

**FORAGE QUALITY, ANIMAL PERFORMANCE AND BEHAVIOUR OF
BRED BEEF HEIFERS GRAZING STOCKPILED PERENNIAL AND
ANNUAL FORAGES IN THE LATE FALL/EARLY WINTER IN
MANITOBA**

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By

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ABSTRACT

Stockpile grazing is practiced to extend the grazing season of beef cows in western Canada. Little research has been conducted to identify plant species for successful stockpile grazing of bred beef heifers during the late fall/early winter. Objectives of this study were to compare the three stockpiled perennial and one annual forage stand based on: 1) forage quality, yield and plant height, 2) performance (weight gain, serum urea nitrogen, intake and methane output) of bred beef heifers, 3) animal activity (distance traveled and time spent at shelter/water). Four stockpiled forage treatments were grazed for two, 28-d periods near Brandon, Manitoba, Canada. Treatments included: 1) Courtney tall fescue (T)/Fleet meadow brome grass (M)/Yellowhead alfalfa (A; TAM), 2) Killarney orchardgrass (OG)/Algonquin alfalfa (A; OGA), 3) Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch (C; TAC) and 4) Fusion corn (COR) in a randomized complete block design (RCBD) with 4 heifers/replicate/treatment.

Forage biomass yield in performance pastures of COR (6,342 kg DM ha⁻¹) was 68%, 79% and 57% higher (P=0.011) than OGA, TAC, and TAM, respectively, which did not differ from each other. Crude protein was highest in TAC (10.29% and 10.90%) and COR was the lowest (6.87% and 6.76%). However, COR had the highest in TDN (72.14% and 71.90%) when compared to perennial forage treatments.

All heifers gained weight in Period 1 (1.36 kg d⁻¹) suggesting that all treatments could be successfully stockpile grazed in the late fall. When temperature fell to <-18°C Period 2 (-2 kg d⁻¹), all heifers lost weight and those grazing perennial pastures spent more time (30-54% of the day) near windbreak shelters. Heifers grazing COR spent 7% of the day near shelter, suggesting COR provided adequate shelter. TAC was identified as the superior perennial forage treatment for stockpile grazing, based on higher CP and lower NDF compared to OGA and TAM, as well as

improved ADG compared to OGA and numerically higher ADG compared to TAM, Although COR had increased yield and TDN with lower CP compared to TAC, ADG was comparable between the two treatments. Nonetheless, significant weight loss in Period 2 indicated that all treatments required supplementation.

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DEDICATION

This thesis is dedicated to my mom, Sandy, who always inspired me and taught me that if I believed in myself and worked hard that I could accomplish anything I set my mind to. Even though she was gone long before I started my grad school journey, I know she was by my side the whole time from field and lab work to the long nights spent writing and editing.

LIST OF ABBREVIATIONS

Abbreviation	Definition
ADF	Acid detergent fibre
ADG	Average daily gain
BCS	Body condition score
BUN	Blood urea nitrogen
BW	Body weight
C31	n-hentriacontane, C ₃₁ H ₆₄
C32	n-dotriacontane, C ₃₂ H ₆₆
Ca	Calcium
CH ₄	Methane
CO ₂	Carbon dioxide
COR	Fusion corn forage treatment
cm	Centimeters
CP	Crude protein
d	Day
DDGS	Dried distillers grain with solubles
DE	Digestible energy
DEI	Digestible energy intake
DM	Dry matter
DMI	Dry matter intake
E	East
EOP	End of Period
g	gram
GC	Gas chromatography
GEI	Gross energy intake
GPS	Global positioning system
ha	Hectare
Hg (mm)	millimetres of mercury
hr	Hour
hrs	Hours
IVDMD	In-vitro dry matter digestibility
IVDOM	In-vitro digestible organic matter
K	Potassium
kg	kilogram
L	Litre
m	Metre
MAP	Monoammonium phosphate
MBFI	Manitoba Beef & Forage Initiatives Inc.
Mcal	Megacalories
ME	Metabolizable energy
mg	Milligram
Mg	Magnesium
min	Minute

ml	Milliliter
mm	Millimeter
NDF	Neutral detergent fibre
NE _{gain}	Net energy for gain
NE _{main}	Net energy for maintenance
NFC	Non-fibre carbohydrates
ng	Nanogram
OGA	Killarney orchardgrass and Algonquin alfalfa forage treatment
P	Phosphorus
perform	Performance pasture
SF ₆	Sulfur hexafluoride
SOT	Start of trial
TAC	Courtenay tall fescue, Algonquin alfalfa, and Oxley II cicer milkvetch forage treatment
TAM	Courtenay tall fescue, Yellowhead alfalfa, and Fleet meadow brome forage treatment
TDN	Total digestible nutrients
TMR	Total mixed ration
TOD	Time of day
um	Micrometer
W	West
wks	weeks
WSC	Water-soluble carbohydrates
yr	year

TABLE OF CONTENTS

ABSTRACT.....	i
ACKNOWLEDGEMENTS	iii
DEDICATION	v
LIST OF ABBREVIATIONS.....	vi
LIST OF TABLES	x
LIST OF FIGURES	xii
FOREWORD	xiv
1.0 GENERAL INTRODUCTION.....	1
2.0 LITERATURE REVIEW	2
2.1 Canadian beef industry and extended grazing.....	2
2.2 Stockpile grazing.....	3
2.3 Selection of forage species for stockpiled grazing.....	4
2.3.1 Perennial grasses and legumes	4
2.3.2 Annual forages used for stockpile grazing	7
2.3.3 Plant height of annual and perennial stockpiled forages	8
2.4 Animal performance when grazing stockpiled forages.....	10
2.5 Forage intake on pasture	14
2.6 Methane emissions associated with grazing stockpiled forages	15
2.7 Use of GPS collar to monitor animal grazing activity	16
2.8 Summary	19
2.9 Future research	20
3.0 RESEARCH HYPOTHESES AND OBJECTIVES.....	21
3.1 RESEARCH HYPOTHESES	21
3.2 OBJECTIVES	22
4.0 MANUSCRIPT.....	23
4.1 ABSTRACT.....	24
4.2 INTRODUCTION.....	26
4.3 MATERIALS AND METHODS	28
4.3.1 Field management.....	28
4.3.2 Animal Management	34
4.3.3 Sample collection and processing.....	36
4.3.4 Statistical analysis.....	45
4.4 RESULTS.....	48
4.4.1 Weather.....	48

4.4.2 Nutrient composition, yield, and plant height of stockpiled forages.....	49
4.4.3 Animal performance and feed intake.....	61
4.4.4 Methane and carbon dioxide output	70
4.4.4 Grazing behaviour	72
4.5 DISCUSSION	79
4.5.1 Yield, plant height and nutrient composition of stockpiled forages.....	79
4.5.2 Forage intake and animal performance	88
4.5.3 Methane and carbon dioxide emissions.....	94
4.5.4 Grazing behavior	94
4.6 CONCLUSIONS.....	97
5.0 GENERAL DISCUSSION	99
6.0 GENERAL CONCLUSIONS.....	104
7.0 LIST OF REFERENCES.....	106

LIST OF TABLES

Table 1. Forage treatments, seeding rates and fertilizer application utilized in the replicated perennial grass-legume and annual pastures	30
Table 2. Forage allocations given to pregnant beef heifers while strip grazing stockpiled perennial and annual forages in the late fall and early winter.....	33
Table 3. Profile analysis of Masterfeeds 16:16 No-Salt HI C-N-Z Mineral Premix fed to pregnant beef heifers while stockpile grazing in the late fall and early winter.....	36
Table 4. Ingredient composition of the n-alkane marked pellets delivered to heifers on a daily basis for measurement of forage DMI.....	39
Table 5. Snow height in perennial and annual stockpiled grazed pastures taken on d 26 of Period 2.....	48
Table 6. Average, maximum and minimum air temperature and wind speed in Brandon, Manitoba, Canada during late fall/early winter stockpile grazing trial.....	48
Table 7. Total precipitation, rain and snowfall during October, November and December 2016 at Brandon, Manitoba, Canada.....	48
Table 8. Forage yield, dry matter (DM) and plant height of perennial and annual stockpiled forages in Performance pastures grazed by bred beef heifers over two 28-d periods in the late fall and early winter (n=8).....	55
Table 9. Forage yield, dry matter (DM) and plant height of perennial and annual stockpiled forages in Intake pastures grazed by bred beef heifers over two 28-d periods in the late fall and early winter (n=8).....	56
Table 10. Nutrient composition (% DM unless otherwise stated) of perennial and annual stockpiled forages in Performance pastures grazed by bred beef heifers over two 28-d periods in the late fall and early winter (n=8).....	57
Table 11. Nutrient composition (% DM unless otherwise stated) of perennial and annual stockpiled Intake pastures grazed by bred beef heifers over two 28-d periods in the late fall and early winter.....	59
Table 12. Stockpiled forage treatment and grazing period interaction of nutrient composition (% DM unless otherwise stated) of perennial and annual stockpiled Intake pastures grazed by bred beef heifers for two 28-d grazing periods in the late fall and early winter.....	60
Table 13. Performance and forage dry matter intake of bred beef heifers grazing perennial and annual stockpiled pastures over two, 28-d periods in the late fall and early winter.....	64

Table 14. Methane and carbon dioxide emissions of bred beef heifers grazing stockpiled perennial and annual forages in Period 1 in the late fall and early winter.....71

Table 15. Grazing behaviour of bred beef heifers grazing three perennial and one annual stockpiled forage measured by GPS grazing collars over a two, 28-d grazing periods in the late fall and early winter (n = 30).....74

LIST OF FIGURES

- Figure 1.** Layout of the four forage treatments (TAM = Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome; OGA = Killarney orchardgrass/Algonquin alfalfa; TAC = Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch) in eight, replicated pastures (n=16) including the location of windbreak fences, salt/mineral feeders, water and designation of pastures used to measure animal intake (Intake) or live weight gain (Performance).....32
- Figure 2.** Pregnant beef heifers consuming C32-marked pellets to facilitate measurement of intake using the n-alkane marker technique.....40
- Figure 3.** Halter and vacuum ball fitted to each intake heifer to measure methane output while grazing over a 24-hr period; A = intake tube where CH₄, SF₆, and CO₂ emissions are captured from the nose and mouth, B = tubing that transfers the air exhaled from the heifer's nose and mouth to the evacuated collection ball, C = stainless steel vacuum ball that collects exhaled air.....43
- Figure 4.** The neutral detergent fibre (%) profile of perennial and annual stockpiled forages grazed by bred beef heifers over two 28-d grazing periods in the late fall and early winter on performance pastures; Forage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.....58
- Figure 5.** Body weight of bred beef heifers grazing perennial and annual stockpiled forages over two 28-d grazing periods during the late fall and early winter; Forage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.....65
- Figure 6.** Average daily gain (ADG) of bred beef heifers grazing perennial and annual stockpiled forages over two, 28-d periods in the late fall and early winter; Forage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.....66
- Figure 7.** Forage dry matter intake (% BW) in bred beef heifers grazing perennial stockpiled forages over two 28-d periods in the late fall and early winter; Forage treatments: OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.....67
- Figure 8.** Crude protein intake of bred beef heifers grazing perennial stockpiled forages over two 28-d periods in the late fall and early winter; Forage treatments: OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.....68
- Figure 9.** Serum urea nitrogen (SUN) concentrations in bred beef heifers grazing perennial and annual stockpiled forages in the late fall and early winter; Forage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin

alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.....69

Figure 10. Length of time spent by pregnant beef heifers at the windbreak shelters during the day and at night while grazing perennial and annual stockpiled forages during an 8-d period in early winter (Treatment x Time of Day); Forage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.....75

Figure 11. Length of time spent by pregnant beef heifers at water during daylight and nighttime while grazing perennial and annual stockpiled forages in both grazing periods (Treatment x Time of Day); Forage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.....76

Figure 12. Length of time spent by pregnant beef heifers spent time at water during daylight and nighttime while grazing perennial and annual stockpiled forages in both grazing periods (Time of Day x Period)77

Figure 13. Length of time spent by pregnant beef heifers spent time at water during Period 1 and Period 2 while grazing perennial and annual stockpiled forages (Treatment x Period); Forage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.....78

FOREWORD

This thesis research is written in manuscript style, comprised of an abstract, introduction, materials and methods, results, discussion, and conclusion. This thesis also contains a general introduction, literature review, general discussion, and general conclusion, followed by the literature cited. The manuscript has not been submitted for publication at the time of thesis completion.

1.0 GENERAL INTRODUCTION

The Canadian beef industry is complex with adoption of management strategies to reduce economic risk in light of fluctuating profit margins (Sheppard et al. 2015). The highest input cost for beef producers in western Canada is feed, with winter feed making up the largest proportion of that cost (Kelln et al. 2011; Kulathunga et al. 2016). Traditionally, conventional winter-feeding methods have included feeding preserved forages to cattle in a drylot confinement setting which requires increased labour and equipment/infrastructure to support feeding and manure removal (Kelln et al. 2011; Jose et al. 2020). Recently, extended grazing management strategies have been adopted by some western Canadian beef producers with increased interest each year (Sheppard et al. 2015; McGeough et al. 2018). These strategies can reduce labor and equipment resources associated with crop harvest, and fall, winter and spring cattle feeding, and manure removal and land application. (Kelln et al. 2011; Baron et al. 2016; Kulathunga et al. 2016; Jose et al. 2020). Common extended grazing strategies in western Canada include bale grazing, stockpile grazing, swath grazing and corn grazing (Sheppard et al. 2015; McGeough et al. 2018).

For extended grazing practices to be successful, the forages grown and offered to cattle must maintain quality till time of consumption. Small plot work in western Canada has suggested that species including alfalfa and cool season perennial grasses such as tall fescue, are high yielding with the potential to be utilized in extended grazing practices (Baron et al. 2004; Biligetu et al. 2014; Hewitt 2018). However, grazing trials must be performed to confirm that forages which are successful in the small plot research can achieve the desired animal performance when grazed in late fall/early winter.

2.0 LITERATURE REVIEW

2.1 Canadian beef industry and extended grazing

Grazing beyond the forage growing season during fall/winter/spring has become an increasingly popular management strategy with beef producers in western Canada to reduce the time that the herd spends in drylot confinement consuming harvested feed (hay, silage, grain, etc.). A 2011 Canadian survey (Sheppard et al. 2015), demonstrated that 68% of beef producers in western provinces practiced some form of winter grazing compared 35% for their counterparts in eastern Canada. This difference was attributed to the excess precipitation that eastern provinces often receive during fall and winter that leads to forage deterioration when left in the swaths or stockpiled. Of the respondents who practiced winter grazing, 44% fed rolled (baled) or processed forages, 42% baled grazed, 25% swath grazed, 29% stockpiled grazed, and 7.1% grazed standing corn (Sheppard et al. 2015).

In a subsequent survey in 2014 (Western Beef Development Centre, 2015), 33%, 17%, 18%, 17% and 6% of the 411 respondents maintained cattle in winter by grazing bales, swaths, stockpiled forage, crop residues and standing corn, respectively, at some point in the winter months. Other strategies used included harvested feed in bale feeders (67%) and bale processors (46%). However, when the same survey was conducted in 2017 (University of Saskatchewan, 2018), 47%, 28%, 40%, 41%, and 13% of the 261 respondents maintained cattle at some point during the winter by grazing bales, swaths, stockpiled forage, crop residues, and standing corn, respectively while only 8% of respondents utilized a bale processor. It is apparent that although traditional confinement feeding was the most popular winter-feeding strategy in 2014, adoption of most extended grazing strategies increased in 2017, particularly the use of stockpiled grazing. In western Canada, research examining performance of cattle using a range of forage species for

stockpile grazing has been more limited compared to other extended grazing strategies (Baron et al. 2016; Kulathunga et al. 2016) and therefore will be the focus of this literature review.

