as monthly averages for the area from 1991-2021 while September had a higher-than-average rainfall in 2021 by 58 mm versus average 1991-2021 data (Table 2). Temperatures were higher than average in Elora for June, August, and September. Mean monthly temperatures for these months were 19, 21 and 15°C respectively, based on data from 1991-2021 (Table 2, Climate-data.org). Average temperatures for May and July (11 and 19°C respectively) in 2021 during the trial were lower than average historical temperatures of 13 and 21°C respectively (Table 2, climate-data.org).

4.2 Botanical Composition of Pastures

Prior to the start of the grazing season, there were no differences (*P* > 0.51, Table 3) in the amounts of available forage biomass across grazing management treatments with values of 1478.9, 1388.5, 1235.8 and 1624.6 kg ha^{-1} for continuous, rotational, set stocking and strip grazing, respectively. This is consistent with Briske et al. (2008) who reviewed studies comparing continuous and rotational grazing and found there were no differences in biomass production in 89% (17 of 20) of the studies with similar stocking rates. Past studies evaluating continuous and rotational grazing commonly reported similar ground cover and forage production between rotational and continuous grazing (Derner and Hart, 2007; Jacobo et al., 2006). Hoekstra et al (2019) studied grazing effects of continuous versus strip grazing in peat meadows in the Netherlands, and found overall biomass increased by 23% when using strip grazing.

There were grazing management treatment differences ($P \leq 0.03$, Table 4) for pre-grazing forage biomass values for Cycle 1, which were lower ($P \leq 0.05$) for set stocked vs. strip grazed pastures. While there were no grazing management treatment differences ($P \geq 0.27$) for pre-grazing forage biomass values for Cycle 2, pre-grazing forage biomass for Cycle 3 was greater ($P \leq 0.05$) for set stocked pastures versus rotational and strip grazed pastures.

However, there was a grazing management technique by cycle interaction ($P < 0.001$; Table 5) for the amount of forage biomass available prior to grazing. Set stocked pastures had numerically lower biomass measurements for the start of the season (Cycle 1), but pre-grazing forage biomass increased as the season went on. In contrast, forage biomass in Cycle 3 was lower ($P \leq 0.05$) than forage biomass in Cycles 1 and 2 for rotationally and strip grazed pastures. This is an unexpected result, as generally more intensive grazing, such as with rotational and strip grazing, is thought to result in greater forage biomass over the season (Badgrey et al., 2017b; Wyatt et al., 2012). Stojanovic et al. (2018) concluded the greatest forage biomass in their study was during the start of the grazing season, with a sharp decrease of more than two thirds of production by the end of the study on June 19th. Teaque et al. (2003) reported greater ground cover area in rotational versus continuously grazing due to an increase in C4 grasses for rotationally grazed pastures due to a decrease in over grazed patches. Bagery et al. (2017a) also reported greater biomass in rotational treatments averaging production of 2.17 t DM Ha^{-1} compared to a production of 1.67 t DM Ha^{-1} and greater ground cover for continuously grazed pastures. The results in the current study were likely due to lower rainfall in May and a large increase in rainfall and daily temperature for June, allowing forage production to rapidly increase. Set stocked fields had a lower ($P < 0.03$, Table 4) biomass production of 2227 kg ha^{-1} in Cycle 1, likely due to this reason. Also, set stocked paddocks were cycled through very quickly at the beginning of the grazing season, and a few fields finished Cycle 1 before the end of May, when rainfall was still low, where the other fields had some paddocks finish Cycle 1 during June, when temperature and rainfall increased. However, the majority of Cycle 1 grazing for set stocked pastures occurred in May. Seasonal changes in forage biomass and animal productivity as affected by the amount of precipitation available are common in pasture studies (Heitschmidt et al., 1990; Venter et al., 2019; Derner and Hart, 2007; Teague et al., 2003).

Entry sward heights were also not different ($P \geq 0.12$; Table 3) across grazing management treatments at 21.6, 34.3, 30.4, 35.2 cm for continuous, rotational, set stocked, and strip grazing respectively. There were no grazing management treatments differences (*P* $\geq$ 0.55; Table 6) for post-grazing sward height throughout the grazing season. Stejskalova et al. (2013) found no differences in post-grazing sward heights when comparing continuous and rotational grazing, despite greater entry sward heights for rotationally grazed pastures. Tuñon et al. (2013) concluded post-grazing sward height had no impact on pre-grazing herbage biomass, regardless of herbage utilization. In the current study, total days grazing were greatest (*P* $\leq$ 0.05, Table 3) for rotationally (113 days, SEM = 4.55) and strip grazed (120 days, SEM=5.18) pastures with fewer total days grazing for set stocked (90 days, SEM=3.6) and continuously grazed (82 days, SEM=4.6) pastures. This is likely due to the addition of extra cow calf pairs to the latter two grazing management treatments during July, in an effort to keep up with forage production, as increased biomass occurred in June once precipitation and rainfall picked up from a below average rainfall in May. Two cow-calf pairs were added to each continuous and set stocked field to prevent wasted forage.

Pre-grazing forage biomass was greater (*P* $\leq$ 0.05; Table 4) in strip grazed vs. set stocked pastures in Cycle 1, with rotationally grazed pastures having similar amounts of pre-grazing forage biomass as strip- and set stocked grazed pastures. There were no differences (*P* > 0.05; Table 4) in pre-grazing sward height across grazing management treatments with values ranging from 25.7-38.3 cm. Post-grazing sward height was greater (*P* $\leq$ 0.05) in rotationally vs. set stocked grazed pastures. There was no exit sward data for strip grazed pastures because it was only decided part way through Cycle 1 that the exit sward heights for strip grazed pastures would be recorded as well. The first cycle ran into late June and early July when precipitation and temperature were optimal for forage growth, so it was challenging to manage the post-grazing forage sward height to the ideal post-grazing height of 10 cm this study aimed for with little trampling and forage waste. Dry matter intake and dry matter intake as a percent of body weight were both greater for rotational grazing ($P \leq 0.05$; Table 4) at 9.9 kg hd^{-1} day^{-1} and 1.5% of body weight compared to set stocking at 5.2 kg hd^{-1} day^{-1} and 0.8% of body weight. No DMI data was collected for strip grazing due to lack of post-grazing biomass data in Cycle 1.

Pre-grazing forage biomass for Cycle 2 was similar ($P \geq 0.27$) across grazing management treatments, ranging from 3796-4519 kg ha^{-1} (Table 4). This is surprising considering the greater post-grazing sward height for rotationally grazed pastures in Cycle 1, which could affect re-growth. Volesky et al. (2007) found that forages clipped to a shorter stubble height took longer to grow back and produced less biomass. Under this context, we may expect rotationally grazed pastures to outperform the other grazing management treatments for biomass production, due to greater post-grazing sward heights in Cycle 1. This is contradictory to Tuñon et al. (2013) who found no pre-grazing sward height or biomass differences based on previous post-grazing sward heights for rotationally grazed pastures. However, Tuñon et al. (2013) used targeted grazing heights that were only 1.5 cm different between the high and low grazed treatments, which may have attributed to lack of differences based on grazed sward height. There were also no differences ($P = 0.85$) in pre- grazing sward height for Cycle 2 grazing management treatments. These values were much greater than the goal for 30 cm pre-grazing sward height, but the trial was challenged by optimal conditions for forage growth and not enough cow-calf pairs to effectively manage the pasture. However post-grazing sward heights in Cycle 2 were greater ($P \leq 0.05$) for strip grazed pastures at 20.0 cm vs. 12.8 and 12.4 cm post-grazing sward heights respectively for rotationally and set stocked grazed pastures. There were no treatment differences ($P \geq 0.40$; Table 4) for dry matter intake or dry matter intake as a percent of body weight for grazing in Cycle 2.

Pre-grazing sward height for strip grazed pastures (27.5 cm) exceeded ($P \leq 0.05$) the pre-grazing sward height for set stocked pastures (25.5 cm) in Cycle 3 (Table 4). The greater pre-grazing sward height for strip grazed pastures in Cycle 3 may be due to greater post-grazing sward height for strip grazed pastures in Cycle 2 (Volesky et al., 2007) due to inadequate numbers of cow-calf pairs to maximally utilize the amount of forage in the strip. Post-grazing sward height was very uniform with no differences ($P \geq 0.20$) across grazing management treatments. There were no treatment differences ($P \geq 0.06$; Table 4) for Cycle 3 dry matter intake or dry matter intake as a percent of body weight.

Overall, when looking at the entire grazing season incorporating data from Cycles 1 to 3, there were no grazing management treatment differences ($P \geq 0.21$) in forage biomass and pre- or post-grazing sward heights (Table 6). However, there were grazing management treatment differences amongst grazing cycles (Table 7). Cycle 2 had the greatest ($P \leq 0.05$) forage biomass at 4146 kg/ha versus Cycles 1 and 3 which had similar ($P \geq 0.05$) amounts for forage biomass at 3239 and 2683 kg ha^{-1} respectively. Cycle 2 took place for most grazing management treatments during late June and early July, when forage growth increased due to increased rainfall and heat. Heitschmidt et al. (1990) and Martz et al. (1999) concluded that performance of a pasture system in terms of biomass production and thus animal performance was highly dependent on temperature and precipitation during the grazing season.

Pre-grazing sward height values differed ($P < 0.001$) across cycle with the greatest ($P < 0.05$) pre-grazing sward height for Cycle 2, the lowest for Cycle 3, with Cycle 1 pre-grazing sward height intermediate with values of 39.8, 34.4, and 26.1 cm, respectively (Table 7). Derner et al. (1994) concluded that sward height is highly dependent on precipitation throughout the season; in 1991, they observed a 1 cm decrease in sward with each cycle but in 1992 they observed a 2.5 cm increase with each cycle. There were post-grazing sward height differences ($P < 0.001$) between cycles with sward height values for Cycle 2 & 3 (10.2 and 15.0 cm respectively) being lower ($P \leq 0.05$) than sward height values for Cycles 1 (17.8 cm).

There was a grazing management treatment x cycle interaction ($P < 0.001$) for pre-grazing forage biomass (Table 5). This interaction was due to grazing management treatment differences in forage biomass production with changes in grazing cycle. For rotationally and strip grazed pastures, forage biomass was similar ($P \leq 0.05$) between treatments in Cycles 1 and 2 and then forage biomass decreased ($P \leq 0.05$) in Cycle 3 for both grazing management treatments. For set stocked pastures, forage biomass in Cycle 1 was lower ($P \leq 0.05$) than Cycle 1 values for strip grazed pasture with a large increase in forage biomass for Cycle 2 that was sustained in Cycle 3. Forage biomass in Cycle 3 for set stocked pastures was greater ($P \leq 0.05$) than forage biomass for rotationally and strip grazed pastures for Cycle 3.

There was also a grazing management technique x cycle interaction ($P = 0.03$) for post-grazing sward height. Sward heights for Cycle 1 with rotationally grazed pastures were greater ($P \leq 0.05$) than sward heights for Cycles 2 and 3 for rotationally grazed pastures. (Table 5). Sward heights for set stocked pastures were similar ($P \geq 0.05$) across cycles. Post-grazing sward heights for strip grazed pastures were greater ($P \leq 0.05$) in Cycle 2 than Cycle 3. The interaction was due to a greater ($P \leq 0.05$) sward height in Cycle 2 for strip grazed pastures that decreased to a greater ($P \leq 0.05$) extent than sward heights in Cycle 3 for rotationally and set stocked pastures.

Intensive grazing management such as rotational and strip grazing may increase grazing days. Although these methods seemed to provide forage for a longer period of time, they did not provide higher biomass into later cycles; both methods had lower Cycle 3 biomass than Cycles 1 and 2 which were effects not seen in continuous and set stocking. Overall, weather contributes the greatest effects, as seen by higher biomass values in Cycle 2, as a result of higher precipitation.

4.3 Botanical Composition of Summer Grazed Forages

Grazing management technique did not affect ($P \leq 0.05$) the percentages of legumes and grasses in pastures but did affect ($P \leq 0.03$) the amounts of weeds and dead material (Table 11). This is consistent with Augustine et al. (2020) who concluded that even with even 10, 15 and 30% increases in stocking rates, continuous grazing did not have a detrimental effect on C3 graminoids in the grazing system when compared with rotational grazing systems, contrary to the authors' original predictions. This finding is also consistent to Venter et al. (2019) who found no differences in forage selectivity for cattle grazing at higher stocking densities. Walker et al. (1989) concluded that grazing selectivity was not determined by grazing pressure but available biomass per unit of land. Badgery et al. (2017) reported no effects of selective grazing on the grass composition of Australian grasses when grazed by sheep, which was attributed to a reported lack of response in stands with over 70% grasses. In the present study, there were greater ($P \leq 0.05$) amounts of weeds for strip versus set stocked pastures and lower ($P \leq 0.05$) amounts of dead material in continuously grazed pastures versus pastures from other grazing management techniques.