2.2 Stockpile grazing

Stockpiling refers to the practice of accumulating perennial or annual forages from the summer growing season after an early-mid season grazing or harvest which is subsequently grazed by cattle in the fall and/or winter (Kulathunga et al. 2016; McGeough et al. 2018). Increased adoption of all extended grazing strategies, including stockpiled grazing, has been attributed to the reduction of input costs related to labour and equipment. (Sheppard et al. 2015; Baron et al. 2016; Kulathunga et al. 2016). Cost savings can be substantial, as winter feeding costs (feed and yardage costs) in western Canada have been estimated to be 60 to 68% of total cost of production for a cow-calf operation over the winter-feeding period (Poore et al. 2000; Schoonmaker et al. 2003; Kelln et al. 2011; Kulathunga et al. 2016). The only infrastructure required for stockpile grazing, other than water and shelter, is fencing; unlike bale grazing or swath grazing where equipment is still needed to harvest the feed (Sheppard et al. 2015; Baron et al. 2016; Kulathunga et al. 2016). Therefore, it is a lower-cost extended grazing strategy for early winter compared to other methods since no mechanical harvesting equipment and less labor is needed. Kulathunga et al. (2016) reported a 45% reduction in winter feed costs for cows that were stockpile grazed compared to those fed hay in a drylot from October to December in Saskatchewan, Canada. Further, Schoonmaker et al. (2003) observed that stockpile grazing orchard grass reduced feeding costs by 9.8% - 47.6%, depending on the physiological status of the cow. Similarly, Poore et al. (2000) reported similar findings and demonstrated that strip grazing stockpiled forages by moving cattle daily can be beneficial economically due to a reduction in feed waste with 85% of available

stockpiled forage utilized compared to 50% forage utilization in a less intensive grazing program. These studies suggests that stockpile grazing can be an effective strategy to reduce winter feeding costs for beef producers in western Canada.

2.3 Selection of forage species for stockpiled grazing

2.3.1 Perennial grasses and legumes

Successful stockpile grazing systems require selection of forage species with superior yield and quality that is maintained during the dormant period. Perennial grass and legume pastures for spring/summer/fall grazing can be favorable because once seeded, the stand can span multiple production years, unlike annual forages, thereby decreasing labor, equipment, and seed costs (Entz et al. 2002). Baron et al. (2004) measured forage quality and yield in eight grasses, as well as alfalfa and an alfalfa-meadow brome mix that were stockpiled until harvest in mid-September, mid-October, and the following year in mid-April. Data from three growing seasons demonstrated that yield losses over the winter (September to April) were lower with grasses (3-35%) than alfalfa (43%). During years of high rainfall, timothy, crested wheatgrass, and orchard grass were high yielding, however during years of low rainfall, smooth and meadow brome grass both had consistently higher yields than other species. An alfalfa and alfalfa-meadow brome mix had the highest yield losses over the winter with high neutral detergent fibre (NDF) and low in vitro digestible organic matter (IVDOM) in the spring. However, meadow brome grass as a pure stand, and when seeded with creeping red fescue, had relatively high IVDOM concentrations, indicating meadow brome grass could possibly be suitable when grazed by cows in the fall and spring. These

results suggest that grasses may be a viable option to extend the grazing season as part of a stockpiled forage stand.

Biligetü et al. (2014) examined yield and quality in three legumes (alfalfa, sainfoin, and cicer milkvetch) as well as two warm season (big bluestem and switchgrass) and six cool season (crested wheatgrass, meadow bromegrass, Russian wildrye, western wheatgrass, northern wheatgrass, and green needlegrass) perennial grasses over seven growing seasons in Saskatchewan. Alfalfa seeded with cool season perennial grasses (except for Russian wildrye) resulted in the highest dry matter (DM) yield when sampled in either August or September. Further, *in vitro* dry matter digestibility (IVDMD) was greater for legume-grass mixtures compared to grass monocultures sampled in September. Western wheatgrass (cool season grass) combined with alfalfa was deemed to be the best species mix for stockpiled grazing based on DM yield and nutrient profile (crude protein (CP) and IVDMD) when sampled in August and September. Although the warm season grasses (big bluestem and switchgrass) had higher calcium (Ca) and phosphorus (P) concentrations than the cool season grasses, DM yield was significantly lower.

Hewitt (2018) examined 23 perennial forages in pure and mixed stands to assess their suitability for use as stockpiled forage for beef cattle in late fall/early winter in Manitoba. Stands were cut in June or July to initiate stockpiling and harvested in mid-October. Courtenay tall fescue and Oxley II cicer milkvetch seeded alone had the highest yield potential for stockpile grazing, however, stands with a grass and legume mix had higher yield, CP, total digestible nutrients (TDN), Ca, and magnesium (Mg). Legume-grass mixtures are common in western Canadian pastures as they have relatively high CP (12-18%) concentration which increases as the proportion of legume in the stand increases (Biligetü et al. 2014). However, legumes are usually not as well

suited for stockpiling as quality typically declines faster than grasses due to leaf loss associated with frost or maturity (Baron et al. 2004). Tall fescue has been identified as an ideal grass species for winter grazing purposes due to its high yield and ability to maintain quality throughout the winter, meeting the nutrient requirements of early to mid-pregnancy mature beef cows (Poore et al. 2000; Poore and Drewnoski, 2010).

Peng (2017) examined the suitability of perennial and annual forage species for stockpiled grazing in western Canada by comparing forage yields and quality over a 2-yr period. Fleet and Armada meadow brome grass, either in pure stands or mixed with legumes, had the highest yields, and therefore were deemed to be suitable for stockpile grazing while stands solely comprised of legumes or Killarney orchardgrass had the lowest DM yield. Success hybrid brome grass had the highest CP of the pure grass stands followed by Fleet and Armada meadow brome grass. Killarney orchardgrass had the lowest CP either in a pure or mixed stand most notably when the period of forage accumulation was from mid-June to mid-October compared to a period of re-growth from mid-August to October. Similarly, the longer the period of accumulation, the higher the NDF and ADF concentration of the forage. Further, in all cases, inclusion of a legume (alfalfa and/or cicer milkvetch) into the perennial forage stand increased the CP but did not affect the TDN, as all mixes and pure stands had similar TDN values in both years. All species examined in this study met the nutrient requirements of dry beef cows during early to mid-pregnancy (Peng 2017).

Quality changes associated with advanced maturity and weathering of the standing forage that can result in decreased CP and TDN and increased NDF concentrations, have also been reported. Kulathunga et al. (2016) observed a decrease in CP (10.7% to 9.5%) and TDN (52.5% to 50.5%) and an increase in acid detergent fibre (ADF; 42.0% to 45.6%) and NDF (61.8% to 66.8%) in stockpiled meadow brome grass and alfalfa when sampled and swathed in mid-October

compared to when sampled in December. Despite the decline in nutritive value, the stockpiled forages met the TDN requirements of mid-gestation beef cows at the onset of the trial in mid-October when temperatures were mild. Energy supplementation was required in December due to lower ambient temperatures leading to an increase in energy demand. Baron et al. (2004) observed that although the quality (CP, IVDOM, water-soluble carbohydrates (WSC), NDF and ADF concentration) of eight grasses ('Kirk' crested wheatgrass, 'Troy' Kentucky bluegrass, 'Manchar' smooth brome grass, 'Paddock' meadow brome grass, 'Kay' orchardgrass, 'Champ' timothy, common quackgrass, and 'Boreal' creeping red fescue) and 'Algonquin' alfalfa met the nutrient requirements of mid-gestation mature beef cows in the early to late fall, several species, including timothy, smooth brome grass, and crested wheatgrass did not meet CP requirements of late gestation beef cows in April. In addition, the overwinter biomass loss from October to the following April was lower in the grass species (3-35%) than observed for alfalfa (43%). Therefore, these authors recommended grazing stockpiled forages in the fall before yield and quality losses occur, especially if legumes are included in the forage stand.

2.3.2 Annual forages used for stockpile grazing

Perennial grasses and legumes are not the only option available for stockpile grazing in western Canada. Annual forages can also be an option for beef producers who wish to utilize stockpile grazing. McCartney et al. (2009) examined the potential for warm season annual forages and *Brassica* crops to support grazing animals and concluded that corn, golden German foxtail millet, kale, and forage rape showed promise to extend the grazing season in western Canada. Corn had the highest DM yield paired with the lowest cost; however, quality was dependent on the number of cobs available on the standing plant at the onset of grazing (McCartney et al. 2009).

These authors concluded that CP concentration in corn met minimum requirements for mid pregnancy dry beef cows. Similar results were reported by Lardner et al. (2017) who reported that corn hybrids grown in a plot based study provided a large biomass yield when compared to barley and further, that corn would meet the energy nutrient requirements of beef cows in mid to late gestation based on the nutrient profile of the corn varieties examined in the corn plots and therefore could be a viable extended grazing strategy with CP and Ca supplementation.

Hewitt (2018) observed that Fusion corn had the highest yield (4.4 – 40.5 t DM ha⁻¹ when sampled in the 3rd week of October) across 3 sites and highest TDN (613 g kg⁻¹ - 733 g kg⁻¹) when compared ‘Haymaker’ oats, ‘Hazlet’ fall rye, ‘Maverick’ barley, ‘Golden’ German foxtail millet, ‘Aubade’ westerwold ryegrass and ‘Mammoth’ soybean seeded in either late May or early June in Manitoba. Yield and NDF increased, while CP and TDN decreased as the forages were weathered and matured from August to October. Fall rye, westerwold ryegrass, and corn were the only annual forages that maintained quality into the late fall/early winter with the highest yield observed in corn in 2015. Also, Jose et al. (2020) observed that whole-plant corn yield (11,200 kg ha⁻¹) was 42% greater than barley (7,900 kg ha⁻¹) in Saskatchewan. This data suggests that corn may be a viable option for fall/early winter stockpile grazing due to increased yield potential and high energy concentration.

2.3.3 Plant height of annual and perennial stockpiled forages

Stockpile grazing in western Canada brings unique challenges such as extreme cold, wind and in some geographic locations, heavy snowfall that can cover available forage. These conditions increase maintenance energy requirements and make it difficult for cattle to graze as compared to

stockpile grazing in regions with more moderate conditions (Kulathunga et al. 2016). Much of the research conducted using stockpiled forages in Canada and the northern United States has measured forage yield and quality but not plant height. In several studies (Hitz and Russell, 1998; Baron et al. 2004; Kulathunga et al. 2016), forages were swathed immediately prior to grazing negating the need to consider plant height. Hewitt (2018) measured plant height of pure and mixed stands of perennial grasses and legumes for stands in which the biomass accumulation started in either June/early July or August, with forage harvested via simulated grazing in October. Plant height was greatest in ‘Oxley II’ cicer milkvetch or any of the grass legume blends with ‘Oxley II’ cicer milkvetch when stockpiling was initiated in June. However, when stockpiling was initiated in early August, plant height differed between locations. Greatest plant heights were observed in ‘Courtenay’ tall fescue and ‘Algonquin’ alfalfa grown at a site near Carman, MB and ‘Oxley II’ cicer milkvetch grown at a site at Arborg, MB, although both sites had similar precipitation in both growing years. Pure stands of ‘Yellowhead’ and ‘Algonquin’ alfalfa were shortest regardless of when stockpiling was initiated. Several species (‘Fleet’ meadow brome, ‘Armada’ meadow brome, ‘Algonquin’ alfalfa, ‘Yellowhead’ alfalfa, and ‘Oxley II’ cicer milkvetch) were taller when grown in a grass-legume blend compared to a pure stand. Therefore, forages grown in a blend compared to a pure stand not only have increased nutritive value (CP and TDN) and yield but may also be more easily grazed as a result in increased plant height (Hewitt 2018) if grazed before a killing frost. Impact of freezing on leaf loss and nutritive value was not evaluated in that study. These observations require validation in a large-scale grazing trial to better understand how plant height of stockpiled forages can affect animal behaviour and performance.

2.4 Animal performance when grazing stockpiled forages

Regardless of the extended grazing practice, nutrient requirements of cattle must be met to maintain body condition and production goals. This can be challenging in western Canada as forage quality on summer grazed pastures is lowest during the fall and winter season as a consequence of increased maturity and potential leaf loss (Baron et al. 2004) at a time when animal nutrient requirements are increasing due to decreased ambient temperatures (Poore et al. 2000). Bred heifers and cows also have increased physiological demands associated with fetal growth throughout gestation.

Over the last several decades, a number of studies (Adams et al. 1994; Hitz and Russell 1998; Schoonmaker et al. 2003; Baron et al. 2016; Kulathunga et al. 2016; Jose et al. 2020) have examined the potential for stockpiled forage to maintain body condition of early-mid pregnancy cows during the fall and winter months compared to confinement feeding of hay in a drylot or other extended grazing methods. Adams et al. (1994) compared three feeding strategies for pregnant beef cows (stockpiled native range, stockpiled native irrigated meadow or hay delivered in confinement) from mid-November to the beginning of March in Nebraska. The cows were then moved into one of two scenarios in spring after calving (01 May to 01 June: (i) hay-fed in confinement or ii) grazing irrigated native meadow pasture that was that was stockpiled the previous growing season. During calving (01 March to 30 April) all cows were together in one group and managed together in drylot until the spring grazing treatment began. Significant differences in body condition score (BCS) were observed at pre-breeding as cows in the May meadow treatment had higher BCS compared to cows in the May hay treatment irrespective of which winter treatment they were grazing. However, no significant differences in BCS (average = 5/10) were observed in cows at pre-calving or weaning (Adams et al. 1994). Further, although

pregnancy rates (mean = 93%) did not differ between feeding strategies, calves from cows grazing stockpiled native range or meadow pastures over the winter months had lower birth weights compared to those from cows fed hay in confinement. Calves from cows that grazed stockpiled meadow pasture in the spring were heavier at weaning compared to those from dams that were fed hay in confinement partly due to the lush spring regrowth in the meadow pasture. Therefore, grazing either stockpiled range or irrigated meadows in the winter and stockpiled irrigated meadows in the spring resulted in comparable cow performance compared to feeding hay (Adams et al. 1994).

Hitz and Russell (1998) examined four winter grazing treatments: i) stockpiled tall fescue alfalfa forage, ii) stockpiled smooth brome grass without (year 1) or with (year 2) red clover, iii) field grazing of corn crop residue (corn crop was harvested for grain prior to grazing) or iv) drylot confinement and fed hay. Supplemental hay was provided to both stockpiled treatments and corn residue treatment when cows were unable to maintain condition or during periods of extreme weather that impeded grazing (i.e., heavy snowfall, cold temperatures or ice cover). The corn crop residue had significantly higher DM yield, higher NDF and ADF concentrations and lower CP and IVOMD than the stockpiled perennial forages, suggesting that grazing of whole corn plant is a better alternative than grazing the crop residue. Stockpile grazing tall fescue-alfalfa or smooth brome grass-red clover decreased the amount of supplemental hay fed by 63% compared to the total hay fed in the drylot from October to March of the study. Grazing tall fescue-alfalfa, smooth brome grass-red clover and corn crop residues resulted in equal or higher BW and BCS compared to cows offered hay in drylot confinement when supplemental hay was provided.

Schoonmaker et al. (2003) examined three feeding strategies in Ohio from November to February (Experiment 1) and January to April (Experiment 2): i) stockpiled grazing orchardgrass,

ii) limit-fed corn (5.8 kg whole shelled corn) with 1.1 kg pellet supplement and 1.2 kg orchardgrass hay daily in a drylot, and iii) ad libitum orchardgrass hay in drylot. Cows grazing stockpiled orchardgrass during mid- to late-gestation maintained body condition during the winter months in both experiments (November to February or January to April). In Experiment 1, the BCS of cow's limit-fed corn (6.6) was greater than stockpiled orchard grass (6.15) and drylot (5.98) treatments when measured in February on a 1 to 9, scale with 1 being thin and 9 being fat. This study concluded that stockpiled orchardgrass and limit-fed corn were suitable alternatives to feeding harvested hay and that both methods could decrease feed costs over feeding hay in drylot (Schoonmaker et al. 2003).

Baron et al. (2016) compared performance of dry, pregnant beef cows in mid-gestation over a 4-yr period (2004-2007; mid-November to mid-March) in Alberta, Canada when offered the following treatments: i) swath-grazed oats, ii) stockpiled meadow bromegrass or iii) a barley silage and straw-based total mixed ration (TMR) in confinement. Cows grazing swathed oats lost weight (ADG of -0.13 kg d^{-1}) while cows grazing the stockpiled perennial grass pasture (0.29 kg d^{-1}) and offered the TMR (0.41 kg d^{-1}) gained weight over the winter. As cows grazing the stockpiled perennial grass had a positive ADG in three (2005-2007) of the 4 yrs, the authors concluded that grazing stockpiled meadow bromegrass was an acceptable strategy to feed dry, pregnant beef cows throughout the winter months. Further, it was a less expensive option than feeding a TMR in confinement. However, the stockpiled forage had the lowest DM yields in all four years compared to the other treatments resulting in a reduced carrying capacity per acre and grazing days compared to the other two methods.

Kulathunga et al. (2016) examined performance of dry, pregnant beef cows grazing a stockpiled meadow bromegrass - alfalfa mix compared to cows offered dry hay bales of the same

forage species in confinement. Supplemental rolled barley was offered in portable feeders (0.2% and 0.01% BW for stockpiled grazing and drylot hay treatments respectfully) throughout the study, based on 14-d average BW and previous 2-wk environmental conditions at the site. In addition, when winter temperatures dropped below -12°C , the 3-d allocations of forage (which were calculated based on animal BW, cow nutrient requirements and forage nutrient density) in both treatments was adjusted for the increased DMI expected due to cold temperatures. There was no difference in cow performance (BW gain and BCS) between the two treatments over the 3-yr study indicating that stockpile grazing perennial forage can be a suitable feeding strategy for beef cows in western Canada when supplemental energy and additional infrastructure including wind fences are provided to ensure that cows do not lose weight.

Jose et al. (2020) examined forage yield and quality, DMI, animal performance (BW, BCS, Rib fat and Rump fat), system costs and ruminal fermentation of bred beef cows: i) grazing standing, whole plant corn, ii) grazing swathed whole plant barley, or iii) fed barley hay in a drylot over 3 yrs in Saskatchewan, Canada. Yield of whole-plant corn (DM basis) was 42% greater than whole-plant barley (prior to swathing) and was higher in TDN. However, CP did not differ between the treatments (10% corn, 11.5% swathed barley and 10.3% barley hay in drylot). The DMI (estimated by measuring feed delivered minus feed waste) was lower for cows grazing corn (9.1 kg d^{-1}) compared to the other two treatments (14.3 kg d^{-1} swathed barley and 13.1 kg d^{-1} barley hay in drylot) but BW, BCS and rib fat did not differ between the three treatments during the 3-year study. However, rump fat was lower in cows on offered barley hay in the drylot (3.83 mm) than cows fed standing corn (4.83 mm) but similar to swathed barley cows (4.37 mm). It was concluded that standing corn and swathed barley reduced winter feeding costs by 25 and 36% respectively, when compared to feeding barley hay in the drylot for bred beef cows.

Research conducted to date suggests that mature mid-pregnancy cows can maintain condition when grazing stockpiled forages over the winter months. However, during periods of cold, cows may require supplementation to avoid loss of BCS or weight. Therefore, stockpile grazing could be a promising solution to save money and reduce infrastructure needed to overwinter dry, pregnant beef cows during Canadian winters. Potential to utilize this strategy for other classes of cattle including replacement heifers requires further research.

2.5 Forage intake on pasture

Forage DM intake on pasture is necessary to evaluate the rumen and metabolic energetic efficiency of cattle in extended grazing environments. To date, intake in extended grazing environments has been primarily measured using equation-based approaches (Kulathunga et al. 2016) or by calculating feed delivered minus feed waste (Jose et al. 2020). Both strategies have shortcomings as individual animal intake cannot be assessed when group feeding cattle and feed lost via wind or contaminated with feces cannot be accurately measured. However, forage intake can be measured on an individual animal-basis on pasture using the n-alkane external marker technique described by Dove and Mayes (1986; 1991; 2005). This technique for measuring intake is possible as all plants have simple straight-chain of hydrocarbons in their cuticle wax called n-alkanes ranging from C₂₅ to C₃₅ (Moshtaghi Nia and Wittenberg, 2002), with odd chain n-alkanes (especially C₃₁ and C₃₃) found in much higher concentrations (Boadi et al. 2002a). Donohoe et al. (2019) demonstrated that the n-alkane technique can be successful in an extended grazing environment for cows bale grazing in December and January in Manitoba. However, the n-alkane technique has not been used for animals that are stockpile grazing in the late fall and early winter. Challenges using this technique under these conditions include forage re-growth late in the

growing season, as well as selective grazing of plant parts (corn cob vs leaf and stem material) which differ in their alkane profile.

2.6 Methane emissions associated with grazing stockpiled forages

Climate change has become a global concern with considerable attention focused on the beef industry due to microbial fermentation in the rumen during digestion of feed leading to the production of methane (CH₄; DeRamus et al. 2003; Beauchemin et al. 2020). In Canada, beef cattle contributed 20,000 kt CO₂ eq to Canadian agricultural emissions via enteric CH₄ in 2018 (Environment Canada, 2020) and globally enteric CH₄ from livestock contributes 6% of total greenhouse gas emissions (GHG; Beauchemin et al. 2020). Enteric CH₄ is a loss of 4-12% of dietary feed energy and therefore identifying strategies to lower emissions is of benefit to the animal in terms of improved production efficiency, while at the same time improving the sustainability of the beef sector (DeRamus et al. 2003; Lassey 2007; Beauchemin et al. 2020). Improving the level of productivity above maintenance is an effective strategy to reduce CH₄ emissions (DeRamus et al. 2003). Therefore, strategies to improve ruminal fermentation efficiency and performance outcomes including ADG will lead to reduced emissions per unit of output. Identifying forage species with potential to improve fermentation efficiency and animal performance will serve to reduce GHG emissions from cattle grazing stockpiled pastures. Annual forages that contain concentrate grain can help to reduce CH₄ output by up to 23% (Benchaar et al. 2001; Beauchemin et al. 2020) due to a higher starch content which increases rumen metabolic efficiency. Identifying dietary mitigation strategies is particularly relevant in the cow-calf sector which accounts for about 80% of total GHG emissions from Canada's beef sector (Beauchemin et al. 2010).

McCaughey et al. (1999) examined the impact of including a legume on enteric CH₄ emissions measured using the SF₆ technique in cows grazing an alfalfa-grass mix (78% alfalfa:22% meadow bromegrass) and pure meadow bromegrass stand. Over the growing season, cows grazing the alfalfa-grass pastures had lower CH₄ emissions (7.1% of gross energy intake (GEI) compared to cows grazing grass only pastures (9.5% GEI). Therefore, including legumes in a pasture can improve rumen metabolic efficiency and reduce enteric CH₄ in beef cows (McCaughey et al. 1999). This is consistent with work conducted by Benchaar et al. (2001) who concluded from a modeling approach that alfalfa hay led to a 21% reduction in CH₄ emissions when compared to a timothy grass hay diet relative to digestible energy. To date, the value of including a legume to reduce GHG emissions in stockpiled forage systems has not been investigated and requires future research.

Donohoe et al. (2019) investigated the impact of bale grazing compared to feeding the same hay diet in drylot on enteric CH₄ emissions in a trial conducted from December to January in Manitoba. Cows bale grazing had significantly higher CH₄ emissions expressed as L d⁻¹, L kg BW⁻¹, L kg DMI⁻¹, and % GEI compared to cows in drylot. These authors also found that cows in the bale grazing treatment had 46% higher feed energy loss expressed as % GEI compared to cows in drylot, indicating that rumen metabolic efficiency may be lower for cows in an extended grazing system in Manitoba.

2.7 Use of GPS collar to monitor animal grazing activity

Global positioning systems (GPS) technology has the opportunity to aid in further understanding animal grazing activity as it relates to pasture utilization, animal energetic efficiency

and animal performance in extended grazing environments. Before the early 1990's, animal behavior research was tracked by visual observation which had high labor requirements, could be difficult to carry out in large pastures and was susceptible to human error (Agouridis et al. 2004; Bailey et al. 2018). However, GPS technology has provided the potential to remotely monitor animal behavior and movement on a continuous basis without interrupting animal activity (Barbari et al. 2006; Bailey et al. 2018). Although GPS devices have been used extensively to monitor grazing activity in summer pastures, to date they have only been used to a limited extent in extended winter grazing systems. However, there is a need for further research to provide much needed information regarding animal activity, leading to an improved understanding of animal energetics and subsequent animal performance.

To preserve battery life of the GPS device (most commonly used in the form of a collar affixed to the animals' head/neck), location 'fixes' are recorded at defined periods of time which may range from 5-min to 24-hr intervals. The collars are typically accurate to within a 5-10 m buffer zone of the actual animal location 95% of the time (Turner et al., 2000; Agouridis et al., 2004; Johnson and Ganskopp, 2008). However, accuracy may be affected by tree cover (Agouridis et al., 2004; Augustine and Derner, 2013), satellite error, satellite orbit error, bounced signals, topography, and atmospheric conditions (Ganskopp and Johnson, 2007). Distance travelled by grazing cattle in a defined period of time can only be estimated if activity is continuously tracked,

To date, GPS data has been used to track the proportion of time that an animal spends in a certain part of a pasture or range rather than the specific distances (Bailey et al. 2001; Barbari et al. 2006; Rawluk et al. 2014; Bailey et al. 2018). Therefore, use of GPS collars can provide valuable information when used in stockpiled grazing scenarios to better understand time spent grazing and the subsequent impact on animal performance. This information is important in

extended grazing environments in western Canada where cattle can experience extreme cold temperatures coupled with wind during the winter months, leading to cold stress (Christopherson and Kennedy, 1983; Kulathunga et al. 2016). Cattle can adapt to cold temperatures and if able to regulate body temperature in a thermoneutral zone their foraging behaviour will not change, however in times of extreme cold weather, thermoregulating behaviour may interrupt normal grazing behaviour as cattle seek shelter to minimize cold stress and attempt to maintain body temperature (Young et al. 1989; Houseal and Olson, 1995; Mader, 2003). Further, providing natural shelter that covers a large portion of the grazing area will increase the likelihood that cattle continue grazing (Houseal and Olson, 1995). Olson and Wallander (2002) observed that the time cattle spent at the windbreak shelter varied greatly from day-to-day and was largely depended on weather conditions which varied from 7.7°C to -24.7°C with winds between 0.1 m s⁻¹ and 12 m s⁻¹ during the trial. Cattle sought shelter more frequently during cold and windy conditions from the end of November to mid-January in Montana, United States, compared to conditions which were warm and windy, or cold without wind (Olson and Wallander, 2002). Cattle did not begin to use the windbreak shelters until December 12 when temperatures dropped (<-17°C) in Montana, and they spent 21% of their time near the shelter under those conditions. Shelter use varied between 0-30% of the day (dawn to dusk) until the end of the trial and use was dependent on daily weather conditions. This further suggests that grazing behaviour during the winter months in temperate climates is a tradeoff between thermoregulation to reduce energy loss and foraging to meet maintenance requirements, subsequently impacting BCS and ADG.

2.8 Summary

In conclusion, stockpile grazing is an economically viable choice for beef producers compared to traditional drylot feeding, based on research conducted to date. Further, stockpiled perennial forages have been shown to provide sufficient forage DM of adequate quality to support dry mid-pregnancy beef cows to maintain condition over the late fall and early winter however performance may be impacted when temperatures fall below -12°C (Kulathunga et al. 2016). Perennial cool season grasses are recommended over warm season grasses for use in western Canada as they have shown to provide higher DM yield and are best paired with a legume such as alfalfa to increase CP and yield. However, leaf loss during the winter grazing season may compromise quality and therefore animal performance. In addition, corn has been shown to serve as a suitable annual crop for stockpiled grazing forage given its superior DM yield but has lower CP compared to several perennial species. Since whole corn plants have higher starch concentration than perennial forages (McCartney et al. 2009; Beauchemin et al. 2010), grazing standing corn has the potential to reduce enteric CH_4 , leading to improved energetic efficiency and reduced animal environmental impact. Use of GPS collars has the potential to further our knowledge of grazing behaviour including time spent at shelter, particularly in western Canada where extreme cold ($<-20^{\circ}\text{C}$; Young et al. 1989) coupled with increased wind velocities under extended grazing conditions, which could have a negative effect on animal energetic efficiency and subsequent performance.

2.9 Future research

Additional research is still needed to further examine perennial and annual forage species used for stockpile grazing to optimize forage quality, yield, and animal performance by selecting forage species best suited for stockpile grazing in the late fall and early winter in western Canada. Information regarding plant height and the ability to withstand heavy snowfall are necessary to fully assess suitability of forage species for stockpile grazing in western Canada. Further, the effects of grazing stockpiled perennial and annual forage species on animal energetics, animal performance and rumen metabolic efficiency as measured by CH₄ production in temperate climates is needed to fully explore how these forage species can effectively be used in extended grazing practices. Finally, information regarding animal behaviour as it relates to animal activity and energetics using GPS collars on cattle grazing stockpiled forages during the late fall and early winter in western Canada has not been explored to date and is necessary to understand the impact of forage species selection on animal grazing behaviour. Collectively, this information will contribute to improved decision-making regarding forage selection to optimize animal performance and reduce environmental impact associated with stockpile grazing systems.

3.0 RESEARCH HYPOTHESES AND OBJECTIVES

3.1 RESEARCH HYPOTHESES

Plot-based studies comparing stockpiled perennial with annual forages for late season fall grazing have reported increased DM yield and TDN concentration but lower CP concentration with annual forages, including corn, compared to perennial legume-grass mixes (Hewitt 2018). Further, animal trials have demonstrated that early-to-mid pregnancy mature cows can successfully graze stockpiled perennial and annual species in temperate environments with positive outcomes as measured by BCS and ADG (Adams et al. 1994; Hitz and Russell 1998; Schoonmaker et al. 2003; Baron et al. 2016; Kulathunga et al. 2016; Jose et al. 2020). However, the physiology and nutritional needs of pregnant beef heifers differs to mature cows since they are growing themselves while supporting a pregnancy thus requiring more energy and CP nutritionally while having a reducing DMI capacity. It is important that we supplement existing literature by addressing the gap that exists regarding identification of stockpiled perennial and annual species that can supply an adequate level of nutrition to growing beef heifers when grazed in the late fall and early winter, especially once ambient temperatures can fall below -20°C and pregnant dry cattle are no longer in their thermoneutral zone (Young et al. 1989).

The hypothesis of this thesis is that stockpiled perennial grass-legume and annual forages can support growth, ruminal efficiency, and nutritive requirements of pregnant beef heifers when grazed in the late fall and early winter with no differences between perennial forage species. The increased energy concentration and forage yield of corn will lead to improved rumen fermentation efficiency and performance with decreased CH_4 output compared to heifers grazing perennial pastures, particularly when cold temperatures increase maintenance requirements and nutrient demand. Further, heifers will travel similar distances and spend the same time at waterer during

the late fall regardless of treatment since their pastures are of similar small size. However, heifers grazing corn pastures will travel shorter distances and spend less time at shelters during periods of cold due to increased protection offered by the taller corn stand compared to the perennial pastures.

3.2 OBJECTIVES

The objectives of the present study are to compare mixed perennial, as well as annual forage stands in stockpiled grazing environments with respect to: 1) pasture forage yield, nutrient profile and plant height; 2) animal performance including DMI, BW, ADG, SUN, rumen metabolic efficiency as measure by enteric CH₄ production; and 3) animal activity and behavior including distance traveled, time spent at shelter and water. Collectively, this information will identify forage species that can be successfully used to stockpile graze bred beef heifers during the late fall/early winter in western Canada.

4.0 MANUSCRIPT

Forage quality, animal performance, and behaviour of bred beef heifers grazing stockpiled perennial and annual forages in the late fall/early winter in Manitoba

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4.1 ABSTRACT

This study compared forage quality and DM yield, as well as performance and grazing behaviour of pregnant beef heifers (535.5 ± 43.9 kg) grazing stockpiled forage in the late fall/early winter. Stockpiled forage treatments were: 1) Fusion corn (COR); 2) Killarney orchardgrass/Algonquin alfalfa (50:50; OGA); 3) Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch (50:25:25; TAC); and 4) Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome (40:20:40; TAM) in a randomized complete block design (four heifers paddock⁻¹ X four paddocks treatment⁻¹ X four treatments). The paddocks were strip grazed for two, 28-d periods from Oct to Dec 2016 near Brandon, Manitoba, Canada.

Forage samples were collected once at the beginning of each period (performance) and daily (d 8-12) each period in intake pastures, dried and ground for wet chemistry analysis. Weight, average daily gain (ADG), and blood samples were taken at the beginning and end of each period. Dry matter intake (DMI) was measured once each period while enteric methane (CH₄), and carbon dioxide (CO₂) were examined in Period 1 only. Thirty heifers (minimum of three heifers treatment⁻¹) were fitted with Lotek 3300L GPS collars to track location every 10 min during the day (05:00-21:00) and every 30 min at night (21:00-05:00) during both periods to determine distance travelled as well as time spent at shelter and water.

Corn had the highest DM biomass compared to OGA, TAC and TAM, with no differences across other treatments. Corn Intake pastures also had higher TDN (71.9%, DM basis; $P < 0.001$) than TAM (52.9%), TAC (52.0%) and OGA (45.1%). However, TAC (10.9%) Intake pastures had a higher CP concentration than OGA (9.1%) which were both higher than COR (6.8%) and TAM (6.5%; DM basis; $P < 0.001$). The DMI (%BW), measured using the n-alkane technique was greater in Period 2 (1.35%) than Period 1 (1.27%; $P < 0.05$), and cows grazing OGA (1.4%) had the highest

intake, followed by TAM (1.32%) and TAC (1.21%; $P>0.05$) across the two periods. There were no treatment differences for ADG which was $1.36 (\pm 0.13) \text{ kg d}^{-1}$ in Period 1, and $-2.00 (\pm 0.13) \text{ kg d}^{-1}$ ($P<0.001$) in Period 2. Also, all treatments had a similar BW at the end of Period 2, compared to their initial BW, except for OGA which was lower weight at the end of Period 2 than the start of Period 1. Heifers grazing TAC and TAM had SUN concentrations consistently above and below the minimum acceptable threshold ($> 2.1 \text{ mmol L}^{-1}$) at all three sampling times. Heifers grazing OGA and COR were inconsistent with respect to SUN. Heifers grazing OGA, TAC and TAM spent significantly more ($P<0.001$) time at windbreak shelters during night hrs (51-73%) compared to day hrs (19-34%). Heifers grazing COR spent significantly less time at these shelters, averaging 4% during daylight and 19% at night.