Based on examining botanical composition, there were major cycle differences ($P < 0.001$) for the major pasture components (Table 12). As the grazing season progressed, the percentages of legumes and dead material increased ($P \leq 0.05$) while the percentages of grasses decreased ($P \leq 0.05$). The lowest ($P \leq 0.05$) amount of legumes and greatest ($P \leq 0.05$) amount of grasses were found in Cycle 1 pastures. Billsman et al. (2020) concluded that a higher proportion of grass resulted from rotational grazing during the season. This is contradictory to our results where no significant grazing management treatment effect ($P \geq 0.05$; Table 13) and no grazing management technique by cycle interaction ($P \geq 0.09$; Table 13) and an overall decrease ($P \leq 0.05$; Table 12) in grass % throughout the season. Martz et al. (1999) concluded that overall, legumes increased in late summer and early fall; however, the past study attributed this to higher-than-normal rainfall in May, which was not the case in the current study where rainfall was below average for the region. Stojanovic et al. (2018) also found that with increasing number of grazing cycles, legumes and weeds remained constant but grass decreased throughout the season from 35% of the stand to 15% by the third cycle.

The weeds fraction in pastures only differed ($P \leq 0.05$) between Cycles 1 and 2 at 5.4 and 3.9% respectively. The dead fraction in pastures was lowest ($P \leq 0.05$) for Cycle 1. Cycles later in the season may have a numerically higher dead fraction due to accumulation of stems and dead material from periods of high forage growth earlier in cycle two. Martz et al. (1999) attributed lower forage growth in later grazing cycles to the accumulation of stem and dead material from periods of accelerated growth earlier in the season as periods of low growth followed the high.

4.4 Forage Quality

There were no grazing management treatment differences ($P \geq 0.06$) on forage quality characteristics that were assessed including NEm, TDN, CP, NDF, ADF, Ca and P (Table 8). There were significant treatment effects for net energy of production ($P <$ 0.02; Table 8); the NE_p for continuous grazing was 0.89 Mcal/kg which was greater ($P \leq$ 0.05) than the NE_p for strip grazing (0.77 Mcal/kg on average): there were no significant differences for NE_p for all other treatments. These results were surprising as it is generally thought that CP would be greater and ADF, NDF values lower for rotational grazing as a result of cattle grazing younger forages throughout the season, as cattle cycle back to an already grazed paddock (Hirschfeld et al. 1996). McCollum and Gillen (1998) concluded that continuously grazed steers consumed more forage containing greater amounts of CP than steers rotationally grazed in a multi-paddock system. Hoakstra et al. (2019, 2008) also found similar results with greater amounts of CP and lower ADF and NDF values for continuously grazed pastures when compared with strip grazing. It is possible that continuously grazed forage is being grazed more frequently and selectively by cattle, resulting in higher quality forage consumed.

Forage cycle differences ($P \leq 0.002$) were present for NEm, NEp, TDN, CP, NDF, ADF, and Ca contents (Table 9) which is to be expected as forage maturity varies over the grazing season. Net energy of maintenance was greatest ($P \leq 0.05$, Table 9) in Cycle 1 at 1.68 Mcal/kg, intermediate in Cycle 2 at 1.54 Mcal/kg, and lowest in Cycle 3 at 1.44 Mcal/kg. The NE_m values were similar between Cycles 2 and 4 and between Cycles 3 and 4. Net energy of production was lower in Cycle 4 than Cycles 1 and 2

($P \leq 0.05$; Table 9), at 0.78, 0.97 and 0.82 Mcal/Kg, respectively. Cycle 3 had similar NEp values to all other cycles. Cycle differences in TDN content followed a similar trend as cycle differences in NE_m values. These findings are consistent with Stojanovic et al. (2018) who concluded that energy value of the rotationally grazed pasture decreased with the grazing season. This was attributed to the higher sugar values in the beginning of the season and the increased fibre contained in the stem mass as the season continued and forages grew taller, resulting in possibly greater stem to leaf ratio. Crude protein was lowest ($P \leq 0.05$) in Cycle 2 relative to the CP content of pastures in Cycles 1 and 4. This is a surprising result as generally, crude protein of forages is greater in the beginning of the season, and decreases toward the end (Wyatt et al., 2012; Hirschfeld et al., 1996, Marshall et al., 1998b). A possible explanation for this result could be the lack of forage growth and thus a shorter rest period between grazing instances in the fourth cycle. This would result in cattle grazing younger forage, which may have contained more protein compared to the older, more well rested forages in earlier cycles. Cycle 2 also experienced a rapid increase in growth, which may have had a dilution effect on plant nutrients. NDF content in pastures was lowest *($P \leq 0.05$)* in Cycle 1 with no cycle content differences in NDF content for Cycles 2, 3, and 4. The ADF content in pastures followed the same trend at NDF, which is to be expected as fibre fraction of the forages increase with shoot elongation throughout the season. Badgery et al. (2017a) concluded that the digestibility of forages was directly correlated to the green forage amount within the stand. Findings in the present study are also in agreement with findings from Marshall et al. (1998b) that found lower NDF and ADF

values in early spring and higher values later in the season. This is in line with the current findings that the dead fraction increased with grazing cycle and the fibre fraction of the pre-grazed forage. Calcium content for pastures was greatest ($P \leq 0.05$) in Cycle 4 at 1.18%, intermediate at Cycle 3 at 0.98% and lowest but not different from each other in Cycles 1 and 2 (0.68 and 0.74%). Forage Ca content tends to increase with maturity, with increased plant material there is an increase in Ca (Oelburg., 1956).

There was a grazing management technique x cycle interaction ($P \leq 0.02$; Table 10) for pasture phosphorus (P) content. Rotational grazing had significantly higher P values for Cycle 3 at 1.03%, with Cycle 3 P concentrations greater ($P \leq 0.05$) than P concentrations in Cycles 1 and 2. Phosphorus concentrations in Cycle 4 were similar to P concentrations for all other cycles for rotationally grazed pasture. For set stocked pastures, P concentrations were similar ($P \geq 0.05$) across Cycles 1 to 3**;** there is also lack of data for Cycle 4 due to set stocked fields being removed from the grazing trial after running out of forage. For strip grazed pastures, Cycle 4 P concentrations exceeded ($P \leq 0.05$) P content of strip grazed paddocks in Cycles 1 and 2. Cycle differences in P concentrations for continuous grazed paddocks follow a similar trend to strip grazed paddocks. For continuously grazed pastures, Cycle 4 and Cycle 3 P concentrations exceeded ($P \leq 0.05$) P content of continuously grazed paddocks in Cycles 1 and 2. The grazing management technique x cycle interaction was due to a limited increase in P content for set stocked pastures between Cycle 2 and Cycle 3 versus the other grazing management techniques along with the trend for a decrease in P content between Cycle 3 and Cycle 4 for rotationally grazed pastures versus the trend for P content to increase between Cycle 3 and Cycle 4 for strip grazed and continuously grazed pastures (Table 8).

4.5 Cow-calf Performance

Throughout the experiment, three cow-calf pairs were removed from the trial due to poor health or lameness for either the cow or calf. There were no differences (*P*≥ 0.16) in initial weight, final weight, weight change, ADG, initial BCS, final BCS, change in BCS, initial backfat, final backfat, initial rump fat, final rump fat, or change in rump fat amongst grazing management techniques (Table 14). It is likely that prior condition of cattle before this study influenced potential animal performance results as animals were very over conditioned, Marshall et al. (1998a) demonstrated that under conditioned animals show an increased response to pasture treatments compared to over conditioned animals. Under Ontario conditions, Marshall et al. (1998a) found that lactating beef cows lost weight over spring/summer grazing for 2 of their 3-year study, while there were only minimal gains in weight (0.002 to 0.16 kg/d ADG) when lactating beef cows rotationally grazed the same pasture used in the present study in 2020 (Conlin, 2021). McCabe et al. (2020) reported losses in body weight over spring/summer grazing for rotationally grazed beef cows grazing perennial ryegrass pastures. This differs from the current study, which used a consistent stocking rate between both continuous and rotational grazing treatments and used a small land base for each treatment**.** Augustine et al. (2020) found that adaptive multi-paddock rotational grazing and continuous grazing had similar forage biomass and proportion of C3 graminoids with a reduced cattle body condition under increased stocking rate on a large range environment. Wyatt et al. (2013) found higher BCS at weaning in cows continuously grazed, which contrasts with Wyatt et al. (2012) where there were no differences in BCS at weaning between continuous and rotationally grazed cows. However, the 2012 grazing season was impacted by lack of precipitation in Wyatt et al. (2012), which could affect cow and calf performance due to lack of forage or poor forage quality. Derner and Hart (2007) also reported no differences in cattle weights, beef production (kg ha^{-1}) and ADG between continuous and rotational grazing. The lack of response for both BCS traits and ultrasound backfat change for the present study was expected as Wlodarski et al. (2021) concluded that changes in backfat measurements are not always detected by a change in BCS, but a change in BCS is usually detected by a change in backfat measurements. BCS and ultrasound measures of fatness were positively correlated in past studies (Domencq et al., 1995; Ayres et al., 2009); however, these traits were not necessarily correlated to body weight measures. The use of ultrasound to measure body condition in beef cows is the most accurate and consistent way to determine changes in body fat reserves; while visual assessment of BCS has been found to be inaccurate. Broring at al. (2003) concluded a maximum accuracy of body condition assessment of 64% with an experienced person performing visual assessment of body condition.

Grazing management technique differences for changes in backfat thickness over the grazing season tended to be present ($P \leq 0.07$; Table 14). Changes in backfat thickness were greater ($P \leq 0.05$) for set stocked cows who gained 0.58 mm backfat compared to strip grazed cows that mobilized 0.72 mm of backfat. Since there generally were no grazing management technique differences on pasture nutrient composition (*P*

≥ 0.06; Table 8), grazing management technique differences for changes in backfat could be explained by possible treatment differences in dry matter intake. When DMI was determined using quadrat measures, strip grazed cattle consumed more (*P* ≤ 0.05; Tables 3 and 14) pasture on a daily basis or as a percentage body weight than set stocked cattle. Since quadrat data was not collected for continuously grazed cattle, the Minson and McDonald (1987) equation for estimating DMI (M & M DMI) was used for all grazing management treatments to include continuously grazed cattle. Using the Minson and McDonald (1987) equation, there were no differences (*P* ≥ 0.05) in daily M & M predicted DMI intakes across grazing management treatments. However, on a percentage of BW basis, continuous grazing had the lowest (*P* ≤ 0.05) M & M DMI on a %BW basis at 1.26% BW per d, set stocked was intermediate at 1.29% BW and was not different from rotational grazing at 1.32% BW. The M &M DMI for strip grazing was also at 1.32% BW, but was not different from rotational grazing at 1.32 % BW. While strip grazed cattle consumed the greatest amount of M&M predicted feed, this does not support changes in backfat findings as strip grazed cows consumed more forage on a bodyweight basis, but lost backfat.

There are some concerns with evaluating DMI data as presented in Tables 3 and 14 since the value for strip grazed cattle does not include DMI data for Cycle 1, as no post-grazing sward heights were collected in Cycle 1 for strip grazed cattle. While the data using the Minson and McDonald (1987) equation to determine DMI enables an estimation of DMI for continuously grazed cattle (M & M DMI), the estimates for DMI on a kg/d or % BW basis are not similar to DMI values obtained for the 3 grazing management treatments using quadrat data (DMI). This may not be surprising as Conlin (2021) found that the Minson and McDonald (1987) equation dramatically underestimated DMI versus DMI determined using quadrat data for rotationally grazed cattle that were managed on the same pasture fields as the present study. The DMI (%BW) values based on the Minson and McDonald (1987) equation for the present study appear low, given that Danelon et al. (2002) found that Holstein cows grazing alfalfa consumed 1.67 to 2.06% of their body weight in pasture and it is reported that Nellore steers consumed 1.42 to 1.86% of their body weight grazing pasture containing 58.8 to 63.4% NDF (Dorea et al., 2020). While grazing management treatment differences for DMI in the present study may appear large based on kg/d values, Meyer et al. (2008) reported cows consuming 12.4 to 15.6 kg DM/d depending on residual feed intake (RFI) classification (low versus high). While Marshall et al. (1998a) found that cows consumed 11.26 to 14.21 kg DM/d depending on frame size for the rotationally grazed cows (medium versus large frame) and year of the study. Gregorini et al. (2009) found that Holstein-Friesian cows (470 ± 47 kg of BW) consumed 11.5 kg/d (~2.44% of BW) of strip grazed pasture when they were allowed to graze for the 8 hour period between milking’s. Rotationally grazed beef cows (577 to 599 kg BW) consumed 11.9 to 12.1 kg DM/d (~2.0% of BW) when grazing perennial ryegrass pastures (McCabe et al., 2020). Conlin (2021) reported that ~691 kg beef cows consumed 13.7 to 18 kg DM/d on rotationally grazed pastures depending if they were supplemented with Biochar with greater DMI for Biochar supplemented cows. The much greater DMI for strip grazed versus rotationally grazed or set stocked cows is supported by Danelon (2002) where strip grazed Holstein cows consumed 2.06% of their BW in alfalfa pasture versus a modified rotational grazing approach where Holstein cows consumed 1.67% of their BW in alfalfa pasture.

Due to the lack of DMI data for strip grazed cows in Cycle 1, DMI values were also calculated on an individual cycle basis (Table 4). In Cycle 1, rotationally grazed cows consumed much greater amounts of DM ($P \leq 0.05$) on both kg/d and %BW bases than set stocked cows. The values for set stocked cattle does not appear to be realistic and can only be explained by the excessive trampling of forage in Cycle 1 for set stocked cattle that resulted in very high amounts of forage sampled in post-grazing quadrats. This affected DMI values, as the ratio of post-grazing biomass to pre-grazing biomass for calculation of dry matter disappearance was much larger than it should be, resulting in inaccurate measures of DMI for the set stocking treatment in Cycle 1. In Cycle 2, there were no differences ($P \geq 0.42$) in DMI amongst grazing management techniques while in Cycle 3, there were trends ($P \leq 0.07$), in which rotationally grazed cattle consumed numerically lower amounts of pasture (kg/d and % BW bases) than set stocked and strip grazed cattle.

There were no differences ($P \geq 0.30$) for any calf measure (initial calf body weight, final calf body weight at end of grazing, and calf ADG across grazing management treatments (Table 15). This was the same conclusion found by Wyatt et al (2012, 2013) when evaluating rotationally and continuous grazed cow-calf pairs. There were also no differences ($P \geq 0.27$) for any weaning data trait (calf weaning weight, cow

BCS at weaning and cow weight at weaning) across grazing management treatment in the Wyatt studies.

4.1 Conclusions

Overall differences for grazing management technique were small. No treatment differences were found for pre-grazing biomass, entry sward height, forage quality, percent of legumes, percent of grasses, weight measures, and cow-calf condition. There were significant differences for grazing management technique ($P \leq 0.05$) for number of grazing days, which indicate a longer number of grazing days for rotational and strip grazing. Weed and dead percentage within the forage stand differed amongst grazing management technique, with strip grazing having more weeds than set stocked pastures, and more dead material in the continuous fields. Although there were minimal differences in cow and calf performance, changes in backfat thickness were greater for set stocked cows, who gained more backfat and lower for strip grazing pastures who cow's mobilized fat. There were cycle differences amongst grazing management techniques that were attributed to timing of rainfall, and grazing management technique differences for maturation of pasture in the stand such as increased fibre fraction of forages in ADF and NDF, lower energy measures, and increased calcium. Intensive grazing methods can increase the length of grazing season, while maintaining weaning weights and calf ADG. Set stocking may be an option for producers who do not want the maintenance of moving cattle every few days or daily with intensive grazing management while still capturing some of the benefits that intensive grazing has.

Table 2. Climate data for the grazing season of summer grazing management experiment

Month	Average maximum temp °C	Average minimum temperature °C	Mean temperature °C	Total precipitation (mm)	Historical Temperature °C (1991-2000)[1]	Historical Precipitation (mm) (1991-2000)[1]
May	18	4.5	11	11	13	92
June	25	13.2	19	106	18	102
July	24	13.5	19	89	21	89
August	27	14.5	21	30	20	79
September	21	8.8	15	139	16	81

[1] Historical averages for temperature and precipitation from https://en.climate-data.org/north-america/canada/ontario/elora-719074/

Table 3. Effects of grazing management technique on pre-grazing forage biomass, sward height, DMI, DMI as a percent of body weight and overall grazing days

	Grazing Management technique[1]								
Item	**Continuous**	**SEM**	**Rotational**	**SEM**	**Set stocked**	**SEM**	**Strip**	**SEM**	**P-value**
Forage biomass: DM kg/ha prior to grazing season	1479	219.2	1389	189.8	1236	169.8	1625	189.8	0.51
Entry Sward height (cm)	21.6	8.67	34.3	1.66	30.4	1.99	35.2	1.57	0.13
Estimated DMI, kg/day[4]	8.9	0.05	9.0	0.05	9.0	0.04	8.9	0.05	0.05
Estimated DMI, kg/day as % of BW[5]	1.26^{c}	0.007	1.32^{ab}	0.007	1.29^{b}	0.006	1.32^{a}	0.007	<0.0001
Grazing days	82^{b}	4.6	113^{a}	4.8	90^{b}	3.6	120^{a}	5.2	<0.0001

[1] Grazing Management Technique: Continuous = cow-calf pairs allocated to 3.2 or 3.6 ha fields to graze at will; Rotational = cow-calf pairs allocated to a 0.40 ha paddock to graze for approximately 4 d; Set stocked = cow-calf pairs allocated to a 0.80 ha paddock to graze for approximately 7 d; Strip = cow-calf pairs allocated to a 0.13 ha strip to graze for 1 day.

[2] DMI calculated across the whole grazing trial using the following equation,

*DMI = (Average pre-grazing herbage biomass - Average post-grazing herbage biomass)/(#cow-calf pairs x #days spent grazing the pasture) (*equation 5 in materials and methods). No data for Continuous grazing as no exit biomass measures were ever collected.

[3] DMI calculated across the whole grazing trial using DMI, kg/d values which were then expressed as a percentage of average body weight over the trial.

[4] DMI calculated by using body weight (BW) and ADG in the equation: $(1.185 + 0.00454BW - 0.0000026BW^2 + 0.315ADG)^2$ from Minson and McDonald (1987).

[5] DMI calculated using M & M DMI, kg/d as a percentage of average body weight.

[a-c] Least square means within a row with different superscripts differ (*P* ≤ 0.05).

Table 4. Effects of grazing management technique on field characteristics by cycle

	Cycle 1: Grazing Management Technique^{1,2}						
Item	**Rotational**	**SE**	**Set stocked**	**SE**	**Strip**	**SE**	**P-value**
Forage biomass: Pre-grazing DM, kg/ha	3508^{ab}	389.8	2227^{a}	461.2	3800^{b}	364.6	0.03
Pre-grazing sward height,	37.6	3.52	25.7	4.16	38.3	3.35	0.05
Post-grazing sward height, ^{2}	19.3^{a}	1.67	15.8^{b}	1.97	-	-	0.02
DMI, kg/day^{3}	9.9^{a}	1.25	5.2^{b}	1.48	-	-	0.02
DMI, kg/day as % of BW^{4}	1.5^{a}	0.18	0.8^{b}	0.22	-	-	0.02
	Cycle 2: Grazing Management Technique						
Item	**Rotational**	**SE**	**Set stocked**	**SE**	**Strip**	**SE**	**P-value**
Forage biomass: Pre-grazing DM, kg/ha	3796	292.8	4519	352.6	4226	270.4	0.27
Pre-grazing sward height,	38.6	2.63	40.2	3.16	40.7	2.67	0.85
Post-grazing sward height,	12.8^{b}	1.66	12.4^{b}	1.96	20.0^{a}	1.83	0.01
DMI, kg/day^{3}	15.5	1.76	18.4	2.08	18.0	1.79	0.48
DMI, kg/day as % of BW^{4}	2.3	0.26	2.6	0.31	2.7	0.27	0.43
	Cycle 3: Grazing Management Technique						

Item	Rotational	SE	Set stocked	SE	Strip	SE	P-value
Forage biomass: Pre-grazing DM,	2088^{b}	151.2	4459^{a}	202.1	2388^{b}	129.7	<0.0001
Pre-grazing sward height,	25.5^{ab}	0.74	24.3^{b}	0.90	27.5^{a}	0.65	0.02
Post-grazing sward height,	10.0	0.19	10.5	0.27	10.4	0.19	0.20
DMI, kg/day[3]	12.2	1.01	16.3	1.45	14.2	1.01	0.07
DMI, kg/day as % of BW[4]	1.8	0.15	2.3	0.21	2.1	0.15	0.08

[1] Grazing Management Technique: Continuous = cow-calf pairs allocated to 3.2 or 3.6 ha fields to graze at will; Rotational = cow-calf pairs allocated to a 0.40 ha paddock to graze for approximately 4 d; Set stocked = cow-calf pairs allocated to a 0.80 ha paddock to graze for approximately 7 d; Strip = cow-calf pairs allocated to a 0.13 ha strip to graze for 1 day.

[2] There are no values for post-grazing sward height for Cycle 1 for strip grazed pastures as data was not collected for post grazing measures until cycle 2. The absence of post-grazing sward heights for strip grazed pastures is also responsible for no Cycle 1 DMI data.

[3] DMI calculated using DM disappearance, equation 5 in materials and methods. No data for Continuous grazing due to no exit biomass measures. No data for Continuous grazing as no exit biomass measures were taken.

[4] DMI calculated using equation 5, as a percent of average body weight.

Table 5. Grazing management technique by cycle interactions for field characteristics

	Grazing Management Technique^{1,2}							P-value
Item	**Cycle**	**Rotational**	**SE**	**Set stocked**	**SE**	**Strip**	**SE**	**Management by cycle interaction**
Forage biomass: Pre-grazing DM, kg/ha	1	3508^{ab}	300.7	2227^{bc}	355.8	3800^{a}	281.3	<0.0001
	2	3796^{a}	295.5	4519^{a}	355.8	4228^{a}	272.9	
	3	2088^{c}	318.2	4459^{a}	425.2	2388^{bc}	272.9	
Post-grazing sward height, cm	1	19.3^{a}	1.35	15.8^{ab}	1.60		281.26	0.03
	2	12.8^{b}	1.35	12.4^{b}	1.60	20.0^{a}	1.49	
	3	10.0^{b}	1.43	10.5^{b}	2.07	10.4^{b}	1.43	

[1] Grazing Management Technique: Continuous = cow-calf pairs allocated to 3.2 or 3.6 ha fields to graze at will; Rotational = cow-calf pairs allocated to a 0.40 ha paddock to graze for approximately 4 d; Set stocked = cow-calf pairs allocated to a 0.80 ha paddock to graze for approximately 7 d; Strip = cow-calf pairs allocated to a 0.13 ha strip to graze for 1 day.

[2] There are no values for post-grazing sward height for strip grazed pastures as post grazing sampling did not start until cycle 2.

$^{a\text{-}c}$Least square means within a row with different superscripts differ ($P \leq 0.05$).

Table 6. Effect of grazing management technique on field characteristics over the entire grazing season

	Grazing Management Technique[2]						
Item	**Rotational**	**SE**	**Set Stocked**	**SE**	**Strip**	**SE**	**P-value**
Forage biomass: Pre-grazing DM, kg/ha	3177	197.6	3654	243.5	3464	178.9	0.29
Pre-grazing sward height, cm	34.3	1.67	30.7	2.06	35.2	1.59	0.22
Post-grazing sward height, cm	14.2	0.89	13.3	1.11	15.0	1.16	0.56

[1] Values in this table present averages for the entire grazing season across all cycles.

[2] Grazing Management Technique: Continuous = cow-calf pairs allocated to 3.2 or 3.6 ha fields to graze at will; Rotational = cow-calf pairs allocated to a 0.40 ha paddock to graze for approximately 4 d; Set stocked = cow-calf pairs allocated to a 0.80 ha paddock to graze for approximately 7 d; Strip = cow-calf pairs allocated to a 0.13 ha strip to graze for 1 day.

Table 7. Effects of grazing cycle on field characteristics[1]

	Grazing Cycle						
Item	**1**	**SE**	**2**	**SE**	**3**	**SE**	**P-value**
Forage biomass: Pre-grazing DM kg/ha	3239^{b}	181.4	4146^{a}	179.0	2683^{b}	199.0	<0.0001
Pre-grazing sward	34.4^{a}	1.56	39.8^{b}	1.61	26.1^{c}	1.64	<0.0001
Post-grazing sward	17.8^{a}	1.07	15.0^{b}	0.88	10.2^{b}	0.95	<0.0001

[1] Values in this table represent differences for grazing cycles using averages from data across all grazing management techniques.

[a-c] Least square means within a row with different superscripts differ ($P \leq 0.05$).

Table 8. Impact of grazing management technique on forage quality

	Grazing Management Technique[1]								
	Continuous	**SE**	**Rotational**	**SE**	**Set Stocked**	**SE**	**Strip**	**SE**	**P-value**
Dry Matter, %	92.6	0.16	93.0	0.15	92.7	0.14	93.1	0.17	0.09
Net energy maintenance, Mcal/kg	1.61	0.038	1.53	0.037	1.56	0.034	1.50	0.040	0.20
Net energy production, Mcal/kg	0.89^{a}	0.025	0.80^{ab}	0.025	0.82^{ab}	0.024	0.77^{b}	0.026	0.01
TDN, %	65.4	1.31	62.6	1.13	63.8	1.17	61.5	1.37	0.20
Crude protein, %	17.8	1.07	15.9	1.02	17.9	0.95	15.8	1.11	0.33
NDF, %	47.5	1.86	52.9	1.79	50.45	1.67	51.1	1.94	0.19
ADF, %	30.2	1.85	33.6	1.77	32.2	1.65	35.21	1.93	0.29
Ca, %	0.94	0.059	0.81	0.057	0.76	0.053	0.88	0.062	0.06
P, %	0.37	0.112	0.34	0.109	0.52	0.101	0.34	0.118	0.57

[1] Grazing Management Technique: Continuous = cow-calf pairs allocated to 3.2 or 3.6 ha fields to graze at will; Rotational = cow-calf pairs allocated to a 0.40 ha paddock to graze for approximately 4 d; Set stocked = cow-calf pairs allocated to a 0.80 ha paddock to graze for approximately 7 d; Strip = cow-calf pairs allocated to a 0.1.3 ha strip to graze for 1 day.