The TAC treatment appeared to maintain nutritive value over the grazing period compared to OGA which had higher ADF and NDF as well as lower TDN in Period 2 compared to Period 1. Although heifers grazing all treatments lost weight when weather conditions declined ($<-20^{\circ}\text{C}$) in Period 2, heifers grazing TAC and TAM lost less weight than those grazing OGA across both periods. Compared to the perennial grass-legume pastures, corn had lower CP, ADF and NDF but higher TDN, leading to a net positive ADG. Heifers assigned to corn had a significantly higher ADG, compared to TAM and OGA and were comparable to TAC. Additionally, taller plant height and less time at shelter suggest that corn offered sufficient shelter to reduce non-grazing time compared to the perennial grass-legume treatments. As heifers grazing all forage treatments lost weight in Period 2 when heavy snowfall and cold temperatures occurred, it is suggested growing bred heifers receive supplemental feed to maintain a positive energy balance and gain weight during periods of extreme cold.

4.2 INTRODUCTION

As extended grazing becomes more widely used as a winter-feeding management strategy in western Canada (Sheppard et al. 2015), producers continue to examine forage species options which will improve productivity and reduce labor costs compared to traditional drylot feeding. Although numerous plot-based trials (Baron et al. 2003; Biligetu et al. 2014; Lardner et al. 2017; Peng, 2017; Hewitt, 2018) have examined biomass yield and nutrient profile of forage species that may be used in stockpile grazing systems, few animal trials have been conducted in western Canada. Much of the existing animal research was completed in the northern and midwestern United States (Adams et al. 1994; Hitz and Russell 1998; Schoonmaker et al. 2003), regions which are characterized by moderate winter climates with warmer temperatures and less snowfall than that typically experienced in western Canada. Several western Canada studies have demonstrated that extended grazing using swathed oats (Baron et al. 2016), stockpiled meadow brome grass and alfalfa (Kulathunga et al. 2016), and swathed barley (Jose et al. 2020) show promise as viable extended grazing strategies. However, further examination of annual and perennial grass-legume forage species is required help producers identify forage species that when stockpiled will support maintenance and productivity of the grazing breeding herd. The need to examine animal performance outcomes in a western Canadian production environment is particularly important where cold temperatures (-20°C; Young et al. 1989) lead to increased maintenance requirements in cattle.

Plant height of stockpiled forage species has not been examined previously in a grazing setting to determine the impact of weathering and snowfall on forage accessibility and forage intake. Plant height has been measured in a small plot study before snowfall (Hewitt 2018). The impact of changes in plant height due to snowfall and weathering on forage DMI, as well as

changes in grazing behaviour (driven by the need to conserve energy and seek shelter; Olson and Wallander 2002) while outside of their thermoneutral zone (-20°C ; Young et al. 1989) on ruminal efficiency, animal energetics (GHG emissions) or animal performance while stockpile grazing has not been examined in western Canada to date.

The objectives of the present study are to compare perennial and annual forage stands in stockpiled grazing environments with respect to: 1) pasture forage yield, nutrient profile and plant height; 2) animal performance including DMI, BW, ADG, SUN, rumen metabolic efficiency as measure by enteric CH_4 production; and 3) animal activity and behavior including distance traveled, time spent at shelter and water. Collectively, this information will identify forage species that can be successfully used to stockpile graze bred beef heifers during the late fall/early winter in western Canada.

4.3 MATERIALS AND METHODS

4.3.1 Field management

The four forage treatments selected for the grazing trial were: 1) COR: Fusion corn (*Zea mays*), 2) OGA: Killarney orchardgrass (OG; *Dactylis glomerata*)/Algonquin alfalfa (A; *Medicago sativa*), 3) TAC: Courtney tall fescue (T; *Schedonorus arundinaceus* (Schreb.) Dumort., formerly *Festuca arundinacea*)/Algonquin alfalfa/Oxley II cicer milkvetch (C; *Astragalus cicer*) and 4) TAM: Courtney tall fescue/Yellowhead alfalfa (A)/Fleet meadow brome (M; *Bromopsis biebersteinii*). Pastures were located at Manitoba Beef and Forage Initiatives' (MBFI) Johnson Farm, Brandon, Manitoba, Canada (49.875931° N, -99.905592° W) and were 50 m wide x 370 m long.

Perennial forage treatments were seeded with a 3 m single disc, zero till drill (John Deere 752 Drill) in the spring 2015 with seeding rates for each forage based on industry cropping practices (B. Coulman, personal communication) to a depth of 1.5 cm and fertilized as described in Table 1. Pastures were re-seeded on August 21, 2015 as described in Table 1 due to poor stand establishment. Following spring visual assessment of pasture botanical composition on June 9 and 10, 2016, reseeded of TAC (tall fescue only) and TAM (tall fescue and meadow brome grass only) pastures occurred due to low plant density associated with poor stand establishment. On April 12, 2016, all pastures were fertilized based on soil tests, with specific rates for each pasture described in Table 1. Cobutox (2, 4-DB, IPCO, Winnipeg, MB, CA) was applied to all perennial pastures at a rate of 2.25 L ha⁻¹ on May 20, 2016 to control weeds. Selected high weed density areas were sprayed again with the same product and rate on June 23-24, 2016. Pastures were harvested on June 6-7, 2016 using a John Deere MOCO 946 discbine and baled for hay to remove early season

growth. Thereafter, forages were allowed to grow and stockpile for the grazing trial which started in mid-October.

The COR treatment was seeded on May 18, 2016 with an 8-row single disc opener corn planter (John Deere 7000 Corn Planter) with 76.2 cm row spacing, seeding depth of 4 cm and seeding rate of 79,074 seeds ha⁻¹. Selected areas of the corn pastures were reseeded on June 17, 2016 and July 21, 2016 due poor germination related to weed competition and a high Richardson ground squirrel rodent population. The COR pastures were sprayed with Roundup Weathermax (Bayer CropScience Canada, Calgary, AB, CA) at a rate of 1.66 L ha⁻¹, with the first application occurring after seeding (pre-emergence – May 18, 2016) and the second application (June 21, 2016) prior to the reaching the 8-leaf stage. Areas with high weed density were re-sprayed on June 29, 2016 using the same product and application rate.

Table 1. Forage treatments, seeding rates and fertilizer application utilized in the replicated perennial grass-legume and annual pastures ^a						
Pasture number	Forage species	June 2015 Seeding rate kg ha ⁻¹	August 2015 Seeding rate kg ha ⁻¹	May/June 2016 Seeding rate kg ha ⁻¹	Fertilizer application	
					May 2015 kg ha ⁻¹	April 2016 kg ha ⁻¹
9W/E	Courtenay tall fescue/ Yellowhead alfalfa/Fleet meadow bromegrass (TAM) ^b	5.2 of tall fescue and 3.4 of alfalfa. 60:40 mix	4.5 tall fescue and 6.0 meadow bromegrass 50:50 mix	tall fescue 5.6 and meadow bromegrass 11.2 ^b	53.8 monoammonium phosphate, 140.0 ammonium sulphate	70.0 ammonium sulphate, 52.8 urea, 22.5 potash
10W/E	Killarney orchard grass/Algonquin alfalfa (OGA) ^c	5.0 of orchard grass and 5.0 of alfalfa 50:50 mix	5.0 of orchard grass and 4.0 of alfalfa 50:50 mix	No reseeding		70.0 ammonium sulphate, 22.5 potash
11W/E	Courtenay tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch (TAC) ^d	4.5 of tall fescue, 2.5 of alfalfa and 7.0 of cicer milkvetch 50:25:25	4.5 of tall fescue, 2.5 of alfalfa and 7.0 of cicer milkvetch 50:25:25	tall fescue 11.2		70.0 ammonium sulphate, 22.5 potash
12W/E	Fusion corn (COR)	N/A	N/A	76.2 cm row spacing, seeding depth of 4 cm and seeding rate of 79,074 seeds ha ⁻¹	NA	21.5 monoammonium phosphate, 123.0 urea, 112.3 potash
13W/E	Courtenay tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch (TAC)	4.5 of tall fescue, 2.5 of alfalfa and 7.0 of cicer milkvetch	4.5 of tall fescue, 2.5 of alfalfa and 7.0 of cicer milkvetch 50:25:25	tall fescue 11.2	53.8 monoammonium phosphate, 140.0 ammonium sulphate	70.0 ammonium sulphate, 22.5 potash
14W/E	Killarney orchard grass/Algonquin alfalfa (OGA) ^b	5.0 of orchard grass and 5.0 of alfalfa 50:50 mix	5.0 of orchard grass and 4.0 of alfalfa 50:50 mix	No reseeding		70.0 ammonium sulphate, 22.5 potash
15W/E	Courtenay tall fescue/Yellowhead alfalfa/Fleet meadow bromegrass (TAM) ^a	5.2 of tall fescue and 3.4 of alfalfa 60:40 mix	tall fescue fleet meadow bromegrass 50:50 mix	tall fescue and fleet meadow bromegrass		70 Ammonium sulphate, 52.8 Urea, 22.5 potash

16W/E	Fusion corn (COR)	N/A	N/A	30-inch row spacing, seeding depth of 4 cm and seeding rate of 79,074 seeds ha ⁻¹	NA	21.5 Monoammonium phosphate, 123 Urea, 112.3 Potash
<p>^a Seeding rates based on industry standard for pure stands of each forage (B. Coulman, personal communication). Killarney orchard grass = 10 kg ha⁻¹, Courtney tall fescue = 9 kg ha⁻¹, Fleet meadow brome = 12 kg ha⁻¹, Algonquin alfalfa = 8 kg ha⁻¹, Yellowhead alfalfa = 8 kg ha⁻¹, Oxley II cicer milkvetch = 14 kg ha⁻¹</p>						
<p>^b Original treatment of tall fescue and yellowhead alfalfa. Due to low availability of alfalfa seed, a reduced seeding rate was used in June 2015. No Yellowhead alfalfa seed was available for August seeding, thus meadowbrome was substituted. In June 2016, meadowbrome seeding rate increased due to use of coated seed which increases seed weight</p>						
<p>^c 50:50 designation based on 5 kg ha⁻¹ orchard grass:4 kg ha⁻¹ alfalfa. Due to hard seed thus low germination rates, seeding rate of Algonquin alfalfa in June 2015 was increased by 25% (4 kg ha⁻¹ + 1 kg ha⁻¹ = 5 kg ha⁻¹). New batch utilized August 2015, thus no adjustment required.</p>						
<p>^d Seeding rate of cicer milkvetch doubled due to achieve the target 25% rate of viable seed. Only tall fescue was reseeded in June 2016.</p>						

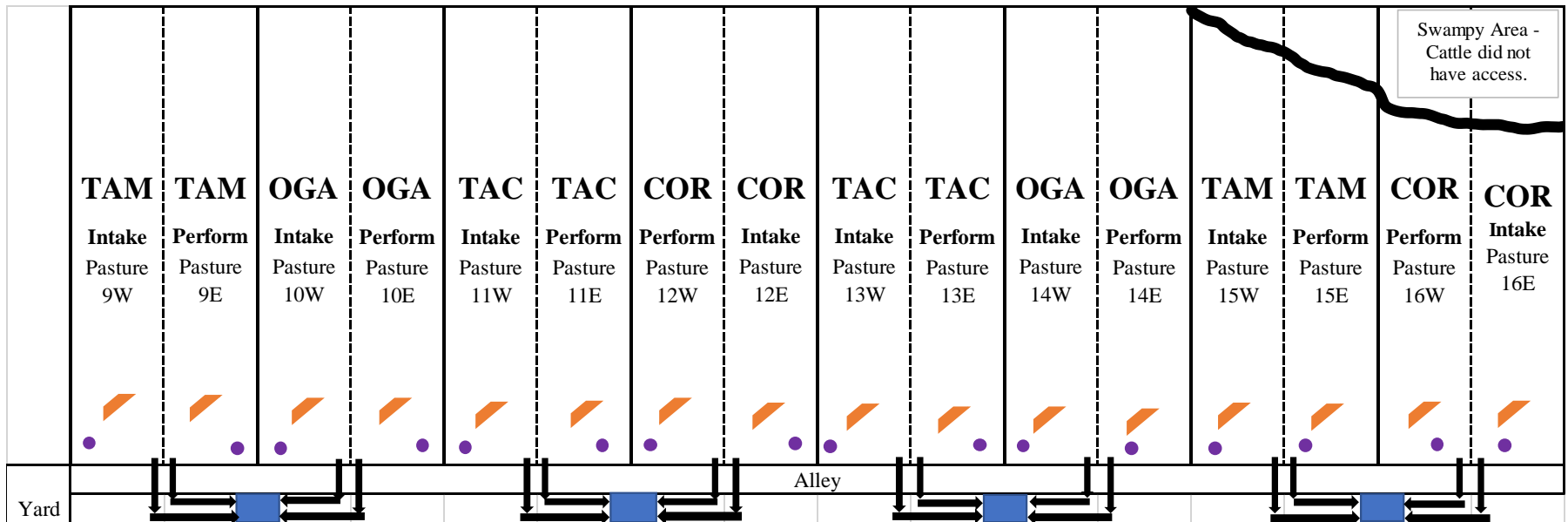


Figure 1. Layout of the four forage treatments (TAM = Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome; OGA = Killarney orchardgrass/Algonquin alfalfa; TAC = Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch) in eight, replicated 3.6 ha pastures (n=16), including the location of windbreak fences, salt/mineral feeders, waterers and designation of pastures used to measure animal intake (Intake) or live weight gain (Perform).

Legend





	Approximate location of portable windbreak fence (Dec 6 - 14, 2016)
	Heated waterer
	Approximate location of salt and mineral self feeder
	Arrows indicate animals' path to access waterer from each pen

Table 2. Forage allocations given to pregnant beef heifers while strip grazing stockpiled perennial and annual forages in the late fall and early winter.

Paddock	Forage treatment	Area given for a 1-day allocation of forage (m ²) ^z	Area given for 2-day allocation of forage (m ²) ^z
9W (intake)	TAM	326.0	652.1
9E (perform)	TAM	322.7	645.5
10W (intake)	OGA	232.9	465.8
10E (perform)	OGA	250.3	500.6
11W (intake)	TAC	167.2	334.4
11E (perform)	TAC	306.6	613.2
12W (perform)	COR	83.6	167.2
12E (intake)	COR	82.8	165.7
13W (intake)	TAC	217.4	434.7
13E (perform)	TAC	255.5	511.0
14W (intake)	OGA	315.5	631.1
14E (perform)	OGA	165.7	331.5
15W (intake)	TAM	210.4	420.7
15E (perform)	TAM	292.0	584.0
16W (perform)	COR	85.5	170.9
16E (intake)	COR	84.8	169.6

^zArea given was based on forage biomass yield (kg ha⁻¹) taken early October prior to the start of the study, heifer average BW taken on arrival at MBFI and assumed 3% forage DMI.

4.3.2 Animal Management

Animals were managed in accordance with the guidelines set out by the Canadian Council on Animal Care (2009) under the approval of the Fort Garry Campus Animal Care Committee at the University of Manitoba (Protocol #11195).

Sixty-four Angus-cross 2-yr old, heifers (542.9 ± 7.22 kg), in the first trimester of gestation, were weighed on two consecutive days and allocated to one of four pasture forage treatments based on initial live weight. As depicted in Figure 1, pastures were divided into two equal sized paddocks and designated as either “Intake” in which heifer DMI and methane output was measured or “Performance” in which live heifer weight gain, SUN and animal behaviour was measured. Four animals were assigned to each paddock. Animals were adapted to their respective paddocks for three days. Paddocks were strip-grazed using temporary electric fencing for two, 28-d grazing periods; October 20 - November 16 and November 17 - December 14, 2016. Strip area allocation in each paddock (Table 2) was based on biomass measurements taken the week prior to the start of Period 1 and initial heifer weights, assuming 3% DMI. To accommodate intake measurements, animals assigned to Intake paddocks were moved once a day. Animals assigned to Performance paddocks were given a 2-d allocation (Table 2) throughout both grazing periods. Strip grazing of the corn paddocks required that a skid steer (Bobcat model 252B; bucket width 1.89 m) knock down corn plants and the allocated forage was cross-fenced. In Period 2, once snow depth prohibited use of the skid steer, a tractor (John Deere 6125 tractor; bucket width 2.21 m) was utilized.