Table 9. Impact of grazing cycle on forage quality

	Cycle								
Item	**1**	**SE**	**2**	**SE**	**3**	**SE**	**4**	**SE**	**P-value**
Dry Matter, %	93.0	0.14	2.9	0.15	92.6	0.15	92.8	0.24	0.41
Net energy maintenance (NE$_m$), Mcal/kg	1.68^{a}	0.023	1.54^{b}	0.025	1.44^{c}	0.024	1.50^{bc}	0.038	<0.0001
Net energy production, (NE$_p$), Mcal/kg	0.97^{a}	0.02	0.82^{b}	0.02	0.72^{bc}	0.02	0.78^{c}	1.050	<0.0001
TDN, %	68.0^{a}	1.82	62.9^{b}	0.87	59.6^{c}	0.84	61.8^{bc}	1.32	<0.0001
Crude protein, %	18.4^{a}	0.82	14.1^{b}	0.88	16.9^{ab}	0.85	19.4^{a}	1.34	0.002
NDF, %	43.4^{a}	1.06	54.2^{b}	1.14	55.1^{b}	1.10	51.1^{b}	1.74	<0.0001
ADF, %	26.2^{b}	1.14	34.3^{a}	1.22	37.6^{a}	1.17	34.8^{a}	1.86	<0.0001
Ca, %	0.68^{a}	0.323	0.74^{a}	0.031	0.98^{b}	0.031	1.18^{c}	0.049	<0.0001
P, %	0.53	0.097	0.32	0.104	0.35	0.101	0.38	0.159	0.45

$^{a-c}$Least square means within a row with different superscripts differ ($P \le 0.05$).

Table 10. Grazing management technique by cycle interactions for pasture phosphorus content

		Grazing Management Technique[1,2]								P-value
Item	**Cycle**	**Rotational**	**SE**	**Set stocked**	**SE**	**Strip**	**SE**	**Continuous**	**SE**	**Management by cycle interaction**
P, %	1	0.62^{d}	0.048	0.72^{d}	0.039	0.64^{d}	0.056	0.72^{d}	0.056	0.01
	2	0.79^{cd}	0.048	0.73^{d}	0.048	0.74^{cd}	0.056	0.67^{d}	0.056	
	3	1.03^{ab}	0.048	0.84^{bcd}	0.043	1.02^{abc}	0.056	1.09^{ab}	0.056	
	4	0.81^{bcd}	0.093	-		1.23^{a}	0.066	1.26^{a}	0.054	

[1] Grazing Management Technique: Continuous = cow-calf pairs allocated to 3.2 or 3.6 ha fields to graze at will; Rotational = cow-calf pairs allocated to a 0.40 ha paddock to graze for approximately 4 d; Set stocked = cow-calf pairs allocated to a 0.80 ha paddock to graze for approximately 7 d; Strip = cow-calf pairs allocated to a 0.13 ha strip to graze for 1 day.

[2] There are no values for P content for set stocked pastures as cattle were removed from fields due to lack of forage.

[a-d] Least square means within a row with different superscripts differ ($P \leq 0.05$).

Table 11. Effects of grazing management technique on botanical composition

	Grazing Management Technique[1]								
Item	**Continuous**	**SE**	**Rotational**	**SE**	**Set Stocked**	**SE**	**Strip**	**SE**	**P-value**
Legumes, %	29.0	2.79	30.7	1.32	30.3	0.96	29.7	1.06	0.92
Grasses, %	62.6	4.38	55.9	2.07	58.9	1.51	53.6	1.66	0.06
Weeds, %	4.9^{ab}	1.34	3.9^{ab}	0.64	3.7^{b}	0.46	5.6^{a}	0.51	0.03
Dead, %	2.0^{b}	2.20	10.3^{a}	0.89	8.2^{a}	0.67	10.1^{a}	0.73	0.001

[1] Grazing Management Technique: Continuous = cow-calf pairs allocated to 3.2 or 3.6 ha fields to graze at will; Rotational = cow-calf pairs allocated to a 0.40 ha paddock to graze for approximately 4 d; Set stocked = cow-calf pairs allocated to a 0.80 ha paddock to graze for approximately 7 d; Strip = cow-calf pairs allocated to a 0.1.3 ha strip to graze for 1 day.

[a-b] Least square means within a row with different superscripts differ ($P \leq 0.05$).

Table 12. Effects of grazing cycle on botanical composition

	Grazing Cycle								
Item	**1**	**SE**	**2**	**SE**	**3**	**SE**	**4**	**SE**	**P-value**
Legumes, %	22.4^{b}	0.86	33.3^{a}	0.88	35.5^{a}	1.00	35.8^{a}	2.43	<0.0001
Grasses, %	70.8^{a}	1.12	55.9^{b}	1.15	40.5^{c}	1.31	38.8^{c}	3.17	<0.0001
Weeds, %	5.4^{a}	0.48	3.9^{b}	0.49	5.4^{ac}	0.56	5.8^{abc}	1.36	<0.0001
Dead, %	1.4^{c}	0.75	7.4^{ab}	0.76	18.6^{a}	0.86	19.5^{a}	2.10	<0.0001

$^{a\text{-}d}$Least square means within a row with different superscripts differ ($P \leq 0.05$).

Table 13. Significance of grazing management technique, cycle and their interaction for botanical composition

Item	Grazing Management Technique	Cycle	Grazing Management Technique by Cycle Interaction
Legumes, %	0.92	<0.0001	0.77
Grasses, %	0.06	<0.0001	0.16
Weeds, %	0.03	<0.0001	0.69
Dead, %	0.003	<0.0001	0.09

[1] Grazing Management Technique: Continuous = cow-calf pairs allocated to 3.2 or 3.6 ha fields to graze at will; Rotational = cow-calf pairs allocated to a 0.40 ha paddock to graze for approximately 4 d; Set stocked = cow-calf pairs allocated to a 0.80 ha paddock to graze for approximately 7 d; Strip = cow-calf pairs allocated to a 0.1.3 ha strip to graze for 1 day.

[2] Cycle = number of times cattle have gone through every paddock within a field.

Table 14. Effects of grazing management technique on cow performance

	Grazing Management Technique[1]								
Item	**Continuous**	**SE**	**Rotational**	**SE**	**Set stocked**	**SE**	**Strip**	**SE**	**P-value**
Initial weight, kg	727.7	18.16	703.4	19.11	713.3	14.45	693.1	20.64	0.62
Final weight, kg	678.5	16.29	663.4	17.17	678.6	12.62	648.2	18.21	0.51
Weight change, kg	-45.3	5.54	-39.9	5.94	-35.0	4.41	-44.9	6.30	0.43
ADG, kg/d[3]	-0.40	0.090	-0.23	0.095	-0.27	0.071	-0.19	0.103	0.38
Initial BCS	3.5	0.06	3.5	0.07	3.5	0.05	3.4	0.07	0.42
Final BCS	3.6	0.08	3.5	0.08	3.5	0.07	3.5	0.09	0.62
Change in BCS	$-1.0e^{-4}$	$4.18e^{-4}$	$9.7e^{-4}$	$4.44e^{-4}$	$4.3e^{-4}$	$3.33e^{-4}$	$8.5e^{-4}$	$4.75e^{-4}$	0.29
Initial Backfat, mm	8.3	0.74	9.8	0.78	10.2	0.59	8.8	0.84	0.19
Final Backfat, mm	8.3	0.86	10.0	0.92	10.2	0.68	8.1	0.98	0.16
Change in backfat, mm	-0.05^{ab}	0.348	0.10^{ab}	0.373	0.58^{a}	0.280	-0.72^{b}	0.396	0.07
Initial Rump fat, mm	12.9	1.42	14.5	1.49	14.0	1.13	11.3	1.61	0.44
Final Rump fat, mm	12.2	1.57	13.7	1.65	13.0	1.25	9.9	1.78	0.43
Change in rump fat, mm	-0.7	0.51	-0.9	0.54	-0.4	0.42	-1.4	0.58	0.65
DMI, kg/day[4]	No data		12.5^{b}	0.91	12.8^{ab}	1.14	16.2^{a}	1.14	0.03
DMI, kg/day as % of BW[5]	No data		1.8^{b}	0.14	1.8^{b}	0.17	2.4^{a}	0.17	<0.0001
M & M DMI, kg/day[6]	8.9	0.05	9.0	0.05	9.0	0.04	8.9	0.05	0.05
M & M DMI, kg/day as % of BW[7]	1.26^{c}	0.007	1.32^{ab}	0.007	1.29^{b}	0.006	1.32^{a}	0.007	<0.0001

[1] Grazing Management Technique: Continuous = cow-calf pairs allocated to 3.2 or 3.6 ha fields to graze at will; Rotational = cow-calf pairs allocated to a 0.40 ha paddock to graze for approximately 4 d; Set stocked = cow-calf pairs allocated to a 0.80 ha paddock to graze for approximately 7 d; Strip = cow-calf pairs allocated to a 0.13 ha strip to graze for 1 day.

[2] Largest SEM (standard error of the mean) is reported.

[3] ADG determined by linearly regressing cattle weights, slope of the curve = ADG.

[4] DMI calculated across the whole grazing trial using the following equation,
DMI = (Average pregrazing herbage biomass - Average postgrazing herbage biomass)/(#cow-calf pairs x #days spent grazing the pasture) (equation 5 in materials and methods). No data for Continuous grazing as no exit biomass measures were ever collected.

[5] DMI calculated across the whole grazing trial using DMI, kg/d values which were then expressed as a percentage of average body weight over the trial.

[6] DMI calculated by using body weight (BW) and ADG in the equation: $(1.185 + 0.00454BW - 0.0000026BW^2 + 0.315ADG)^2$ from Minson and McDonald (1987).

[7] DMI calculated using M & M DMI, kg/d as a percentage of average body weight.

[a-b] Least square means within a row with different superscripts differ ($P \leq 0.05$).

Table 15. Effects of grazing management technique on calf performance during grazing and at weaning

	Grazing Management Technique[1]								
Item	**Continuous**	**SE**	**Rotational**	**SE**	**Set stocked**	**SE**	**Strip**	**SE**	**P-value**
Calf Initial weight, kg	107.2	3.51	110.3	3.66	108.3	2.89	112.2	3.93	0.75
Calf weight at end of grazing, kg	243.7	6.32	249.2	6.93	234.6	5.00	235.7	7.07	0.31
Calf ADG, kg/d	1.30	0.083	1.23	0.087	1.17	0.065	1.23	0.094	0.60
Calf weaning weight, kg	288.1	6.22	299.5	6.55	290.6	5.11	299.5	7.07	0.45
Cow BCS at weaning	3.5	0.06	3.7	0.07	3.5	0.05	3.5	0.07	0.27
Cow weight at weaning,	662.2	14.61	669.3	15.40	652.1	12.01	662.0	16.99	0.84

[1] Grazing Management Technique: Continuous = cow-calf pairs allocated to 3.2 or 3.6 ha fields to graze at will; Rotational = cow-calf pairs allocated to a 0.40 ha paddock to graze for approximately 4 d; Set stocked = cow-calf pairs allocated to a 0.80 ha paddock to graze for approximately 7 d; Strip = cow-calf pairs allocated to a 0.1.3 ha strip to graze for 1 day.

5.0 Materials and Methods for the Addition of Legumes to an Ontario Stockpiled Grazing System

5.1 Pre-grazing Field Management

Twelve 1.01 ha fields were developed in land previously used in a conventional crop production (corn, hay/silage) at the Elora Research Station (Figure 2). These fields were first seeded in spring of 2018 with a mixture of diverse grasses at varying seeding rates: Dividend VL Orchard Grass (*Dactylis glomerata*) at 6.16 kg ha^{-1}, Pardus Meadow Fescue (*Festuca pratensis*) at 10.81 kg ha^{-1}, Fleet Meadow Brome (*Bromopsis bierbersteinii*) at 10.81 kg ha^{-1}, Ginger Kentucky Bluegrass (*Poa pratensis*) at 9.25 kg ha^{-1}, Lofa Festulolium at 10.81 kg ha^{-1}, Kokanne Tall Fescue (*Festuca* arundinacea) at 24.71 kg ha^{-1}, and Express Timothy (*Phleum* pratense) at 15.45 kg ha^{-1}. In four of the 12 fields (101, 106, 108 on 112 in Figure 1), CRS1001 Alfalfa (*Medicago sativa,* CRS1001) was seeded at 61.93 kg ha^{-1} to target the production of an approximately 40% legume stand. In another 4 fields (103, 105, 107, 110 in Figure 1) Bruce Birdsfoot trefoil (*Lotus* corniculatus) was seeded at 33.08 kg ha^{-1} to again target the production of an approximately 40% legume stand. Four fields (102, 104, 109, 111 in Figure 1) were only seeded with the diverse grass mixture. The initial seeding was unsuccessful due to limited precipitation during the growing season, so the fields were reseeded again in spring of 2019. The 2019 seeding was successful so that 12 fields were available for stockpile grazing in fall, 2020 with 3 pasture treatments based on forage botanical composition with 4 replicate fields for each pasture treatment: 1) Diverse mixture of grasses with no legumes seeded during establishment. 2) Diverse mixture of grasses with alfalfa seeded as the legume anchor based on targeting a 40%

legume stand. 3) Diverse mixture of grasses seeded with birdsfoot trefoil as the legume anchor based on targeting a 40% legume stand.

Details for the method of sampling were previously described in section 3.2. Quadrat samples were taken prior to the grazing season for estimation of forage biomass prior to cutting for conserved forage. In 2020, conserved forage was harvested twice prior to fall grazing; in 2021, conserved forage was only harvested once to increase biomass accumulation for fall grazing.

Quadrat samples were taken from the pasture at least once weekly for determination of forage biomass, dry matter (DM), nutrient composition, and botanical composition. Further details of forage sampling and measurements following sampling are described above in section 3.2

The representative sample saved for botanical composition was weighed and then sorted by each collected shoot into legume, weed, grass or dead fractions. Each fraction was observed for the predominant species it contained and weighed out separately in order to later determine the % of individual fractions in the forage sample. The botanical composition for each field was then recorded as a percentage of the total sample in each paddock.