Heifers had ad libitum access to water via heated watering bowls and windbreak fences (Figure 1) which were placed in each paddock for shelter from d 20-28 of Period 2 when ambient temperature dropped below -18°C . The windbreak shelters were constructed with 2 - 2.5 cm thick

untreated wooden boards that were 14.5 cm wide and 248 cm tall with 5 - 7 cm gaps between boards, supported by steel pipes with perpendicular legs to make the fences self-standing. Each windbreak fence was 274 cm tall and 915 cm wide. Heifers also had ad libitum access to loose mineral (16:16 No-Salt HI C-N-Z Mineral, Masterfeeds, Brandon, MB, CA; Table 3) and cobalt iodized salt (Co-op Feeds, Brandon, MB, CA) delivered at a 50:50 ratio in mineral feeders (Meyer Manufacturing Corporation, Dorchester, WI, USA) with one feeder located per paddock (Figure 1). In addition, barley-based pelleted-supplement (Table 4) containing dotriacontane (C32; Food Science and Technology Centre, Food and Bio-Processing Division, Alberta Agriculture and Forestry, Brooks, AB, CA) as an internal marker was offered daily on d 1-13 of each of the two grazing periods to facilitate measure of forage DMI using the n-alkane external marker technique described by Boadi et al. (2002a) and Moshtaghi Nia and Wittenberg (2002). Pellets (1 kg head⁻¹ day⁻¹) were fed in individual stalls (Figure 2) and any leftover pellets that were not eaten were weighed and recorded daily on an individual animal basis. All heifers offered pellets were eating their full allotment each day by d 2 or 3 of Period 1 except for three heifers which were excluded from forage DMI analysis. Therefore, forage DMI was measured in OGA (n = 6), TAC (n = 8) and TAM (n = 7) treatments in both grazing periods.

Table 3. Profile analysis of Masterfeeds 16:16 No-Salt HI C-N-Z Mineral Premix fed to pregnant beef heifers while stockpile grazing in the late fall and early winter.

Ingredient	DM basis
Calcium (Actual %)	16.0
Phosphorus (Actual %)	16.0
Copper (Actual mg kg ⁻¹)	4,000
Manganese (Actual mg kg ⁻¹)	9,000
Zinc (Actual mg kg ⁻¹)	12,000
Cobalt (Actual mg kg ⁻¹)	70
Iodine (Actual mg kg ⁻¹)	200
Selenium (Actual mg kg ⁻¹)	60
Vitamin A (min; IU kg ⁻¹)	1,000,000
Vitamin D (min; IU kg ⁻¹)	120,000
Vitamin E (min; IU kg ⁻¹)	1,000
Fluorine (max; mg kg ⁻¹)	3,000

4.3.3 Sample collection and processing

Forage and pellet sampling and analysis

Forage samples were obtained from the Performance paddocks early in each grazing period (d 8 in Period 1 and d 27 in Period 1 (Period 2 sample)) by placing a 0.25 m² quadrat at ten locations in an M pattern. Three pre- and post-grazing forage samples were obtained prior to entry and following exit, respectively, from each Intake paddock on a daily basis from d 8 to d 12 of each grazing period. Samples were collected by randomly placing a 0.25 m² quadrat at three locations and cutting forage within the quadrat using a sickle knife at 5 - 7 cm above the soil surface. Plant height measurements were taken at the same time as quality sampling in all pastures by measuring grass, legume and corn height of a single plant of each plant species group at each sampling spot and recording the height of the tallest part of the plant. End of Period (EOP) plant and snow height samples from all forage treatments were taken on d 26 of Period 2. Snow height was measured similarly to plant height using a metre stick to measure the top of the snow cover.

Whole plant samples (5 per pasture) were obtained once per grazing period from all corn paddocks. Plants were cut in two adjacent 3.05 m long rows in the grazable area in each period at a cutting height of 15 cm. The corn was hand chopped to 5 – 10 cm, weighed and frozen for subsequent drying and chemical analysis to determine nutrient composition.

Subsamples of offered n-alkane-marked pellets were obtained daily via multiple grab samples while pellet allocations were weighed out.

Sample processing and chemical analyses

All annual and perennial forage samples and n-alkane-marked pellets were weighed following collection and stored at -20° C until further processing. Prior to analysis, samples were dried at 60° C for 48 hr and weighed to determine DM content. Samples were ground through a 1 mm screen in a Thomas Wiley Laboratory Mill Model #4 (Thomas Scientific, Swedesboro, NJ) and submitted to Central Testing Laboratory in Winnipeg, MB for wet chemistry analysis. All dried forage samples were analyzed for crude protein (CP) using a Kjeltec 1030 auto analyzer [Tecator Inc., Herndon, VI; Association of Official Analytical Chemists (AOAC) 1990, method no. 984.13], acid detergent fibre (ADF) and neutral detergent fibre (NDF) determined using an ANKOM 200 fibre analyzer (Fairport, NY), with procedures described by Komarek (1993), and gross energy (GE) analyzed using a Par 6300 Automatic Isoperibol Calorimeter (Moline, IL). Mineral analyses in feed and fecal samples were determined by inductively coupled plasma emission spectroscopy (Vista MPX ICP, Varian Canada Inc., Mississauga, ON; Method 985.01; AOAC, 2005).

In addition to the wet chemistry analysis, forage and pellet samples were analyzed for n-alkane content. N-alkane analysis was conducted on the dried and ground pellet and forage samples as described by Moshtaghi Nia and Wittenberg (2002) with the modifications described in Manafiazar et al. (2015). Briefly, a known amount of dried and ground sample was digested overnight at 90°C in an Isotemp oven (Fisher Scientific, Ottawa, ON) with ethanolic potassium hydroxide and an internal standard containing C34. After cooling, 8 ml of heptane and 8 ml of warm distilled water were added. Samples were vortexed before warming in a water bath set to between 50°C and 60°C for at least 5 mins to allow the phases to separate. Following the addition of three, 5-ml aliquots of heptane, the extract was evaporated to dryness by placing the vials in a water bath maintained between 70°C and 90°C, using compressed air to hasten the process. After dissolving the alkanes with heptane in a water bath, the solution was filtered through a silica gel column for a total of five times, rinsing the vial each time with heptane. The filtrate was then evaporated to dryness using the same method as above, and samples were prepared for the GC by adding n-undecane to the vials, warming and rinsing with the solution, and transferring to GC vials. An in-house standard with a well-characterized n-alkane profile was extracted in duplicate and analyzed between every 44th sample to ensure consistency. In addition, a blank sample was analyzed with the same frequency to ensure samples were free from contamination. The reconstituted samples were analyzed using a Varian Model 3900 gas chromatograph, set to split injection mode at 300°C. The GC was calibrated using an external standard containing all n-alkanes between C24 and C36.

Animal measurements

Animal performance

A 2-d average live weight was obtained for each heifer at the beginning and end of each grazing period (d 1, 2, and 28 of Period 1 and d 1, 27 and 28 of Period 2). Animals were weighed before daily forage allocation and ADG was calculated for both grazing periods. The BW and ADG were calculated using only weights of Performance heifers since they were only consuming the available forage and did not receive n-alkane dosed pellets.

Forage dry matter intake

Forage DMI was measured in the perennial Intake paddocks during both grazing periods using the n-alkane external marker. Three heifers were excluded from the perennial intake analysis due to low pellet consumption in Period 1. Further, intake was not measured in the corn pastures due to potential selective grazing of the cob vs. leaf/stem with variable n-alkane concentration in these plant parts (Dove et al. 1996). This lack of homogeneity in n-alkane profile between plant components and uncertainty surrounding animal selectivity rendered this method ineffective for DMI determination.

Table 4. Ingredient composition of the n-alkane marked pellets delivered to heifers on a daily basis for measurement of forage DMI.

Ingredient	% (as fed)
Ground whole barley	54.46
Ground whole wheat	20.00
Canola meal	16.00
Corn dried distillers grain with solubles (DDGS)	5.30
Canola oil	1.00
Shredded beeswax	0.70
Dotriacontane (C32)	0.04
Canola oil (to be coated post extrusion)	2.50

(Meng 2017)



Figure 2. Pregnant beef heifers consuming C32-marked pellets to facilitate measurement of intake using the n-alkane marker technique. (Credit: J.Dickson)

Fecal grab samples were taken from each heifer twice daily (in the morning prior to pellet dosing and afternoon) on d 8-12 of each grazing period. Fecal samples were frozen until drying at 60° C for 4 days. N-alkane analysis was conducted on the dried fecal samples, as described for forage and pellet samples.

Dry matter intake was calculated using the formula:

$$\text{DMI intake (kg d}^{-1} \text{ DM)} = [(F_i/F_j) \times D_j + ((D_j \times P_j) - (D_j \times P_i))]/[H_i - (F_i/F_j) \times H_j]$$

where H_i , P_i , and F_i are the concentration ($\text{mg kg}^{-1} \text{ DM}$) of the naturally occurring odd-chain alkane C31 in consumed forage, dosing pellets and feces respectively. H_j , P_j , and F_j are the equivalent concentration of the even-chained alkane C32 in consumed forage, dosing pellets and feces, respectively. D_j is the dose rate of the even-chain alkane C32 (mg d^{-1} ; Moshtaghi Nia and Wittenberg, 2002; Manafiazar et al. 2015).

Dry matter intake (% BW) was calculated using the formula:

$$\text{DMI intake (\% BW)} = [\text{DMI (kg d}^{-1})/\text{BW (kg)}] \times 100$$

Start of Period 1 and start of Period 2 BWs were used to calculate DMI intake (% BW).

Digestible energy intake (DEI) was calculated using the following formula (National Research Council, 2016):

$$\text{DEI (Mcal d}^{-1}\text{)} = [\text{TDN (\%)/100}] \times \text{DMI (kg d}^{-1}\text{)} \times 4.409$$

Serum Urea Nitrogen

Blood samples were obtained from each heifer on d 1 of Period 1 and 2 and d 28 of Period 2 via tail vein or jugular vein into serum separator vacutainers (10 ml; BD, Mississauga, ON, CA) containing clotting activator. Serum was extracted from each separated sample in a centrifuge. Urea nitrogen levels were measured using a colorimetric test with a Vitros 250 BUN method (Ortho-Clinical Diagnostics Inc., Rochester, NY, USA) with analysis performed by Veterinary Diagnostic Services (Manitoba Agriculture and Resource Development, Winnipeg, MB, CA). The minimum recommended threshold for SUN in beef cattle is 2.1 mmol L⁻¹ (Hammond, 1994).

Greenhouse gas emissions

Enteric CH₄ and carbon dioxide (CO₂) emissions were determined using the sulfur hexafluoride (SF₆) tracer gas method as described by Boadi et al. (2002b) and Johnson et al. (1994). In brief, stainless-steel permeation tubes (12.5 mm x 40 mm) were filled with SF₆, incubated at 39°C and weighed weekly for 15 wks to ensure consistent gas release. The average release rate of SF₆ from the permeation tubes was 650.54 ng min⁻¹, calculated using an average of

the last 4 wks of measurement. Permeation tubes were inserted into the rumen using a metal speculum on d 1 of Period 1 to allow the SF₆ tracer gas to equilibrate in the rumen.

Enteric CH₄ emissions were measured once (24-hr measurement) in each grazing period which was d 13 in Period 1 and d 15 in Period 2. The collection apparatus (Figure 3) consisted of an evacuated stainless-steel ball (130 mm diameter) connected to 900 mm of capillary tubing (128 µm internal diameter), with a 15 µm filter and a flexible nose piece designed to collect exhaled gases from the heifer's nose and mouth. The collection apparatus was connected to a collar placed around the animal's neck. The steel balls were evacuated immediately prior to being connected to the capillary tubing on the halter. Once connected, the valve was turned to the open position, the time recorded, and the heifers returned to their respective pastures for 24 hrs. During the 24-hr collection period, a background ball and halter were placed in a metal grazing cage, to correct for the background CH₄ and CO₂. After 24 hrs, the pressure in the ball was measured following apparatus removal and those with a pressure of 200 – 650 mm Hg and without any visible damage or blockage in the hose canisters were pressurized with 10 psi of N₂ to prevent sample contamination and to facilitate injection of samples into the gas chromatograph. Gas samples were subsequently analyzed for SF₆, CH₄, and CO₂ using a gas chromatograph (Agilent 7890B Series GC Custom, Agilent, Santa Clara, CA).

Daily CH₄, as well as CO₂ produced from heifers with a positive energy balance, were calculated using the following formulas (Boadi et al. 2002^b):

$$\text{CH}_4 (\text{L min}^{-1}) = \text{permeation tube SF}_6 \text{ release rate (L min}^{-1}) \times [\text{CH}_4 (\text{ng kg}^{-1})]/[\text{SF}_6 (\text{ng kg}^{-1})]$$

$$\text{CO}_2 (\text{L min}^{-1}) = \text{permeation tube SF}_6 \text{ release rate (L min}^{-1}) \times [\text{CO}_2 (\text{ng kg}^{-1})]/[\text{SF}_6 (\text{ng kg}^{-1})]$$

where concentrations of CH₄ and SF₆ are represented in the equation as [CH₄] and [SF₆] respectively, adjusted for the removal of background concentrations of CH₄ and SF₆.



Figure 3. Halter and vacuum ball fitted to each intake heifer to measure CH₄ output while grazing over a 24-hr period; A = intake tube where CH₄, SF₆, and CO₂ emissions are captured from the nose and mouth, B = tubing that transfers the exhaled from the heifer's nose and mouth to the evacuated collection ball, C = stainless steel vacuum ball that collects exhaled air.

Grazing behaviour

Lotek 3300L GPS collars (Lotek, Newmarket, ON, CA) were fitted to 30 heifers (OGA and TAM, n = 7; COR and TAC, n = 8 per treatment) due to collar availability during Periods 1 and 2. Collars were programmed to record location fixes every 10 minutes during the daylight hours (05:00 – 21:00) and every 30 minutes after sunset (21:00 – 05:00). Collars were tested on d 1 of each period and randomly throughout the trial using a receiver to ensure batteries were operational in the extreme cold. Data was downloaded on d 28 of Period 1 and collars were then placed on the same animal on d 1 of Period 2 where they remained until d 28 of Period 2. Three different behaviors were measured using GPS collar data; i) time spent at the windbreak shelter, ii) time spent at the waterer, and iii) distance travelled. Grazing behaviour data from d 1-14 of each

grazing period was removed since cattle did not have access to water throughout the day due to sampling procedures in other pastures therefore only GPS data from d 15-28 (14 days) was used for each grazing period. Time of day used in the GPS analysis was calculated using average time of sunrise and sunset (National Research Council Canada, 2018) during sampling days.

Time spent at the windbreak shelters was estimated from the GPS location of the shelter and the GPS fixes of the collar. If the fix location was within 10 m from the shelter, time elapsed between fixes was estimated as the time spent at shelter. Time spent at shelter during average daylight and nighttime hours between Dec. 6-13, 2016 (08:30-16:40); night = average nighttime hours (16:40-08:30) was measured on d 20-27 of Period 2 since the windbreak shelters were not in place prior to this time.

Time spent at the waterers was estimated in the same manner as time at shelter using time that elapsed between the change in location of the GPS fixes. However, time at water was measured on d 15-27 of both grazing periods (November 3-15 and December 1-13, 2016) but was not measured during n-alkane intake dosing as heifers did not have access to waterers for short periods of time on those dates. Daylight hours of 07:40-17:00 and 08:20-16:40 for d 15-27 during Period 1 (Nov. 3-15, 2016) and Period 2 (Dec. 1-13, 2016), respectively, were determined using average time of sunrise and sunset (National Research Council Canada, 2018)

Distance traveled by each heifer for a 24-hr period was estimated by calculating the distance between locations during the same days and daylight hours used to measure time spent at water, as described above.

4.3.4 Statistical analysis

This experiment was analyzed as a RCBD with $n = 4$ heifers in each of four paddock (two performance and two intake paddocks) replicates for each of the four forage treatments. Data from the two grazing periods were treated as repeated measures. For BW and SUN, Start of Trial (SOT) and for plant height, End of Period (EOP) numbers were ran as a third repeated measure with grazing period fixed effect. Intake measurements did not include COR treatment. Data were analyzed using the Proc Mixed procedure of SAS version 9.4 (SAS Inst. Inc., Cary, NC) for all analyses. Fixed effects were forage treatment and grazing period, with a treatment x period interaction. For grazing behavior analysis, the fixed effects were forage treatment, grazing period, and time of day (night or day) with interactions of treatment x period, treatment x time of day, period x time of day, and treatment x period x time of day. A t-test was used to determine significance between values for all the variables run in SAS with significance being $P < 0.05$. Normality of the data and homogeneity of variance were tested using the protected LSD test with the results reported in least squared means and the standard error of the mean.