The representative sample used for dry matter determination was then ground small enough to pass through a 1 mm screen using a Thomas Wiley feed grinder (Wiley Mill, Arthur H. Thomas, Philadelphia, PA, USA). Samples were numbered by field, sample date, and trial and placed into a Whirlpak bag to composite at a later time.

Samples were composited based on sampling date for subsequent determination of nutrient composition on the basis that nutrient composition will be similar over a short chronological time frame. Weekly samples were composited into bi-weekly samples for analysis. In 2020, individual ground forage samples were grouped by sampling date into the pre-grazing sample, and the first two weeks and the last two weeks of sampling. In 2021, the grazing season continued longer into the fall than the 2020 extended grazing season, so all fields had at least seven samples for compositing.

Samples were sent to A&L Canada Laboratories INC (London, Ontario, Canada). Lab analyses conducted can be found in section 3.2 above. The process of compositing samples into representative smaller samples is better described in detail previously in section 3.2.

5.2 Animal Management on Pasture

The study was completed under the approval of the University of Guelph's Animal Care Committee based on the submission and approval of Animal Utilization Protocol AUP 4157. All animals were cared for in accordance with the guidelines presented by the Canadian Council on Animal Care (1993). Each year, 4 heifers were allocated to each of the 12 extended grazing fields (48 heifers in total per year) balanced by weight. Starting weight of heifers in 2020 ranged from 407 to 585 kg, while starting weight for 2021 heifers ranged from 454 to 586 kg. In 2020, mainly bred heifers were used; however, due to limited availability of bred heifers, eight open heifers were added to balance animal numbers. One heifer was added in field 16, three in field 23, and four in field 21. For the 2021 extended grazing season, only bred heifers were used. Heifers were allotted into 4 groups of four heifers per field for each of the three pasture treatments based on forage species. There were four replicate fields of heifers for each pasture treatment as presented in Table 1. Cattle were managed and cared for at the Ontario Beef Research Centre (OBRC) in Elora, ON. Heifers were grazed using strip grazing with no back fence and were moved every day by station staff. The area for grazing was determined by an experienced individual from the OBRC staff who used visual information on the extent of grazing in the previous strip for determination of the subsequent day's allocation of pasture area to be grazed. The pasture evaluator assessed the previously grazed strip for under or overgrazing to determine whether to allow more or less area to graze for the next day. Strips were allocated so animals would have enough forage for the day, but efficiently use available biomass, such that there was limited to no biomass remaining. Heifers always had ad libitum access to Alfasure (Rafter 8, Calgary, AB) treated water at 50ml of Alfasure in 100L of water for 4 hiefers and free-choice mineral.

Grazing for the 2020 season started on October 30th after a killing frost and finished on November 13th. Groups of heifers were removed as they reached the end of the allotted grazing area for each field. The 2021 grazing season commenced on October 19th after a killing frost, and concluded on December 9th with the removal of the final field of heifers. Heifers were double weighed, and body condition scored on entry and removal from pastures. Methodology for body condition scoring was conducted as described in section 3.4. The heifers were also weighed bi-weekly to track their body weights across the season. Average daily gain was calculated in 2020 using the difference between finishing and start weights over the number of pasture days due to most animals only having 3 body weight measurements throughout the season. In 2021, cattle were on pasture significantly longer than in 2020; to capture the fluctuation in body weights, a linear regression of weight and days was used to determine the ADG as the slope of the regression, as described in section 3.4. Dry matter intake was calculated using equations 5 & 6 in section 3.4.

5.3 Statistical Analysis

The study was arranged as a randomized complete block design with four replicates of the three stockpiled pasture treatments. Heifer performance was assessed via statistical analysis of body weight, ADG, and BCS data. Individual animal data were averaged for individuals within a field. Forage growth and progress were assessed via statistical analysis of overall yield, nutrient composition, botanical composition, and time on pasture data. Data were statistically analyzed using SAS OnDemand for Academics, SAS Studio edition (SAS studio, SAS Institute Inc., Cary, NC, USA). The Proc Glimmix procedure of SAS was used to analyze data for fixed treatment effects, and the Tukey-Kramer post hoc test for was used for separation of means for forage pasture species and the forage pasture species by year interaction. A P-value ≤ 0.05 was considered significant, while a trend was noted when $P \leq 0.10$.

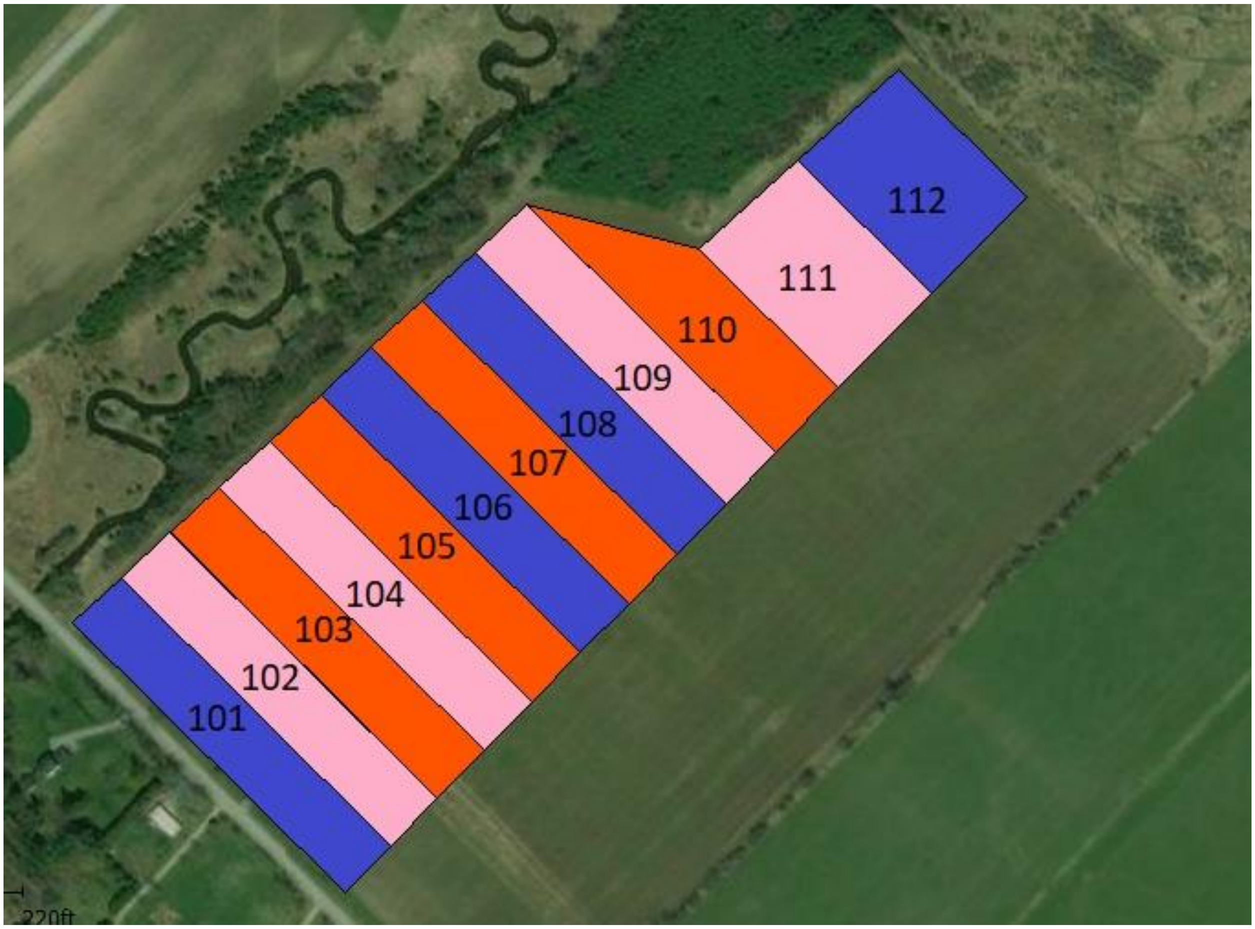

Figure 2. Pasture Field Layout for Fields Used for Stockpile Grazing in the Fall

6.0 Results and Discussion Extended Grazing

6.1 Climate Data for the Grazing Season

In Elora, Ontario, the critical period for plant dormancy is mid-October based on OMAFRA guidelines for the critical period for Alfalfa harvest **(Ontario.ca).** Grazing commenced after the critical period. In 2020, cattle grazed in November with an average temperature of 8.6°C and total precipitation of 18.3 mm. The grazing season in 2021 was during October, November and December, which had a mean temperature (°C) of 12.1, 1.9, and -0.6, respectively. Total precipitation (mm) was 20.9, 5.6, and 20.5 for October, November, and December, 2021 respectively. Average maximum temperature °C, Average minimum temperature °C, average mean temperature °C and average precipitation (mm) for each month of grazing are listed below in Table 16 for 2020 and 2021 based on meteorological data from climate.weather.gc.ca.

6.2 Forage Biomass and Time on Pasture for Stockpiled Pastures

Forage biomass ha^{-1} at the start of fall grazing was greater (*P* = 0.001) in 2021 (2760 kg DM ha^{-1}) versus 2020 (1777 DM kg DM ha^{-}1; Table 17). This is most likely due to year differences in forage harvesting prior to allowing the pastures to rest before the start of fall stockpile grazing. In 2020, forage was harvested twice for the production of conserved forage, once in June and then again in late July**.** While in 2021, the forage was only harvested in late June allowing a much longer time for 2021 forage to accumulate before the beginning of fall grazing and greater year differences in the amount of forage biomass prior to grazing. The year differences in forage harvesting were likely due to the amounts of rainfall during the summer (Table 16). In 2021, the amount of rainfall was greater in June and July than in 2020 with rainfall much lower in August. Overall precipitation was high in July, 2021, but the rain only fell over a few days in the month. In late July, it was dry, and grass and trefoil treatments were not progressing enough that they could handle another cut and recover to be stockpiled for fall grazing. Alfalfa fields could likely handle two cuts prior to stockpiling but it was important to keep cutting consistent for all treatments. So alfalfa fields were not cut as it was a concern that grass and trefoil fields would not re-grow enough from a second cut to be grazed in the fall. All pasture treatments were cut twice prior to stockpiling for fall grazing in 2020, which explains yield differences between years. Rainfall was also low after the second cut in 2020, which further accentuated yield differences, as forage did not recover from the second cut as planned.

There were no significant differences ($P = 0.19$) for kg forage biomass ha^{-1} amongst forage species treatments (Table 17). Cassida et al. (2000) demonstrated that dry matter yield for both alfalfa and birdsfoot trefoil declines with a harvest, resulting in less dry matter yield for each subsequent cutting. This may partially explain lower biomass yields for the 2020 grazing year compared to the 2021 season, which received two and one cuttings respectively prior to the grazing season. Kunelius and. Narasimhalu (1983) found that trefoil was the least productive legume for biomass production in a monoculture or stand with Italian Ryegrass and Westerwolds Ryegrass. However, this is not supported in the present study where no differences in forage biomass between alfalfa and trefoil treatments were observed. Belanger et al. (2017) found that mixtures with grass and trefoil overall produced more dry matter yield than alfalfa or white clover mixes, producing on average 5760 kg ha^{-1}, compared to 5450 kg ha^{-1} and 4860 kg ha^{-1}, respectively. Cassida et al. (2000) reported higher growth values for trefoil and red clover than alfalfa for both cuttings and in 1993, they reported higher growth in trefoil treatments than alfalfa or red clover. While there were no forage species differences in forage biomass production in the present study, there were numerical differences in forage biomass production with alfalfa having the numerically greatest forage biomass production at 2673 DM kg ha^{-1} with trefoil intermediate (2528 DM kg ha^{-1}) and grass lowest (2046 DM kg ha^{-1}).

Gierus et al. (2012) evaluated different legume-perennial ryegrass mixes including white clover, trefoil, grazing alfalfa, hay type alfalfa, caucasian clover, and red clover for yield, net energy of lactation, and CP for the first year of cutting in which the forage was cut 3 or 5 times in a season. In that study, birdsfoot trefoil was affected by cutting frequency, dropping in DM yield by 38% with an extra two cuttings, versus cutting the trefoil only three times. The hay-type alfalfa in the Gierus et al. (2012) study had 35% lower dry matter yields with cutting five times versus 3, but the grazing-type alfalfa maintained yields, with greater cutting frequency only reducing yield by 7% with 5 cuttings compared to 3. Alfalfa cultivars selected for grazing were used in the present study which may be responsible for the numerically greater forage biomass ha^{-1} observed between alfalfa and trefoil (Table 18). As previously stated, there were no significant forage species differences in forage biomass production. However, there were forage species and year differences in time on pasture ($P < 0.0001$; Table 17), along with a forage species by year interaction for time on pasture ($P < 0.0001$; Tables

17 and 18). This interaction was due to time on pasture being lower for trefoil versus alfalfa fields in 2020 ($P \leq 0.05$; Table 19), while time on pasture was greater ($P \leq 0.05$; Table 18) for trefoil versus alfalfa and grass pastures in 2021. The lower time on pasture for trefoil fields was due to numerically lower biomass production in 2020 versus 2021 fields. Time on pasture was lowest for grass vs. legume fields ($P \leq 0.05$; Table 17) and for 2020 vs 2021 ($P < 0.0001$; Table 17). These yearly differences in time on pasture are most likely due to the previously mentioned differences in forage biomass production due to number of cuts in the summer before forage was allowed to accumulate in fields for stockpile grazing.