The statistical model used for the analysis of the data (forage yield and nutritive values, ADG, and methane/carbon dioxide output) was:

$$y_{ijk} = \mu + f_i + p_j + fp_{ij} + e_{ijk}$$

where f = the effect of the i^{th} forage treatment, p = the effect of the j^{th} grazing period, fp = the interaction effects of the i^{th} forage treatment and the j^{th} grazing period and e = the error deviation of the k^{th} bred heifer of the i^{th} forage treatment in the j^{th} grazing period. In this study $i = 1$ to 4 (forage treatment, 1 = COR, 2 = OGA, 3 = TAC or 4 =TAM), $j = 1$ to 2 (2 consecutive 28-d periods) and $k = 1$ to 64 bred heifers.

The statistical model used for the analysis of the data (DMI) was:

$$y_{ijk} = \mu + f_i + p_j + fp_{ij} + e_{ijk}$$

where f = the effect of the i^{th} forage treatment, p = the effect of the j^{th} grazing period, fp = the interaction effects of the i^{th} forage treatment and the j^{th} grazing period and e = the error deviation of the k^{th} bred heifer of the i^{th} forage treatment in the j^{th} grazing period. In this study $i = 1$ to 3 (forage treatment, 1 = OGA, 2 = TAC or 3 =TAM), $j = 1$ to 2 (2 consecutive 28-d periods) and $k = 1$ to 21 bred heifers.

The statistical model used for the analysis of the data (forage plant height, BW and SUN) was:

$$y_{ijk} = \mu + f_i + p_j + fp_{ij} + e_{ijk}$$

where f = the effect of the i^{th} forage treatment, p = the effect of the j^{th} grazing period, fp = the interaction effects of the i^{th} forage treatment and the j^{th} grazing period and e = the error deviation of the k^{th} bred heifer of the i^{th} forage treatment in the j^{th} grazing period. In this study $i = 1$ to 4 (forage treatment, 1 = COR, 2 = OGA, 3 = TAC or 4 =TAM), $j = 1$ to 3 (2 consecutive 28-d periods and Start of Trial (SOT) or End of Period (EOP)) and $k = 1$ to 32 bred heifers.

Three intake heifers were excluded from DMI calculations as they did not consume a sufficient quantity of the n-alkane tracer pellets in Period 1. All animals that were fitted with GPS collars had successful readings (30 out of 32 Performance heifers) but two Performance heifers did not have GPS collars due to lack of collar availability.

Enteric CH₄ and CO₂ emissions are reported in Table 14 for Period 1 only as only 10 of the 32 heifers with collection harnesses had successful gas collection observations in Period 2. Poor

collections were the result of snow plugging the vacuum hose over the nostrils. Thus, with insufficient data points for adequate replication as well as weight loss during Period 2, CH₄ and CO₂ data from Period 2 were removed from the analysis. In Period 1 collection of CH₄ and CO₂, 24 out of the 32 heifers with collection harnesses had successful gas collection observations. Damage to the collection device by the animal on pasture resulted in missing observations. Time at shelter was only determined for d 20 – 27 of Period 2 when the shelters were placed on pasture.

The statistical model used for the analysis of the grazing behavior data was:

$$y_{ijk} = \mu + f_i + p_j + d_m + fp_{ij} + fd_{im} + pd_{jm} + fpd_{ijm} + e_{ijk}$$

where f = the effect of the i^{th} forage treatment, p = the effect of the j^{th} grazing period, d = the effect of the m^{th} time of day, fp = the interaction effects of the i^{th} forage treatment and the j^{th} grazing period, fd = the interaction effects of the i^{th} forage treatment and the m^{th} time of day, pd = the interaction effects of the j^{th} grazing period and the m^{th} time of day, fpd = the interaction effects of the i^{th} forage treatment and the j^{th} grazing period and the m^{th} time of day, and e = the error deviation of the k^{th} bred heifer of the i^{th} forage treatment in the j^{th} grazing period of the m^{th} time of day. In this study $i = 1$ to 4 (forage treatment, COR, OGA, TAC or TAM), $j = 1$ to 2 (2 consecutive 28-d periods), $m =$ day light or nighttime, and $k = 1$ to 64 bred heifers.

4.4 RESULTS

4.4.1 Weather

The air temperature ($^{\circ}\text{C}$) and wind speed (km hr^{-1}), depicted in Table 6, were collected from an Agriculture and Agri-Food Canada Weather Station located at Chater Lagoon, 3 km east of the study site. Precipitation, depicted below in Table 7, was collected from an Environment Canada Weather Station at Brandon Airport located 4 km north west of the study site. Snow height (Table 5) was measured on d 26 of Period 2 within the grazing area of each pasture.

Table 5. Snow height in perennial and annual stockpiled grazed pastures taken on d 26 of Period 2.

	Treatment ^z			
	COR	OGA	TAC	TAM
Snow height (cm)	25.2	19.7	29.7	21.7

^zForage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome grass.

Table 6. Average, maximum and minimum air temperature and wind speed in Brandon, Manitoba, Canada during late fall/early winter stockpile grazing trial.

	Grazing Period		
	1	2	d 20-27 of Period 2 ^z
Daily Average Air Temperature ($^{\circ}\text{C}$)	5.1	-7.3	-18.1
Daily Minimum Air Temperature ($^{\circ}\text{C}$)	-7.7	-29.7	-29.7
Daily Maximum Air Temperature ($^{\circ}\text{C}$)	18.6	6.4	-3.7
Daily Average Wind Speed (km hr^{-1})	10.4	13.9	17.7
Daily Minimum Wind Speed (km hr^{-1})	0.0	0.3	2.9
Daily Maximum Wind Speed (km hr^{-1})	36.2	39.2	39.2

^zTime spent at windbreak fence shelter was measured on d 20-27 of Period 2.

Table 7. Total precipitation, rain and snowfall during October, November and December 2016 at Brandon, Manitoba, Canada.

Month	Total Precipitation (mm)	Rain (mm)	Snow (cm)
October	108.2	108.2	-
November	10.2	3.2	8.2
December	50.2	-	56.0

4.4.2 Nutrient composition, yield, and plant height of stockpiled forages

Intake and Performance pasture forage yield, plant height and nutrient composition of annual and perennial stockpiled forages followed a similar pattern, however they are discussed separately given that there were differences in yield and several nutrients.

Forage yield

Performance pastures

Forage biomass yield of COR (6,342 kg DM ha⁻¹) was 68%, 79% and 57% higher (P=0.011) than OGA, TAC, and TAM, respectively, which did not differ from each other (P<0.011; Table 8). Neither period nor treatment x period interactions (P>0.05) were observed for forage yield in Performance pastures.

Intake pastures

No significant treatment, period or treatment x period interactions were observed for forage yield in the Intake pastures (P>0.05; Table 9). However, there was a tendency (P=0.082) for COR biomass (6262 kg DM ha⁻¹) to be greater than the perennial treatments.

Dry matter

Performance pastures

Forage dry matter of COR (65.24%) was 31%, 51% and 44% higher ($P=0.003$; Table 8) than OGA, TAC and TAM respectively, which did not differ from each other. Average (DM) was higher in Period 2 (61.45%) than Period 1 (40.32%; $P<0.001$). No significant treatment x period interaction was observed for forage DM in the performance pastures ($P>0.05$; Table 8).

Intake pastures

Forage DM content of COR (63.12%) was 27%, 50% and 44% higher than OGA, TAC and TAM respectively. Dry matter of OGA (49.78%) was 18% and 14% higher than TAC and TAM respectively, which did not differ from each other ($P<0.001$; Table 9). Period 2 forage DM (58.42%) was higher than Period 1 (40.98%; $P<0.001$). No significant treatment x period interaction was observed for forage DM in the intake pastures however there was a trend towards significance ($P=0.05$; Table 9).

Plant height

Performance pastures

Height of OGA was 26% and 22% less ($P=0.009$) than TAC and TAM respectively, which did not differ from each other (Table 8). Average height of all treatments did not differ between Period 1 and 2 when measured on d 27 of Period 1 (34.3 vs 33.9 cm, respectively), however, height at EOP (15.2 cm) was 56% and 55% lower than Period 1 and 2, respectively ($P<0.001$).

There was no difference in legume height between the perennial forage treatments ($P=0.659$; Table 8), however a significant period effect was observed ($P=0.018$). As per the

grasses, EOP height of legumes (40.8 cm) was 22% and 24% less than start of Period 1 (52.1 cm) and Period 2 (53.4 cm), respectively, which did not differ from each other.

Corn height did not differ between Period 1 and 2, however EOP height (151.7 cm) was 20% less than the start of Period 1 (189.3 cm; $P < 0.05$).

Intake pastures

Height of TAC (27.8 cm) and TAM (24.0 cm) was 32% and 14% higher than OGA, respectively (21.1 cm; $P < 0.05$; Table 9). There was a significant difference in grass plant heights between grazing periods ($P < 0.05$), as Period 1 (32.0 cm) was 17% higher than Period 2 (27.3 cm) and EOP plant heights were shorter than when measured in Period 1 and 2 (13.6 cm).

There was a significant difference in legume height ($P < 0.05$; Table 9) as OGA (52.4 cm) and TAC (53.0 cm) were taller than TAM (39.5 cm). No significant effect ($P > 0.05$) of period on legume height was observed.

Corn height was 14% and 42%, greater at the beginning of Period 1 (198.6 cm), compared to Period 2 (174.2 cm) and EOP (140.0 cm) respectively.

Nutrient composition

Performance pastures

Crude protein concentration differed between treatments as TAC was 50%, 21% and 42% higher ($P < 0.001$) than COR, OGA and TAM, respectively (Table 10). Period differences were also observed for CP concentration, with Period 1 being 21% higher ($P < 0.006$) than Period 2. No

significant period effects were observed for the other nutrients measured. A significant period x treatment interaction was observed for NDF ($P=0.019$, Figure 4). In Period 1, OGA had a 12%, 8%, and 37% higher NDF concentration than TAC, TAM and COR, while TAC (58.66%) and TAM (60.62%) were similar and significantly higher than COR (47.83%). In Period 2, NDF concentration in COR (42.17%) was 12 % lower than in Period 1 and lower than the perennial treatments in Period 1 and 2.

No significant treatment x period interactions were observed in the nutrient composition of the stockpiled performance pastures except for NDF. The NDF concentrations for OGA (68.42%) and TAM (64.91%) did not differ from each other in Period 2, however TAM was 7% higher than in Period 1 while OGA did not differ between the two periods. In Period 2, NDF concentration of TAC (60.04%) was the lowest of the three perennial treatments and did not differ from Period 1.

Acid detergent fibre also differed ($P<0.001$) between annual and perennial treatments, as OGA was 23% and 20% higher than TAC and TAM, respectively, which did not differ from each other, and approximately 103% higher than COR. The COR treatment had the highest TDN concentration ($P<0.001$) compared to the perennial treatments; 61% higher than OGA and 31% and 34% higher than TAC and TAM, respectively, which did not differ from each other. A similar profile was apparent for DE, ME, NE_{main} , NE_{gain} , and NFC whereby COR was higher than all perennial forage treatments, while energy of TAC and TAM were higher than OGA but did not differ from each other.

Phosphorus ($P=0.301$) and Na ($P=0.441$) concentrations did not differ between forage treatments in the performance pastures. Calcium concentration was highest in OGA (0.75%), followed by TAC (0.64%), TAM (0.55%) and COR (0.12%) with all four treatments being significantly different ($P<0.001$) from each other. Magnesium concentrations did not differ

between TAC and TAM; however, TAC was 26% and 107% greater than OGA and COR, respectively ($P < 0.001$; Table 10). Further, Mg concentrations did not differ between OGA and TAM. Similarly, K concentrations did not differ between TAC and TAM, however, TAC was 57% and 120% greater than COR and OGA, which did not differ from each other ($P < 0.013$; Table 10).

Intake pastures

In the Intake pastures, CP concentrations differed ($P < 0.001$) between forage treatments; TAC was 20%, 67% and 61% greater than OGA, TAM, and COR respectively (Table 11). No significant period or period x treatment interactions were observed for CP, P, Ca, Mg, Na, or K in the stockpiled Intake pastures ($P > 0.05$; Table 11). However, significant treatment x period interactions were observed for NDF, ADF, TDN, DE, ME, NE_{main} , NE_{gain} , and NFC ($P < 0.05$, Table 6). The NDF and ADF concentrations were highest in OGA and lowest in COR across both periods. Although TAC and TAM had similar ADF and NDF concentrations in Period 2 ($P < 0.05$; Table 12), TAM NDF was 7% higher than TAC in Period 1. Concentrations of TDN, DE, ME, and NE_{main} , followed a similar treatment x period interaction pattern ($P < 0.05$; Table 12). The highest energy concentrations were observed in COR in Period 2, which were 4%, 4%, 4%, and 5% higher, expressed as TDN, DE, ME, and NE_{main} , respectively, compared to Period 1 and significantly higher than the perennial treatments in both periods. There were no differences between COR NE_{gain} in Period 1 and 2. Regardless of the unit of measure, energy concentration between TAC and TAM did not differ from each other in either Period 1 or 2, nor did they differ within treatments between periods except for TAC in which ME was 5% higher in Period 1 compared to Period 2. The lowest energy concentrations ($P < 0.05$) were observed in OGA in Period 2, regardless of the unit of measure, which were 8%, 8%, 8%, 16% and 38% lower for TDN, DE,

ME, NE_{main} , NE_{gain} , respectively in Period 1 and lower than COR, TAC and TAM in both periods. Following a similar pattern to that observed with energy, COR had the highest NFC in Period 2 which was 15% higher than Period 1 and greater than the other treatments in both periods. Conversely, OGA had the lowest ($P < 0.001$) overall NFC in Period 2, which was 20% lower in Period 1 compared to Period 2. The NFC concentrations for TAC and TAM were intermediate to COR and OGA and although they did not differ from each other in Period 1 or Period 2, TAC was 15% higher in Period 1 than in Period 2 while TAM did not differ between periods.

Phosphorus and Na did not differ between forage treatments ($P > 0.05$; Table 11). Calcium concentrations were highest in OGA (0.84%), which did not differ from TAC (0.73%), but were 42% and 546% higher than TAM and COR, respectively ($P < 0.001$; Table 11). Magnesium concentration was significantly lower in COR compared to the perennial forage treatments ($P = 0.001$) which did not differ from each other. Concentrations of K did not differ between the perennial forage treatments, but TAC and TAM were significantly higher than COR which did not differ from OGA ($P = 0.018$; Table 11). A period effect was observed for Ca and Mg concentrations which were 43% and 30% higher, respectively in Period 2 compared to Period 1 in the stockpiled forages ($P < 0.05$; Table 11). There were no significant treatment x period interactions observed for any of the minerals ($P > 0.05$).

Table 8. Forage yield, dry matter content (DM) and plant height of perennial and annual stockpiled forages in Performance pastures over two 28-d periods in the late fall and early winter^z (n=8).

	Treatment (T) ^w				SE	<i>P-Value</i>	Grazing Period (P) ^y			SE	<i>P-Value</i>	<i>TxP P-Value</i>
	COR	OGA	TAC	TAM			1	2	EOP			
Forage yield (kg DM ha ⁻¹)	6,342 ^a	3,871 ^b	3,587 ^b	4,044 ^b	469.8	0.011	4,476	4,446	-	332.2	0.952	0.664
Dry matter (%)	65.24 ^a	49.95 ^b	43.09 ^b	45.27 ^b	2.886	0.003	40.32 ^b	61.45 ^a	-	2.041	<0.001	0.317
Grass height (cm)	-	23.0 ^b	31.2 ^a	29.3 ^a	1.50	0.009	34.3 ^a	33.9 ^a	15.2 ^b	1.50	<0.001	0.340
Legume height (cm)	-	50.0	49.6	46.7	2.72	0.659	52.1 ^a	53.4 ^a	40.8 ^b	2.72	0.018	0.250
Corn height (cm)	170.0	-	-	-	3.31	-	189.3 ^a	169.1 ^{ab}	151.7 ^b	5.74	0.043	-

^zWithin a treatment or within period within a row, means without a common superscript differ (P<0.05).

^yPeriod 1 forage samples and heights were taken on d 8 (perennial) and d 11 (annual). Period 2 forage samples and heights were taken on d 26 in Period 1. End of period (EOP) heights measured on d 26 of Period 2 following snowfall (24 cm).

^wForage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

Table 9. Forage yield, dry matter (DM) and plant height of perennial and annual stockpiled forages in Intake pastures grazed by bred beef heifers over two 28-d periods in the late fall and early winter^z (n=8).

	Treatment (T) ^w				SE	<i>P-Value</i>	Grazing Period (P) ^y			SE	<i>P-Value</i>	<i>TxP P-Value</i>
	COR	OGA	TAC	TAM			1	2	EOP			
Forage yield (kg DM ha ⁻¹)	6,262	4,006	4,265	4,490	568.7	0.082	4,537	4,974	-	402.1	0.465	0.846
Dry matter (%)	63.12 ^a	49.78 ^b	42.13 ^c	43.77 ^c	1.055	<0.001	40.98 ^b	58.42 ^a	-	0.746	<0.001	0.050
Grass height (cm)	-	21.1 ^b	27.8 ^a	24.0 ^a	1.41	0.025	32.0 ^a	27.3 ^b	13.6 ^c	1.41	<0.001	0.817
Legume height (cm)	-	52.4 ^a	53.0 ^a	39.5 ^b	1.93	0.001	49.8	50.6	44.5	1.93	0.101	0.863
Corn height (cm)	170.9	-	-	-	2.75	-	198.6 ^a	174.2 ^b	140.0 ^c	4.77	0.007	-

^zWithin a treatment or within period within a row, means without a common superscript differ (P<0.05).

^yPeriod 1 forage samples and heights were taken on d 8 (perennial) and d 11 (annual). Period 2 forage samples and heights were taken on d 26 in Period 1. End of period (EOP) heights measured on d 26 of Period 2 following snowfall (24 cm).

^wForage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

Table 10. Nutrient composition (% DM unless otherwise stated) of perennial and annual stockpiled forages in performance pastures grazed by bred beef heifers over two 28-d periods in the late fall and early winter^z (n=8).

	Treatment (T) ^y				SE	<i>P-Value</i>	Grazing Period (P)		SE	<i>P-Value</i>	<i>TxP</i> <i>P-Value</i>
	COR	OGA	TAC	TAM			1	2			
Crude Protein	6.87 ^c	8.51 ^b	10.29 ^a	7.25 ^{bc}	0.423	<0.001	9.00 ^a	7.46 ^b	0.299	0.006	0.133
Neutral Detergent Fibre	45.00 ^d	67.07 ^a	59.35 ^c	62.76 ^b	0.890	<0.001	58.21	58.88	0.629	0.471	0.019
Acid Detergent Fibre	24.80 ^c	50.37 ^a	40.91 ^b	41.90 ^b	0.982	<0.001	39.1	39.89	0.695	0.442	0.120
Total Digestible Nutrients	72.14 ^a	44.83 ^c	54.93 ^b	53.87 ^b	1.050	<0.001	56.87	56.02	0.742	0.443	0.120
Digestible Energy (Mcal kg ⁻¹)	3.18 ^a	1.98 ^c	2.42 ^b	2.38 ^b	0.047	<0.001	2.51	2.47	0.033	0.459	0.136
Metabolizable Energy (Mcal kg ⁻¹)	2.64 ^a	1.64 ^c	2.01 ^b	1.97 ^b	0.039	<0.001	2.08	2.05	0.028	0.464	0.128
Net Energy for Maintenance (Mcal kg ⁻¹)	1.73 ^a	0.80 ^c	1.16 ^b	1.13 ^b	0.035	<0.001	1.22	1.19	0.024	0.326	0.130
Net Energy for Gain (Mcal kg ⁻¹)	1.11 ^a	0.27 ^c	0.60 ^b	0.57 ^b	0.032	<0.001	0.65	0.62	0.022	0.320	0.124
Non-fibre Carbohydrates	37.34 ^a	13.62 ^c	19.57 ^b	19.19 ^b	0.816	<0.001	21.99	22.86	0.577	0.316	0.061
Minerals											
Phosphorus	0.22	0.18	0.23	0.2	0.021	0.301	0.23	0.18	0.015	0.052	0.883
Calcium	0.12 ^d	0.75 ^a	0.64 ^b	0.55 ^c	0.023	<0.001	0.54	0.49	0.017	0.06	0.831
Magnesium	0.14 ^c	0.23 ^b	0.29 ^a	0.25 ^{ab}	0.013	<0.001	0.22	0.23	0.009	0.455	0.639
Sodium	0.01	0.01	0.013	0.01	0.001	0.441	0.01	0.01	0.001	0.347	0.441
Potassium	0.69 ^c	0.97 ^{bc}	1.52 ^a	1.38 ^{ab}	0.145	0.013	1.27	1.02	0.103	0.125	0.958

^zWithin a treatment or within period within a row, means without a common superscript differ (P<0.05).

^yForage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

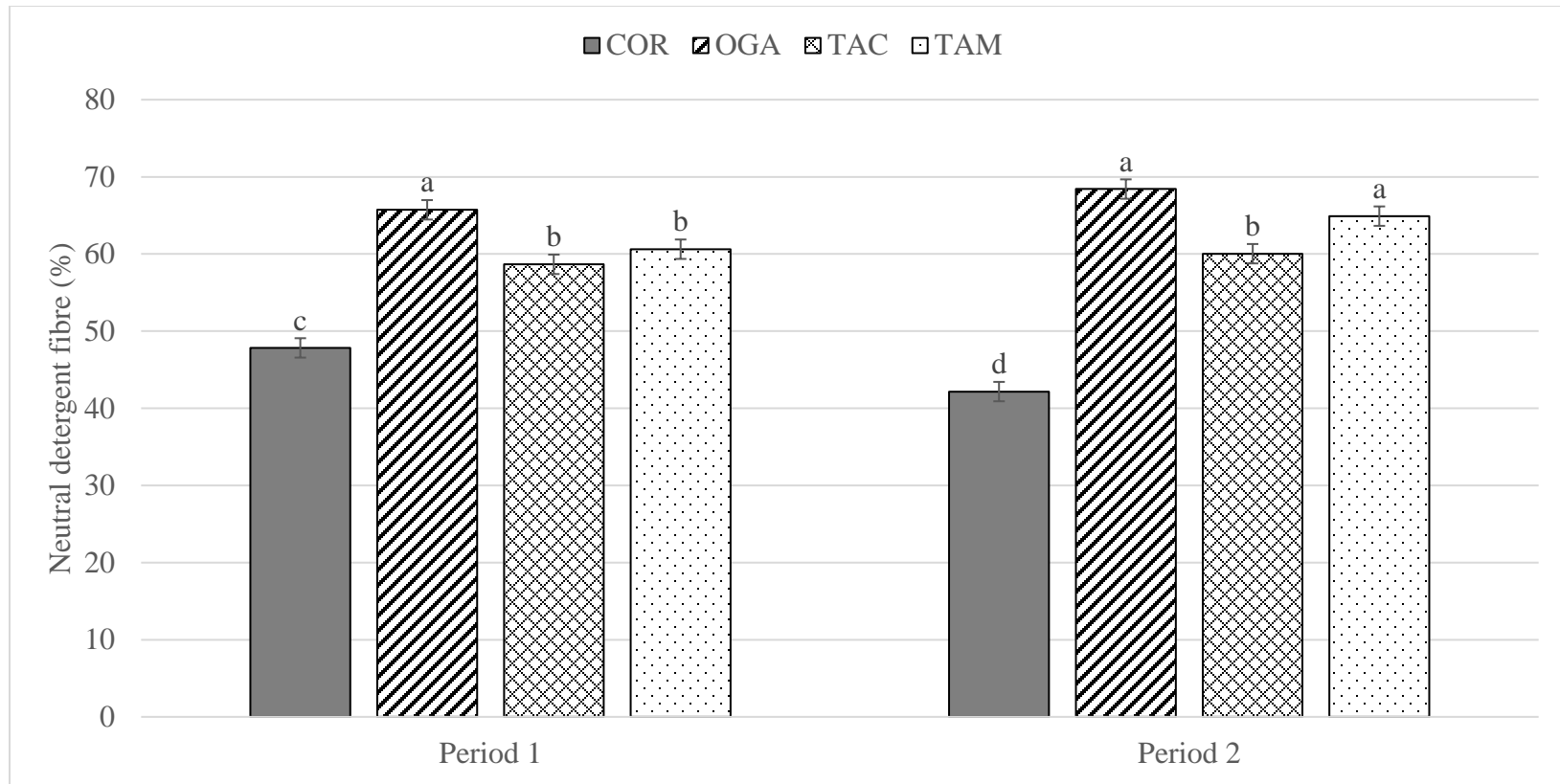


Figure 4. The neutral detergent fibre (%) profile of perennial and annual stockpiled forages grazed by bred beef heifers over two 28-d grazing periods in the late fall and early winter on Performance pastures; Forage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

Table 11. Nutrient composition (% DM unless otherwise stated) of perennial and annual stockpiled Intake pastures grazed by bred beef heifers over two 28-d periods in the late fall and early winter^z

	Treatment (T) ^y				SE	<i>P-Value</i>	Grazing Period (P)		SE	<i>P-Value</i>	<i>TxP</i> <i>P-Value</i>
	COR	OGA	TAC	TAM			1	2			
Crude Protein	6.76 ^c	9.08 ^b	10.90 ^a	6.51 ^c	0.519	0.001	8.78	7.84	0.367	0.107	0.607
Neutral Detergent Fibre	45.39 ^d	67.37 ^a	61.23 ^c	64.58 ^b	0.750	<0.001	59.00	60.29	0.530	0.123	0.007
Acid Detergent Fibre	25.03 ^c	50.14 ^a	43.66 ^b	42.81 ^b	0.552	<0.001	39.80	41.02	0.390	0.059	0.018
Total Digestible Nutrients	71.90 ^a	45.07 ^c	52.00 ^b	52.90 ^b	0.591	<0.001	56.11	54.82	0.418	0.059	0.019
Digestible Energy (Mcal kg ⁻¹)	3.17 ^a	1.99 ^c	2.29 ^b	2.33 ^b	0.026	<0.001	2.47	2.42	0.019	0.065	0.020
Metabolizable Energy (Mcal kg ⁻¹)	2.63 ^a	1.65 ^c	1.90 ^b	1.94 ^b	0.021	<0.001	2.06	2.01	0.015	0.052	0.017
Net Energy for Maintenance (Mcal kg ⁻¹)	1.72 ^a	0.81 ^c	1.06 ^b	1.09 ^b	0.021	<0.001	1.20 ^a	1.15 ^b	0.015	0.041	0.019
Net Energy for Gain (Mcal kg ⁻¹)	1.11 ^a	0.27 ^c	0.51 ^b	0.54 ^b	0.019	<0.001	0.63 ^a	0.58 ^b	0.014	0.044	0.028
Non-fibre Carbohydrates	37.06 ^a	12.76 ^c	17.07 ^b	18.12 ^b	0.429	<0.001	21.43	21.08	0.303	0.438	0.001
Minerals											
Phosphorus (%)	0.20	0.19	0.23	0.17	0.016	0.160	0.20	0.20	0.011	0.940	0.492
Calcium (%)	0.13 ^c	0.84 ^a	0.73 ^{ab}	0.59 ^b	0.055	<0.001	0.47 ^b	0.67 ^a	0.039	0.005	0.183
Magnesium (%)	0.14 ^b	0.23 ^a	0.28 ^a	0.27 ^a	0.016	0.001	0.20 ^b	0.26 ^a	0.012	0.011	0.229
Sodium (%)	0.01	0.01	0.01	0.01	0.001	0.441	0.01	0.01	0.001	0.347	0.441
Potassium (%)	0.56 ^b	1.05 ^{ab}	1.57 ^a	1.31 ^a	0.173	0.018	1.04	1.21	0.123	0.345	0.873

^zWithin a treatment or within period within a row, means without a common superscript differ ($P < 0.05$).

^yForage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

Table 12. Stockpiled forage treatment and grazing period interaction of nutrient composition (% DM unless otherwise stated) of perennial and annual stockpiled intake pastures grazed by bred beef heifers for two 28-d grazing periods in the late fall and early winter^z

	Treatment (T) ^y x Grazing Period (P)								SE	<i>TxP</i> <i>P-Value</i>
	1				2					
	COR	OGA	TAC	TAM	COR	OGA	TAC	TAM		
Neutral Detergent Fibre	47.89 ^d	64.98 ^b	59.51 ^c	63.62 ^b	42.90 ^e	69.76 ^a	62.96 ^{bc}	65.54 ^b	1.060	0.007
Acid Detergent Fibre	26.41 ^e	48.42 ^b	42.56 ^{cd}	41.83 ^d	23.65 ^f	51.87 ^a	44.76 ^c	43.80 ^{cd}	0.780	0.018
Total Digestible Nutrients	70.43 ^b	46.91 ^e	53.17 ^{cd}	53.95 ^c	73.38 ^a	43.23 ^f	50.82 ^d	51.84 ^{cd}	0.835	0.019
Digestible Energy (Mcal kg ⁻¹)	3.11 ^b	2.07 ^e	2.34 ^{cd}	2.38 ^c	3.24 ^a	1.91 ^f	2.24 ^d	2.29 ^{cd}	0.037	0.020
Metabolizable Energy (Mcal kg ⁻¹)	2.58 ^b	1.72 ^e	1.95 ^c	1.98 ^c	2.69 ^a	1.58 ^f	1.86 ^d	1.90 ^{cd}	0.030	0.017
Net Energy for Maintenance (Mcal kg ⁻¹)	1.68 ^b	0.88 ^e	1.10 ^{cd}	1.13 ^c	1.77 ^a	0.74 ^f	1.02 ^d	1.05 ^{cd}	0.029	0.019
Net Energy for Gain (Mcal kg ⁻¹)	1.07 ^a	0.34 ^d	0.55 ^{bc}	0.57 ^b	1.15 ^a	0.21 ^e	0.47 ^c	0.51 ^{bc}	0.027	0.028
Non-fibre Carbohydrates	34.52 ^b	14.14 ^e	18.25 ^c	18.80 ^c	39.60 ^a	11.39 ^f	15.89 ^{de}	17.43 ^{cd}	0.606	0.001

^zWithin a treatment or within period within a row, means without a common superscript differ (P<0.05).

^yForage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

4.4.3 Animal performance and feed intake

Body weight and average daily gain

Heifer SOT BW were similar between treatments (Figure 5) and all weighed significantly more at the end of Period 1 than they did at the start of Period 1 (SOT). As indicated in Table 13, there was a significant treatment x period interaction for BW ($P < 0.05$), with no differences between the four treatments at the start of Period 2, however at the end of Period 2 TAC heifers (547.9 kg) weighed 10% more than TAM heifers (499.5 kg), as indicated in Figure 5. Further, BW at the end of Period 2 was not significantly different than the weight at the start of the trial for any of the treatments, except for heifers grazing OGA (Figure 5).

Although not significant, there was a tendency ($P = 0.06$; Table 13) for a treatment x period interaction for ADG. Average daily gain was significantly different between treatments, with heifers grazing COR having a positive gain (0.07 kg d^{-1}) over the duration of the trial while all three perennial treatments had net negative gains. However, TAC (-0.10 kg d^{-1}) did not differ from COR nor TAM (-0.53 kg d^{-1}), nor did OGA (-0.72 kg d^{-1}) differ from TAM but OGA was significantly lower than TAC. All treatments gained weight during Period 1 ($\text{ADG} = 1.36 \text{ kg d}^{-1}$; Table 13), however, all heifers lost weight in Period 2 ($\text{ADG} = -2.00 \text{ kg d}^{-1}$; Table 13).

Forage dry matter and nutrient intake

There were no significant differences ($P = 0.300$) in DMI (kg d^{-1}) between heifers grazing the three perennial stockpiled forage treatments, however, there was a significant period effect ($P < 0.001$; Table 13). On average, forage DMI was 10% lower in Period 2 (6.6 kg d^{-1}) compared

to Period 1 (7.3 kg d⁻¹; Table 13). No treatment x period interactions were observed for forage DMI (P=0.178).

When expressed on a BW basis, there was a significant (P=0.006) treatment x period interaction for forage DMI for the three perennial treatments. As illustrated in Figure 7, forage DMI (% BW) did not differ between treatments in Period 1 for TAM and TAC, however, in Period 2, OGA (1.51) was 26% and 14% higher than both TAC (1.20) and TAM (1.33) respectively. However, Period had no effect on forage DMI (% BW) in TAC and TAM which both had similar forage DMI (%BW) in both periods.