6.3 Botanical Composition of Stockpiled Pastures

Botanical composition of stockpiled pastures (percent legumes, grasses, weeds, dead material) are presented in Table 19. While there were forage species and year differences in the percentages of legumes and grasses in the stockpiled pastures ($P \leq 0.01$; Table 19), forage species by year interactions were also present ($P < 0.0001$; Tables 19 and 20). Many of the botanical composition differences in the present study were due to year differences in the amounts of legumes. The percentages of legumes, grasses, and weeds in the stand were greater ($P \leq 0.04$; Table 19) in 2020 vs. 2021. Prigge et al. (1999) reported higher legume, grass and weed concentrations at the end of the grazing season within fields that were grazed in the spring, then cut mid-summer for hay and later used for fall grazing. In their study, Prigge et al. (1999) used orchard grass and timothy treatments with overseeded red clover, which may respond differently to cutting than with cutting a stand containing at least 40% legumes, as seen in the present study. The lower amounts of legumes and grasses in 2021 vs. 2020 pastures are most likely due to much greater amounts of dead material ($P < 0.0001$; Table 19) in 2021 pastures. Since the fields were only harvested once in the summer in 2021 vs. 2 harvests in 2020, more standing forage was able to mature and die in 2021, due to limited forage removal to stimulate forage production. There were no forage species treatment differences in the amounts of dead material ($P \geq 0.31$; Table 19).

Weeds were also greater in 2020 (1.5%) as compared to for 2021 (0.7%). On average, the forage was shorter in 2020 with lower forage biomass production due to cutting the standing forage twice during summer before fall grazing, which may have allowed more opportunity for the growth of weeds throughout the forage stand (Mølgaard, 1977; Ludvíková et al., 2015). A shorter forage stand allows more light through to various forage species in the stand and allows germination at the base of the sward; taller forages in the second grazing year (2021) did not allow as much light to penetrate the stand, so it is likely fewer weeds were able to establish. Supek et al. (2017) observed increased percentages of dandelion (*Taraxacum officinale* agg.) in forages managed under any harvest technique. Although this conclusion was generally supported for the first ten years after establishment, there was a longer-term trend toward more dandelion plants in fields cut and grazed (Supek et al., 2017). In the present study, there were no statistical differences in weed content between treatments ($P \geq 0.10$) and no interaction effects of treatment and year ($P \geq 0.52$; Table 19).

The forage species by year interactions ($P < 0.0001$; Table 20) for percentage of legumes and grasses in the fields were due to a much greater percentage decrease in legumes and percentage increase in grasses for alfalfa fields between 2020 and 2021, versus a percentage decrease in legumes with no change in the percentage grasses for trefoil fields over the 2 years (Table 20). In addition, there was no change in the legume fraction of grass fields (3.1 vs 2.2%) while there was a major decrease in the percentage of grasses in grass fields (86.9 vs. 60.1%) between 2020 and 2021. Bélanger et al. (2018) found that grazed alfalfa and trefoil had a lower proportion of legumes in the third and fourth year of grazing; in the same study, this result was not found for fields seeded with grass species which persisted well after seeding. Bélanger et al. (2018) speculated that increased selective grazing for the alfalfa and trefoil led to a lack of persistence for the legume stands in the following years. This selective grazing would be less of an issue in the current study due to the use of very mature forages and strip grazing to limit selectivity. Hitz and Russell (1998) evaluated tall fescue/alfalfa fields in which the percentage of legumes in the stand in October were 47.4, 10.7, and 30.5% in years 1, 2 and 3, respectively. These researchers attributed lower alfalfa persistence after the first year of study to a possible fungal infection due to higher precipitation in the fall of the first year and summer of the second (Hitz and Russell, 1998). In the present study, the percentage of legumes in alfalfa fields was not significantly different from the percentage of legumes in trefoil or grass fields in 2021 (Table 20). However, the percentage of legumes in trefoil fields did differ significantly from the percentage of legumes in grass fields in the same year ($P \leq 0.05$, Table 20). This contrasts to the percentages of legumes differing in each forage species treatment in 2020.

The percentage of grasses in legume fields (alfalfa vs. trefoil) did not differ in 2020 while as expected, grass fields contained a greater ($P \leq 0.05$) percentage of grasses than legume fields. This was not the case in 2021 as the percentage of grasses was similar ($P > 0.05$; Table 20) between alfalfa and grass fields. Barnett and Polser (1983) concluded that legumes seeded into a grass stand would result in an increased overall yield over a pure grass stand, but intermediate to the pure grass stand fertilized with 90 kg N ha^{-1}, due to the additional legume fraction which could explain why the alfalfa fields had a similar percentage of grass in comparison to grass fields in 2021. Similarity, this was not found for trefoil, but in the same study, Barnett and Polser (1983) concluded that the grasses in a mixed legume stand produced 0.78, 1.49, 1.17 and 0.89 times more DM yields than an unfertilized pure grass stand. Legumes in a stand actually enhance the yield of grasses within a pasture, resulting in an increased overall yield. This is consistent with Kunelius and Narasimhalu (1983) who found that legume-ryegrass stands were intermediate to pure grass stands and grass stands that had been fertilized. Shaeffer et al. (1984) also found similar findings where trefoil in a blend for both grazing years never outperformed trefoil in a monoculture; the trefoil content of the stand was negatively correlated with grass content. In both years of the current study, the grass content of trefoil fields remained constant. There was a much greater ($P <$ 0.0001; Table 19) dead fraction in 2021 (32.9% of total forage sampled) vs 6.7% in 2020, likely due to forages not being cut twice in 2021 before grazing. Thus, stockpiled forage fields in 2021 were very long with large amounts of forage observed lying on the ground, which likely contributed to this increase in dead fraction among samples.

6.4 Forage Analysis of Stockpiled Pastures

There were year differences (*P* ≤ 0.01: Table 21) for all major nutrients measured with NEm, NEp, TDN, CP, Ca, and P values decreasing from 2020 to 2021, while ADF and NDF values increased from 2020 to 2021. Forage quality will increase with cutting of forages. Gierus et al. (2012) demonstrated that higher CP in legume stands resulted from using a five-cut system versus cutting only three times; CP content in the 5 cut system was overall 27% higher compared to a three-cut system. Forages generally decline in quality with increasing DM yield (Bélanger et al., 2017; Bélanger et al., 2001) which appears to be the case in the present study based on year differences in forage biomass ha^{-1} (Table 17) and available energy (NEm, NEp, or TDN) and crude protein contents of stockpiled pasture *(P* < 0.0001; Table 21). This demonstrates that longer, more mature forage produces higher yields, but results in lower nutritional value due to growth of cell wall components with the maturation of forages. There was a forage species by year interaction (*P* ≤ 0.04; Tables 21 and 22) for $NE_{m.}$ likely due to a smaller decrease in energy content between 2020 and 2021 for grass fields versus legume fields. Gierus et al. (2012) showed that NE_l was increased with a 5-cut versus a 3-cut system, regardless of legume type. The inverse relationship of yield to digestibility and energy measures for forages is well known. As yield increases, plants are generally more mature and increase in NDF content, and thus have lower energy and digestibility measures (Belanger et al., 2017; Badgery et al., 2017a; Sleugh et al., 2000, Hoekstra and Schulte, 2008). Sturludóttir et al. (2013) found that adding legumes to grass fields increased DM yield without compromising quality; mixtures with red clover had higher protein in the first year, with no differences in CP content in the following years. However, monocultures of white clover consistently had 18 to 20% higher protein than mixtures in every year of the study. There was a numerical increase in forage biomass ha^{-1} when legumes were added to grasses in the present study (Table 17).

This increase in forage quality also resulted in lower ($P \leq 0.05$) NDF content for legumes when comparing alfalfa versus grass pastures (Table 21). Gierus et al. (2012) found that a five- cut system had lower NDF content, which is consistent with our findings. In the present study, NDF and ADF values were lower ($P < 0.0001$) in 2020 vs. 2021 for stockpiled forage, when 2020 forage was mechanically harvested twice before grazing versus a single harvest for 2021 stockpiled forage (Table 21). While NDF content was similar in alfalfa and trefoil pastures (Table 21), alfalfa contained less NDF than grass pasture fields with no differences in ADF content across forage pasture species (Table 21). In Bélanger et al. (2017), alfalfa and trefoil contained average ADF and aNDF (neutral detergent fibre with removal of starches using amylase) with above average TDN content while maintaining high DM yields. Trefoil produced an average yield of 5760 kg ha^{-1} for all three locations**,** Normndin, QC, Lévis, QC and Nappan, NS, while maintaining consistent ADF values below the study average (30.6%), averaging 30.3% ADF; aNDF followed a similar trend at 46.4% which was the same average aNDF value as alfalfa. The TDN content for trefoil in Bélanger et al. (2017) was also consistently above the average of 61.5 %, at 62.0%. Alfalfa in Bélanger et al. (2017) also followed similar trends with alfalfa field with an average ADF of 30.5%, aNDF of 46.4% and TDN of 61.3% which was slightly below the average of 61.5%**.** This is also consistent with the findings of Sleugh et al. (2000), who concluded that alfalfa mixes had lower NDF concentrations than trefoil mixes (43.7 vs 47.1% NDF). In contrast, Hoffman et al. (1993) found that trefoil had a lower NDF concentration than alfalfa at every stage of maturity, late vegetative: 26.5 versus 31.0%, late bloom: 34.1 versus 42.6%, and mid-bloom: 44.4 versus 47.3% for trefoil and alfalfa, respectively when evaluating the legumes in an *in situ* degradability trial. However, the Hoffman et al. (1993) study evaluated pure legumes, unlike the present study where there were legume/grass mixtures. Hoffman et al. (1993) also noted the difference in growth characteristics between alfalfa and birdsfoot trefoil**,** that show a trend toward lower increases in crude fibre, with increasing maturity for trefoil as compared to alfalfa.

While alfalfa fields contained greater ($P \leq 0.05$; Table 21) amounts of crude protein than trefoil and grass fields, there was a forage species by year interaction ($P \leq 0.02$; Tables 21 and 22) for crude protein content. This interaction was due to a much greater decrease in crude protein content between 2020 and 2021 for alfalfa (41.1%) versus trefoil and grass fields (36.8 and 34.0% respectively). Both trefoil and grass fields had similar crude protein levels to each other in 2020 and 2021. Hitz and Russel (1998) observed 5.5% greater CP on an organic matter basis (to correct for soil contamination) in stockpiled tall fescue/alfalfa treatment than stockpiled smooth bromegrass/red clover mix in the first year of grazing. Sleugh et al. (2000) also found higher CP content in alfalfa mixes than in trefoil mixes.

There were major forage species differences ($P < 0.0001$; Table 21) in calcium (Ca) content of stockpiled pastures with alfalfa having the greatest ($P \leq 0.05$) amount of

Ca (1.11% Ca), with trefoil intermediate (0.78% Ca) and grasses lowest in Ca content (0.55% Ca). Stockpiled pastures grazed in 2020 contained more ($P < 0.0001$) Ca than 2021 pastures most likely due to the higher quality, increased leaf content in less mature plants and lower NDF content for 2020 vs. 2021 stockpiled pastures. There was a forage species by year interaction ($P < 0.0001$; Tables 21 and 22) for Ca content due to a massive decrease in alfalfa calcium content between 2020 and 2021 (1.4 vs 0.8% respectively) as compared to the decrease in Ca content for trefoil (0.91 vs 0.66% Ca) with no change in grass Ca content (0.55% Ca) between the 2 years. Pasture phosphorus (P) content did not differ between forage species ($P \geq 0.81$; Table 21) while 2020 pastures contained more ($P \leq 0.01$; Table 21) P than 2021 pastures. The greater P content in 2020 vs 2021 pastures (0.32 and 0.29% P respectively) is most liked due to the higher quality and lower NDF content for 2020 vs. 2021 stockpiled pastures. This is also likely due to a higher proportion of legumes being present in 2020 forages vs 2021. Collins (1983) reported a decrease in phosphorus content of 28 and 33% in alfalfa and trefoil respectively, in late autumn compared to early autumn due to changes in forage quality. This could partially explain increased P in 2020 pastures for the present study, as heifers grazed for a considerably shorter period. Collins (1983) and Biligetu et al. (2014) found the opposite to be true for Ca content, which increased in both alfalfa and trefoil with progression into late autumn, which conflicts with current results. However, leaf mass may play a factor in the higher Ca in 2020 forage. Gross and Jung (1981) reported Ca in alfalfa exceeding 2.0% in autumn, which was not observed in this study, with higher Ca:P ratios in alfalfa than grasses.

6.5 Growth Performance and Changes in Body Condition for Heifers on Pasture

While there were no forage species or year effects for initial body weight ($P \geq 0.19$; Table 17), body condition score (BCS) was greater for heifers starting on alfalfa pastures ($P \leq 0.05$; Table 17). Forage species by year interactions ($P < 0.02$) were present for both initial and final BCS (Table 18). In 2020, there were no significant treatment differences ($P > 0.05$, Table 18) differences between initial BCS or final BCS, other than a numerically smaller final BCS for heifers on grass in 2020. In 2021, alfalfa had a higher ($P \leq 0.05$) initial and final BCS compared to trefoil. The lack of forage species or year effects for initial body weight is likely due to how heifers were allocated to experimental treatments, as in both years fields had similar initial body weights across forage species. The lack of year effects for initial body weight is due to using common genetics and management across years at the Ontario Beef Research Centre. The forage species and year differences ($P \leq 0.05$; Table 17) in initial BCS are of questionable biological significance when BCS is assessed on a 5-point scale. The intent for the study was to allocate heifers to experimental treatments such that initial weight and BCS would be similar across forage species. While the 2020 BCS score of 3.7 exceeds ($P \leq 0.02$; Table 17) the 2021 BCS score of 3.5, the numerically similar initial BCS values are again due to using common genetics and management across years at the Ontario Beef Research Centre.

While there were no forage species or year differences ($P \geq 0.11$; Table 17) in body weight change or final weight, there were year differences ($P \leq 0.02$) in average daily gain (ADG) (1.24 kg/d in 2020 vs. 0.72 kg/d in 2021) with no forage species differences (*P* ≥ 0.99) in ADG. Between the 2 years, there were crucial differences in forage biomass ha^{-1} and forage quality which contributed to the year differences in ADG. Stockpile forage quality was greater in 2020 vs. 2021, with greater amounts of available energy (NE, TDN), crude protein, Ca, and P, and lower NDF and ADF in 2020 vs. 2021 pastures (Table 22). This enabled 2020 heifers to gain similar amounts of weight as 2021 heifers, but on almost 21 fewer days on pasture. The amounts of available energy and protein in forages are major factors impacting cattle growth on pastures. Lyons et al. (2016) found that heifers receiving additional protein through a mineral lick tub had higher ADG and serum urea nitrogen as a result of higher CP content and concluded that protein as a limiting factor in the growth of heifers grazing stockpiled tall fescue. Poore et al. (2006) reported higher ADG, BCS and SUN in the whole cottonseed supplemented group for cattle grazing stockpiled tall fescue. Stockpiled pastures in the present study for 2020 not only had greater amounts of available energy and CP content than 2021 pastures (Table 21), but a higher proportion of legumes in the stand (Table 19), which may explain year differences for ADG.

There were forage species by year interactions (*P* ≤ 0.02; Tables 17 and 18) for both initial and final BCS. Initial BCS for alfalfa, trefoil and grass in 2020 were 3.6, 3.6, and 3.5, and 2021 values were 3.9, 3.6, and 3.7, respectively. Final BCS for alfalfa, trefoil and grass was 3.5, 3.6, and 3.5 for 2020 and 3.9, 3.6 and 3.7 for 2021, respectively. These interactions are of questionable biological significance as the values are numerically similar; in addition, there were no forage species or year differences (*P*

≥ 0.76; Table 17) in change in BCS across the 2 years of the study. In addition, the final BCS score for each respective forage species in a given year are identical to the initial BCS score for each respective forage species in a given year (Table 17). This is likely a factor of limited time on pasture as animals in 2021 were on pasture for a maximum of 46 days and in 2020 were only on pasture a maximum of 21 days, it is very unlikely that animals would lose/gain enough weight on pasture to be apparent by body condition in that short of a period. Although Lyons et al. (2016) and Poore et al. (2006) both concluded that protein supplementation increased BCS and ADG in heifers, Straunch et al. (2001) found no differences in BCS, ADG or calf parameters following fall grazing on stockpiled tall fescue when supplemental protein to increase UIP was provided.

There were no pasture treatment differences ($P \geq 0.43$, Table 17) for estimated dry matter intake (DMI; kg/hd/d or % BW basis) over the entire study; however, there were year differences ($P < 0.0001$, Table 17). Estimated DMI was higher in 2020 at 10.48 kg hd^{-1} day^{-1} (1.98 %BW) than the DMI value for 2021 at 9.59 kg hd^{-1} day^{-1} (1.80% BW). This correlated directly with higher ADG values in 2020 as increased DMI is directly related to increased ADG. The year differences in DMI and ADG are most likely attributed to the higher quality of stockpiled pasture in 2020 vs. 2021 with greater ($P < 0.001$; Table 21) amounts of energy, protein, Ca, and P with lower ($P \leq 0.01$; Table 21) amounts of NDF and ADF and dead material ($P < 0.001$; Table 19). These year differences in DMI and ADG translate into feed to gain values of 9.19 and 13.32 kg, respectively for heifers in 2020 and 2021. These year differences in feed efficiency are likely also related to longer days on pasture for the 2021 season, meaning heifers were consuming lower quality feed for a longer period of time.

There was a pasture treatment by year interaction ($P \leq 0.008$; Table 18) for estimated DMI (kg/hd/d or % BW basis). While DMI (kg/hd/d or % BW basis) decreased ($P \leq 0.05$) from 2020 to 2021 for alfalfa and trefoil pastures, there were no year differences ($P \geq 0.05$) in DMI intake for grass pastures.

6.6 Conclusions

Overall, forage biomass was greater in the 2021 grazing season, due to one less harvest during summer prior to accumulation for stockpiling, with no forage species differences for biomass ha^{-1} between 2020 and 2021. There was an interaction between year and forage species type for time on pasture, with trefoil pastures holding animals for a shorter duration in 2020, and the longest in 2021. Grass and alfalfa fields held animals for less time than trefoil in 2021. Legumes, grass and weed percentages within the pasture stand were also greater in 2020, with lower amounts of dead material. There was a forage species by year interaction for the percentage legumes in the pastures, with a decrease in % legumes in alfalfa and trefoil fields and increase in grasses in alfalfa fields from 2020 to 2021. Grass fields however saw a decrease in percentage of grass from 2020 to 2021. Overall forage quality was better in 2020 pastures with higher energy measures, minerals, and crude protein and lower fiber components, likely due to advanced maturity of forages in 2021 that had a longer accumulation period compared to 2020. Average daily gain and dry matter intake estimates followed similar trends, both being higher in 2020 when higher quality forage was offered over a shorter amount of time. This study provides promising insight into possible advantages of legume stands in stockpile grazing. Legumes provide more protein, as seen with increased protein in alfalfa stands for this study and numerically higher CP values for trefoil compared to grass fields. Treatment effects on animal performance from this increase in protein were not demonstrated in this trial, likely because of a short grazing season. However, it is likely a longer trial may show effects of increased protein on animal parameters. While there were few statistical differences in animal performance across the forage species studied in this stockpiled pasture system, further investigation should be done to better understand the uses of legumes in stockpiled grazing systems. Longer trials on an increased land base would likely demonstrate more clear results on heifer condition and weight. More research is needed in the Ontario climate to better understand the effectiveness of legumes in an extended grazing system on heifer productivity.

Table 16. Year differences in climate data[z] for stockpile grazing of heifers

Month in 2020	**Average maximum temp °C**	**Average minimum temperature °C**	**Mean temperature °C**	**Total precipitation (mm)**
November	9.1	0.2	4.6	18.3
Month in 2021	Average maximum temp °C	Average minimum temperature °C	Mean temperature °C	Total precipitation (mm)
October	16.1	8.1	12.1	20.9
November	6.1	-2.3	1.9	5.6
December	2.8	-4.1	-0.6	20.5

[z] Climate data sourced from climate.weather.gc.ca

Table 17. Effects of forage species on time on pasture, changes in body weight and bcs, and adg for pregnant heifers managed using stockpile grazing

	Forage Species in Stockpiled Pastures^z						Year				P-value		
Item	**Alfalfa**	**SE**	**Trefoil**	**SE**	**Grass**	**SE**	**2020**	**SE**	**2021**	**SE**	**Species**	**Year**	**Species by year interaction**
Forage Biomass DM kg ha^{-1}	2673	246.4	2528	244.5	2046	258.9	1777	235.1	2760	176.3	0.19	0.001	0.56
Time on pasture, d	31^a	0.4	32^a	0.4	27^b	0.4	19	0.3	41	0.3	<0.0001	<0.0001	<0.0001
Initial weight, kg	512.5	7.90	522.5	7.90	532.9	7.09	526.4	11.18	518.8	11.18	0.20	0.41	0.07
Final weight, kg	539.0	6.98	545.6	6.98	556.9	6.98	549.2	5.70	543.2	5.70	0.11	0.46	0.23
Weight change, kg	24.0	6.14	23.6	6.14	23.1	6.14	22.8	3.54	24.3	3.54	0.99	0.77	0.23
ADG, kg/d	0.95	0.146	0.92	0.146	0.93	0.146	1.14	0.12	0.72	0.12	0.99	0.01	0.10
Initial BCS	3.8	0.05	3.6	0.05	3.6	0.05	3.7	0.04	3.5	0.04	0.05	0.01	0.02
Final BCS	3.7^a	0.04	3.6^{ab}	0.04	3.6^b	0.04	3.7	0.01	3.5	0.01	0.04	0.001	0.02
Change in BCS	-0.02	0.031	-0.02	0.031	-0.04	0.031	-0.05	0.198	-0.0002	0.198	0.83	0.20	0.83
DMI kg/hd/day^y	9.92	0.141	10.00	0.141	10.18	0.141	10.48^a	0.124	9.59^b	0.107	0.43	<0.0001	0.007
DMI (%BW)	1.90	0.028	1.88	0.028	1.87	0.028	1.9	1.98	0.025	1.80	0.81	<0.0001	<0.0001

^{z}Forage Species in Stockpiled Pastures: Alfalfa = fields seeded to target 40% alfalfa in the grass sward; Trefoil = fields seeded to target 40% birdsfoot trefoil in the grass sward; Grass = fields seeded with a diverse mixture of grasses and no legumes.

^{y}DMI was calculated based on the equation 6 which included ADG and BW.

$^{a\text{-}b}$For forage species, Least square means within a row with different superscripts differ ($P \leq 0.05$)

Table 18. Forage species by year interactions on bcs and time on pasture for pregnant heifers managed using stockpile grazing

	Forage Species in Stockpiled Pastures^{z}							P-value
Item	**Year**	**Alfalfa**	**SE**	**Trefoil**	**SE**	**Grass**	**SE**	**Species by year interaction**
Time on pasture, d	2020	20.8^{d}	0.55	17.5^{e}	0.55	19.5^{ed}	0.55	<0.0001
	2021	41.3^{b}	0.55	46.1^{a}	0.55	35.0^{c}	0.55	
Initial BCS	2020	3.6^{b}	0.07	3.6^{b}	0.07	3.5^{b}	0.07	0.02
	2021	3.9^{a}	0.07	3.6^{b}	0.07	3.7^{ab}	0.07	
Final BCS	2020	3.5^{b}	0.06	3.6^{b}	0.06	3.5^{a}	0.06	0.02
	2021	3.9^{a}	0.06	3.6^{b}	0.06	3.7^{ab}	0.06	
DMI kg/hd/day^{y}	2020	10.7^{a}	<0.0001	10.4^{a}	<0.0001	10.3^{ab}	<0.0001	0.007
	2021	9.2^{c}	<0.0001	9.6^{bc}	<0.0001	10.0^{ab}	<0.0001	
DMI (%BW)	2020	2.1^{a}	0.04	2.0^{ab}	0.04	1.9^{bc}	0.04	<0.0001
	2021	1.7^{d}	0.04	1.8^{cd}	0.04	1.9^{bc}	0.04	

^{z} Forage Species in Stockpiled Pastures: Alfalfa = fields seeded to target 40% alfalfa in the grass sward; Trefoil = fields seeded to target 40% birdsfoot trefoil in the grass sward; Grass = fields seeded with a diverse mixture of grasses and no legumes.

^{y}DMI was calculated based on the equation 6 which included ADG and BW in calculations.

$^{a-e}$For a given trait, Least square means with different superscripts differ ($P \leq 0.05$).

Table 19. Effects of forage species on botanical composition of pastures for pregnant heifers managed using stockpile grazing

	Forage Species in Stockpiled Pastures[z]						**Year**				**P-value**		
Item	**Alfalfa**	**SE**	**Trefoil**	**SE**	**Grass**	**SE**	**2020**	**SE**	**2021**	**SE**	**Species**	**Year**	**Species by year interaction**
Legume %	30.7^{a}	1.96	26.9^{a}	2.00	2.6^{b}	2.02	29.3	1.84	10.9	1.38	<0.0001	<0.0001	<0.0001
Grass %	48.5^{b}	1.88	46.8^{b}	1.92	73.5^{a}	1.94	59.4	1.77	53.1	1.33	<0.0001	0.005	<0.0001
Weeds %	1.3	0.31	0.5	0.32	1.3	0.32	1.5	0.29	0.7	0.22	0.11	0.03	0.53
Dead %	19.5	2.01	21.4	2.05	18.8	2.07	6.7	1.89	32.9	1.42	0.31	<0.0001	0.32

[z] Forage Species in Stockpiled Pastures: Alfalfa = fields seeded to target 40% alfalfa in the grass sward; Trefoil = fields seeded to target 40% birdsfoot trefoil in the grass sward; Grass = fields seeded with a diverse mixture of grasses and no legumes.

[a-b] For forage species, Least square means within a row with different superscripts differ ($P \leq 0.05$).

Table 20. Forage species by year interactions for legume, grass and weed content of forages used in stockpile grazing

		Forage Species in Stockpiled Pastures[z]						
	Year	**Alfalfa**	**SE**	**Trefoil**	**SE**	**Grass**	**SE**	**P-value**
Legume %	2020	49.5^{a}	3.14	35.2^{b}	3.29	3.1^{d}	3.14	<0.0001
	2021	11.9^{cd}	2.36	18.7^{c}	2.27	2.2^{d}	2.55	
Grass %	2020	42.7^{c}	3.02	48.7^{bc}	3.16	86.9^{a}	3.02	<0.0001
	2021	54.4^{b}	2.26	44.8^{c}	2.18	60.1^{b}	2.45	

[z] Forage Species in Stockpiled Pastures: Alfalfa = fields seeded to target 40% alfalfa in the grass sward; Trefoil = fields seeded to target 40% birdsfoot trefoil in the grass sward; Grass = fields seeded with a diverse mixture of grasses and no legumes.

[a-d] For a given trait, Least square means with different superscripts differ ($P \leq 0.05$).

Table 21. Effects of forage species on nutrient composition of pastures for pregnant heifers managed using stockpile grazing

	Forage Species in Stockpiled Pastures^z						Year				P-value		
Item	**Alfalfa**	**SE**	**Trefoil**	**SE**	**Grass**	**SE**	**2020**	**SE**	**2021**	**SE**	**Species**	**Year**	**Species by year interaction**
Net energy maintenance (NE_m), Mcal/kg	1.57	0.014	1.57	0.143	1.58	0.015	1.76	0.014	1.39	0.009	0.91	<0.0001	0.04
Net energy production, (NE_p), Mcal/kg	0.85	0.017	0.86	0.171	0.86	0.017	1.04	0.017	0.67	0.010	0.89	<0.0001	0.12
TDN, %	63.67	0.513	64.12	0.507	64.36	0.517	70.26	0.505	57.85	0.308	0.62	<0.0001	0.13
Crude protein, %	16.7^a	0.45	13.3^b	0.44	11.9^b	0.45	17.2	0.44	10.7	0.27	<0.0001	<0.0001	0.02
NDF, %	45.4^b	1.46	48.9^{ab}	1.44	50.9^a	1.47	38.9	1.43	57.8	0.88	0.03	<0.0001	0.12
ADF, %	31.2	0.86	31.8	0.85	31.5	0.87	23.6	0.86	39.5	0.90	0.41	<0.0001	0.32
Ca, %	1.11^a	0.029	0.78^b	0.028	0.55^c	0.029	0.96	0.028	0.67	0.017	<0.0001	<0.0001	<0.0001
P, %	0.30	0.010	0.31	0.010	0.30	0.010	0.32	0.009	0.29	0.006	0.82	0.007	0.27

^{z}Forage Species in Stockpiled Pastures: Alfalfa = fields seeded to target 40% alfalfa in the grass sward; Trefoil = fields seeded to target 40% birdsfoot trefoil in the grass sward; Grass = fields seeded with a diverse mixture of grasses and no legumes.

$^{a\text{-}c}$For forage species, Least square means within a row with different superscripts differ ($P \leq 0.05$).

Table 22. Forage species by year interactions on nutrient composition of pastures used to manage pregnant heifers with stockpile grazing

		Forage Species in Stockpiled Pastures[z]						
	Year	**Alfalfa**	**SE**	**Trefoil**	**SE**	**Grass**	**SE**	**P-Value**
Net energy maintenance (NE$_m$), Mcal/kg	2020	1.78^{a}	0.025	1.77^{a}	0.025	1.74^{a}	0.025	0.04
	2021	1.36^{b}	0.015	1.38^{b}	0.014	1.42^{b}	0.016	
Crude protein, %	2020	20.9^{a}	0.77	16.3^{b}	0.77	14.4^{bc}	0.77	0.02
	2021	12.3^{c}	0.47	10.3^{d}	0.45	9.5^{d}	0.48	
Ca, %	2020	1.43^{a}	0.049	0.91^{b}	0.049	0.55^{c}	0.049	<0.0001
	2021	0.79^{b}	0.030	0.66^{c}	0.029	0.55^{c}	0.031	

[z] Forage Species in Stockpiled Pastures: Alfalfa = fields seeded to target 40% alfalfa in the grass sward; Trefoil = fields seeded to target 40% birdsfoot trefoil in the grass sward; Grass = fields seeded with a diverse mixture of grasses and no legumes.

[a-c] For a given trait, Least square means with different superscripts differ ($P \leq 0.05$).

Table 23. Nutrient composition of pastures by year

	2020				2021		
	Forage Species in Stockpiled Pastures				Forage Species in Stockpiled Pastures		
Item	**Alfalfa**	**Trefoil**	**Grass**		**Alfalfa**	**Trefoil**	**Grass**
Net energy maintenance (NE_m), Mcal/kg	1.78	1.77	1.74		1.36	1.38	1.42
Net energy production, (NE_p), Mcal/kg	1.06	1.04	1.02		0.64	0.68	0.70
TDN, %	70.37	70.70	69.71		56.96	57.55	59.02
Crude protein, %	20.9	26.3	14.4		12.3	10.3	9.47
NDF, %	34.3	38.7	43.8		56.5	59.0	57.9
ADF, %	22.7	23.4	24.6		39.7	40.2	38.4
Ca, %	1.43	0.91	0.54		0.79	0.66	0.55
P, %	0.03	0.34	0.32		0.30	0.28	0.29

7.0 Conclusions and Implications

Pre-grazing biomass was greater in Cycle 1 for strip grazing vs. set stocking. This is primarily due to how quickly different grazing systems transverse the cycles within the season. Cattle on set stocked pastures were through cycle 1 very quickly before forage had begun rapid growth, whereas other grazing management treatments took longer to reach the second cycle. Cycle 2 biomass was similar across treatments with Cycle 2 having the highest pre-grazing sward heights. Cycles 1 and 2 also had higher post-grazing sward heights than Cycle 3. All these results are due to increases in forage growth during grazing for June. Which further demonstrates the already well understood fact that weather plays a major roll in any grazing system, regardless of management technique. Although weather impacted the grazing cycles, which is expected, total grazing days were greatest for rotational and strip grazing, compared to set stocked and continuous, which is in line with the initial hypothesis which predicted better forage utilization for the strip grazing treatment. Intensive grazing such as strip and rotational grazing may dampen weather impacts by providing more stable forage throughout the season.

Forage quality measures are easily influenced by forage progression throughout the season; young forages in the spring are generally less fibrous and more energy rich. An unexpected result was that CP was lowest in Cycle 2, due to increased biomass that could not be grazed fast enough and became mature. This led to increasing the number of cattle on a few treatments to decrease smothering of pastures and waste by cattle trampling long forages. This is also what lead coordinators of this research to decide to mow all treatments after grazing, so that later cycles would not be affected by overgrowth and selective grazing. This change may have impacted results for grazing management treatments, as intensive grazing is supposed to encourage younger re-growth that subsequently are better quality. By mowing all pastures this result may have been achieved to a greater extent by mowing instead of the actual treatment.

There were no differences in initial weight, final weight, weights change, ADG, initial and final BCS, initial backfat, initial and final rump fat, change in rump fat or cow DMI across the 4 grazing management techniques. Backfat thickness was greater in set stocked cows vs. strip grazing cows who mobilized fat from the back. This observation somewhat aligns with the initial hypothesis which stated that strip grazing would have ideal forage utilization but poorer animal performance. Although strip grazed cows mobilized backfat, there were no other data suggesting that performance was poor, and certainly not any performance indicators that would indicate poor performance on a practical, on farm level. Lack of treatment effect for many of the animal parameters can be partially attributed to the overcondition of heifers used in this trial, as discussed within the previous trail. Differences in DMI as a % of BW were apparent; DMI was lowest for continuously grazed cows, with DMI increasing for set stocking, rotational and strip grazing in ascending order. This is an expected result as generally more intensive grazing is thought to increase forage utilization, so DMI should realistically be higher in intensive grazing treatments. There were no grazing management treatment differences for any calf measure including initial weight, final weight, calf ADG and there were no differences in any cow or calf measures for weaning data.

Grazing management technique may not have provided the expected results in all aspects of the study, but it did demonstrate definite differences in forage utilization. Data for forage quality and animal performance was minimally supportive of hypothesized results due to lack of treatment differences which may have been exacerbated my management factors such as adding animals or additional mowing of pastures. There are some data supporting the use of intensive grazing methods though it was hypothesized that animal performance measures such as cow weight would be enhanced by less intensive methods of grazing such as set stocking or continuous grazing, but with lack of treatment differences this was not proven and should be further researched.

Overall, there were few differences between the legume and grass pastures studied using a stockpiled grazing system. One of the most notable differences was a higher crude protein concentration in the alfalfa fields. This result is not reflected in the initial hypothesis, where it was predicted that alfalfa would have lower protein content compared to other species due to leaf loss after the killing frost. Both legume pastures contained less NDF compared to the pure grass fields, which is unexpected considering leaf to stem mass in legumes, which would suggest that legumes may have a higher NDF content. Legume fields also supported grazing at least 4 more days on average than grass fields did. This result suggests that legumes held biomass consistently enough to maintain grazing for longer than grass fields, which contradicts the initial hypothesis. There were no notable differences amongst forage species for animal performance, signifying that legumes in a stockpiled grazing system did not hinder animal performance and performed on a comparable level to a grass pasture system for this application. Short duration of the grazing trial may have had an impact on animal performance measures, more research is needed to better understand impacts of legumes in a stockpiled grazing system under longer term grazing. This research did however demonstrate that legumes within a stockpiled grazing system could potentially have greater practical application on a farm level.

Legume fields however, lacked persistency in legume content as legume content in fields dropped drastically from 2020 to 2021, while grasses remained constant. While legumes may provide a potentially higher protein, lower fibre stand, it is notable that the need for overseeding of legumes may influence the decision of producers to use legumes for application in a stockpile grazing system.

Summer management of stockpiled pastures was also shown in this study. Fields in 2020 were cut twice prior to accumulation for fall grazing, where fields were only cut once prior to accumulation in 2021. Trefoil fields in 2020 underperformed, holding animals for less time on pasture than alfalfa fields; however due to the change in cutting during the summer months, trefoil held animals for longer than alfalfa in the subsequent year of grazing (2021). This result was contradictory to the hypothesized results, it was thought with decline in temperature legumes would decrease in biomass and potentially protein content with leaf loss. This hypothesized result is shown in a few sources, but none utilized stockpiled grazing of these forages to test the use of legumes in fall/winter grazing, so it is still relatively unresearched. More studies should be conducted to better understand how legumes function in a stockpiled grazing system in terms of quantity and quality. Forage stands in 2021 also had 26.2% higher dead material, which was likely a result of longer forages lodging due to increased height and tension on stems. As a result of less cutting, maturity was higher in forages for 2021, affecting forage quality. With more mature forage, decreased quality is expected; there was a decrease from 2020 to 2021 in NEm, Nep, TDN, CP, Ca and P content. The cutting of forage only once in 2021 resulted in greater biomass for stockpile grazing and a longer grazing season, but provided a lower quality of forage that resulted in lower ADG and DMI. For practical implications these are results to consider, as biomass for fall grazing will be higher with only one cut, however the producer will harvest less hay.

Overall, legumes in a stockpiled grazing system have benefits that grasses cannot provide, such as increased protein content. The use of trefoil, while uncommon in current pasture mixes, may have advantages as there is negligible bloat risk compared to alfalfa. Trefoil, however, as indicated by year differences in cutting, may only handle one cutting for hay in the summer season, where alfalfa can handle two cuts. While alfalfa fields contained more protein than trefoil in the present study, alfalfa lacks persistency from year to year. Heifer performance was not affected by the forage species used in the pastures (legumes vs. grasses). More research is warranted to better understand the effects of using legumes in a stockpiled system and cost/production benefits of cutting once or twice prior to stockpiling.

Although animal performance results may not be supportive of intensive grazing, there are some benefits to producers. Intensive grazing, although labour intensive, is a way to better utilize currently available pasture and thus possibly extend the grazing season longer than using traditional grazing methods such as continuous grazing. Extended grazing will also extend the grazing season, meaning producers can potentially graze from May through December. In these trials there were no supplemental feed added, however, in a practical scenario producers may utilize hay to keep animals on pasture during times of unfavorable weather resulting in longer time on pasture and potentially favorable animal performance results. Use of legumes in an extended grazing system may also limit need for supplemental feed to maintain animal condition in a longer grazing scenario. Overall, producers have many scenarios to consider when implementing grazing strategies labour, cost, animal performance, forage utilization, forage quality and quantity are just some of the possible variables effected by management.

8.0 Appendix

Appendix Table 1. ANOVA for field characteristics			
Item	***P*-Values**		
	Grazing Management Technique	**Cycle**	**Grazing Management Technique by Cycle Interaction**
Pre-grazing DM Kg/Ha	0.29	<0.0001	<0.0001
Pre-grazing sward height, cm	0.22	<0.0001	0.09
Post-grazing sward height, cm	0.56	<0.0001	0.03

Appendix Table 2. ANOVA for forage quality measures

	***P*- Values**		
Item	**Grazing Management Technique**	**Cycle**	**Grazing Management Technique by Cycle Interaction**
Net energy maintenance (NE_m), Mcal/kg	0.50	<0.0001	0.60
Net energy production, (NE_p), Mcal/kg	0.20	0.501	0.86
TDN, %	0.39	<0.0001	0.70
Crude protein, %	0.19	0.0019	0.60
NDF, %	0.29	<0.0001	0.46
ADF, %	0.06	<0.0001	0.43
Ca, %	0.57	<0.0001	0.36
P, %	0.50	0.453	0.01

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