Heifers grazing TAC (15.67 Mcal d⁻¹) and TAM (16.79 Mcal d⁻¹) pastures had 16% and 25% higher forage digestible energy intake (DEI), respectively than those grazing OGA (13.48 Mcal d⁻¹; P<0.001; Table 13). Further, forage DEI was 17% higher in Period 1 (16.50 Mcal d⁻¹; P<0.001) than in Period 2 (14.13 Mcal d⁻¹; P<0.001; Table 13), with no treatment x period interactions observed.

There was a significant treatment x period interaction for forage CP intake, as heifers grazing TAM had 34% and 29% lower forage CP intake, than heifers grazing TAC and OGA in Period 1, as well as 40% and 17% lower than TAC and OGA in Period 2 (P=0.02; Figure 8). The forage CP intake of heifers grazing TAC in Period 1 (0.79 kg d⁻¹) did not differ from heifers grazing OGA; however, in Period 2 it was higher than those grazing TAM and OGA. (0.73 kg d⁻¹; P<0.05).

Serum urea nitrogen

At the start of Period 1, following a 3-d adaptation period on their respective forage treatments, heifers grazing OGA (3.66 mmol L⁻¹) and TAC (4.14 mmol L⁻¹) had significantly

higher SUN levels than COR (1.63 mmol L⁻¹) and TAM (1.73 mmol L⁻¹) and were above the minimum acceptable SUN concentration of 2.1 mmol L⁻¹ (Hammond et al. 1994) while both COR and OGA were below. A significant treatment x period interaction (P<0.05) was observed for SUN concentrations (Table 13; Figure 9). At the beginning of Period 2, SUN of heifers grazing TAC (3.03 mmol L⁻¹) was significantly higher than that of all other forage treatments (P<0.05; Figure 9). Although SUN of heifers grazing OGA pastures (2.03 mmol L⁻¹) was lower than those grazing TAC, they were significantly higher than COR heifers (0.91 mmol L⁻¹) and TAM (1.11 mmol L⁻¹). The SUN concentration for all treatments was significantly lower in Period 2 compared to Period 1. At the end of Period 2, SUN of TAC heifers (2.81 mmol L⁻¹) did not differ from the start of Period 2 and was still higher than OGA (1.56 mmol L⁻¹) and TAM heifers (1.78 mmol L⁻¹) but did not differ from COR heifers (2.31 mmol L⁻¹). The SUN concentration in COR heifers was significantly higher than OGA heifers at the end of Period 2 and was also significantly higher (P<0.001; Table 13) than when measured at the start of Periods 1 and 2.

Table 13. Performance and forage dry matter intake of bred beef heifers grazing perennial and annual stockpiled pastures over two, 28-d periods in the late fall/early winter.^z

Item	n	Treatment (T) ^w				P-value	Grazing Period (P)			SE	P-value	TxP P-value
		COR	OGA	TAC	TAM		SOT ^x	1	2			
Body Weight (kg)	32	544.0± 13.70	556.0 ± 13.70	567.0 ± 13.70	531.6 ±13.70	0.314	542.9 ^b	581.0 ^a	525.1 ^c	7.22	<0.001	<0.001
Forage Dry Matter Intake (kg d ⁻¹) ^y	21 ^v	-	6.8 ± 0.21	6.8 ± 0.19	7.2 ± 0.20	0.300	-	7.3 ^a	6.6 ^b	0.15	<0.001	0.178
Forage Intake as % of BW ^y	21 ^v	-	1.40 ^a ± 0.049	1.21 ^b ± 0.042	1.32 ^{ab} ±0.045	0.028	-	1.27 ^b	1.35 ^a	0.030	0.014	0.006
Forage Crude Protein Intake (kg d ⁻¹) ^y	21 ^v	-	0.62 ^b ± 0.021	0.75 ^a ± 0.018	0.47 ^c ± 0.020	<0.001	-	0.68 ^a	0.54 ^b	0.015	<0.001	0.020
Forage Digestible Energy Intake (Mcal d ⁻¹) ^y	21 ^v	-	13.48 ^b ± 0.481	15.67 ^a ± 0.417	16.79 ^a ± 0.448	<0.001	-	16.50 ^a	14.13 ^b	0.332	<0.001	0.111
Average Daily Gain (kg d ⁻¹)	32	0.07 ^a ±0.164	-0.72 ^c ± 0.164	-0.10 ^{ab} ± 0.164	-0.53 ^{bc} ± 0.164	0.007	-	1.36 ^a	-2.00 ^b	0.129	<0.001	0.066
Serum Urea Nitrogen (mmol L ⁻¹) ^x	32	1.62 ^c ± 0.128	2.42 ^b ± 0.128	3.33 ^a ± 0.128	1.54 ^c ± 0.128	<0.001	2.79 ^a	1.77 ^c	2.12 ^b	0.090	<0.001	<0.001

^zWithin a treatment or within period within a row, means without a common superscript differ (P<0.05).

^yDry matter intake (DMI) was not measured on heifers grazing corn pastures.

^xStart of Trial (SOT) are values taken on day 1 of Period 1.

^wForage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

^vDue to three heifers not eating sufficient amounts of n-alkane marked pellets in Period 1, they were excluded from forage intake measurements. Therefore: OGA (n = 6), TAC (n = 8) and TAM (n = 7)

± SE was included with means when they differed from each other and were listed at the end of the means when they were the same.

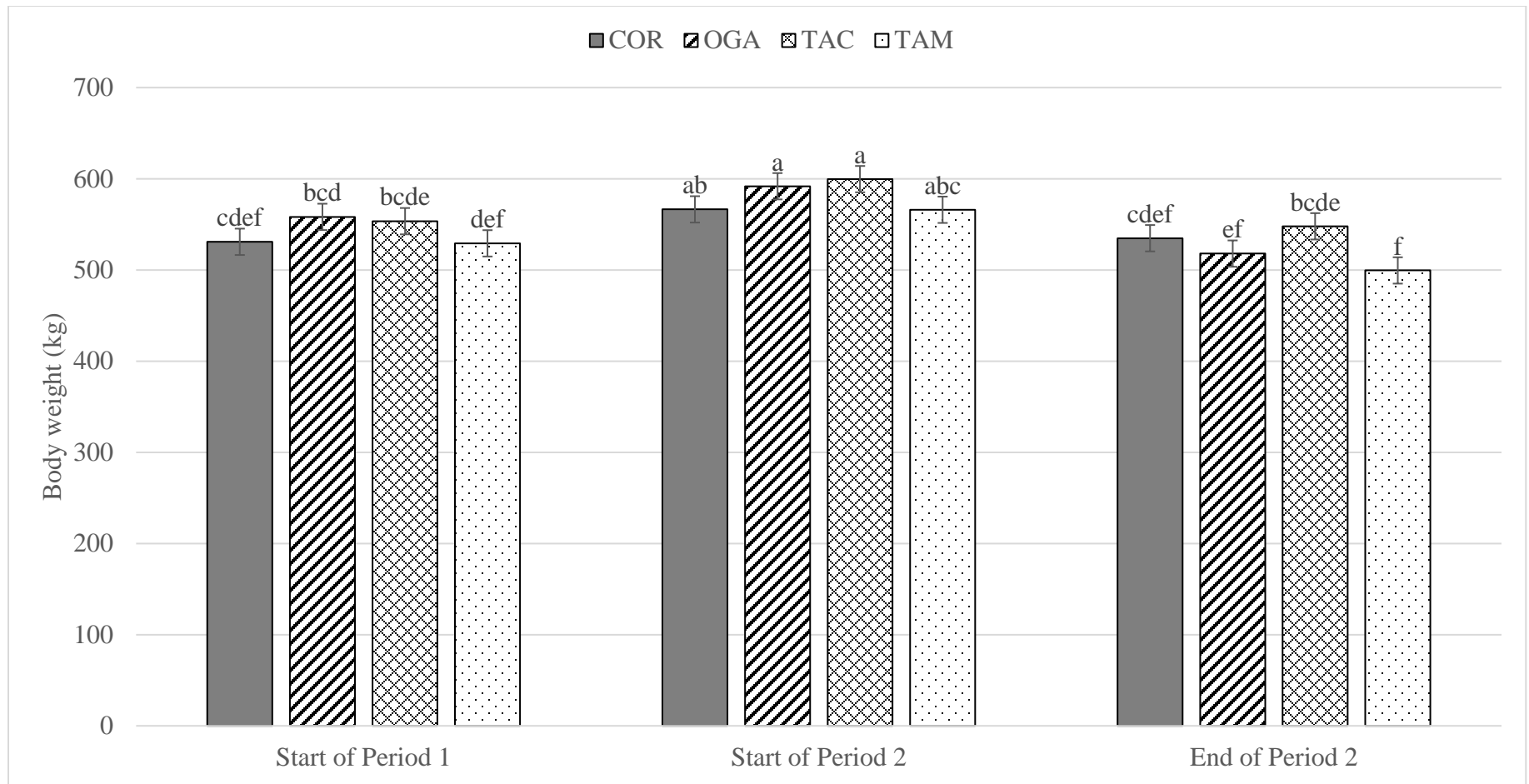


Figure 5. Body weight of bred beef heifers grazing perennial and annual stockpiled forages over two 28-d grazing periods during the late fall and early winter; Forage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

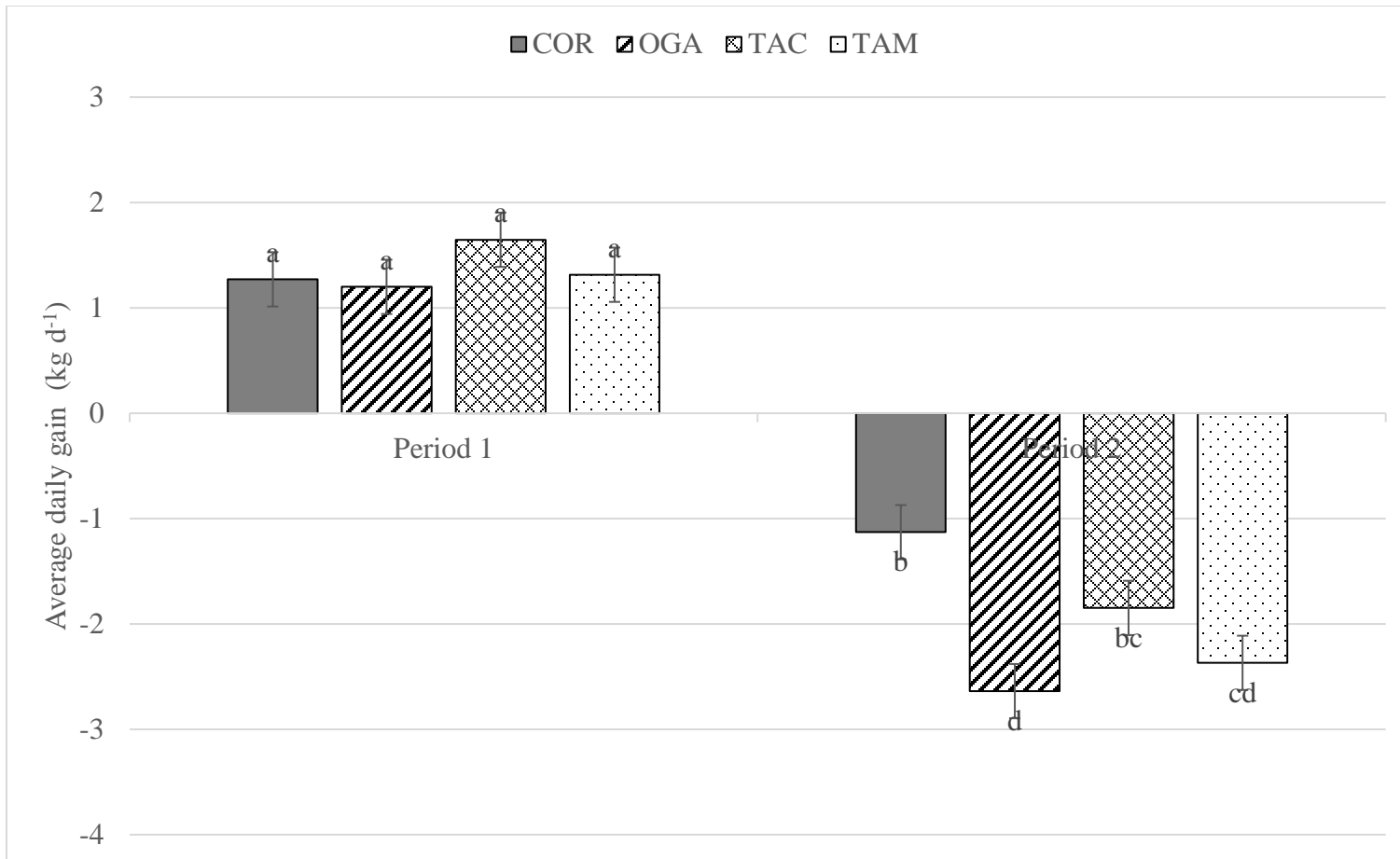


Figure 6. Average daily gain (ADG) of bred beef heifers grazing perennial and annual stockpiled forages over two, 28-d periods in the late fall and early winter; Forage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

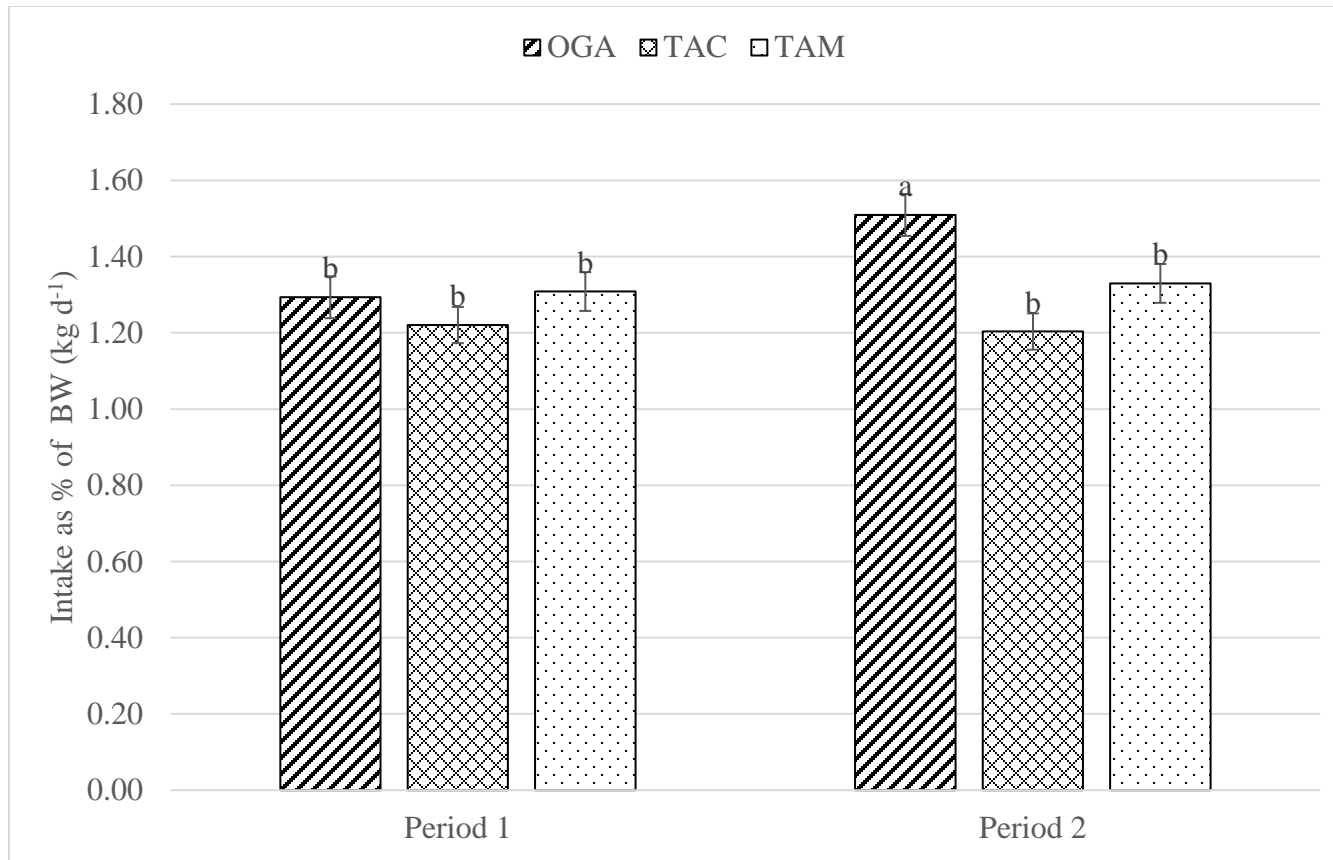


Figure 7. Forage dry matter intake (% BW) in bred beef heifers grazing perennial stockpiled forages over two 28-d periods in the late fall and early winter; Forage treatments: OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

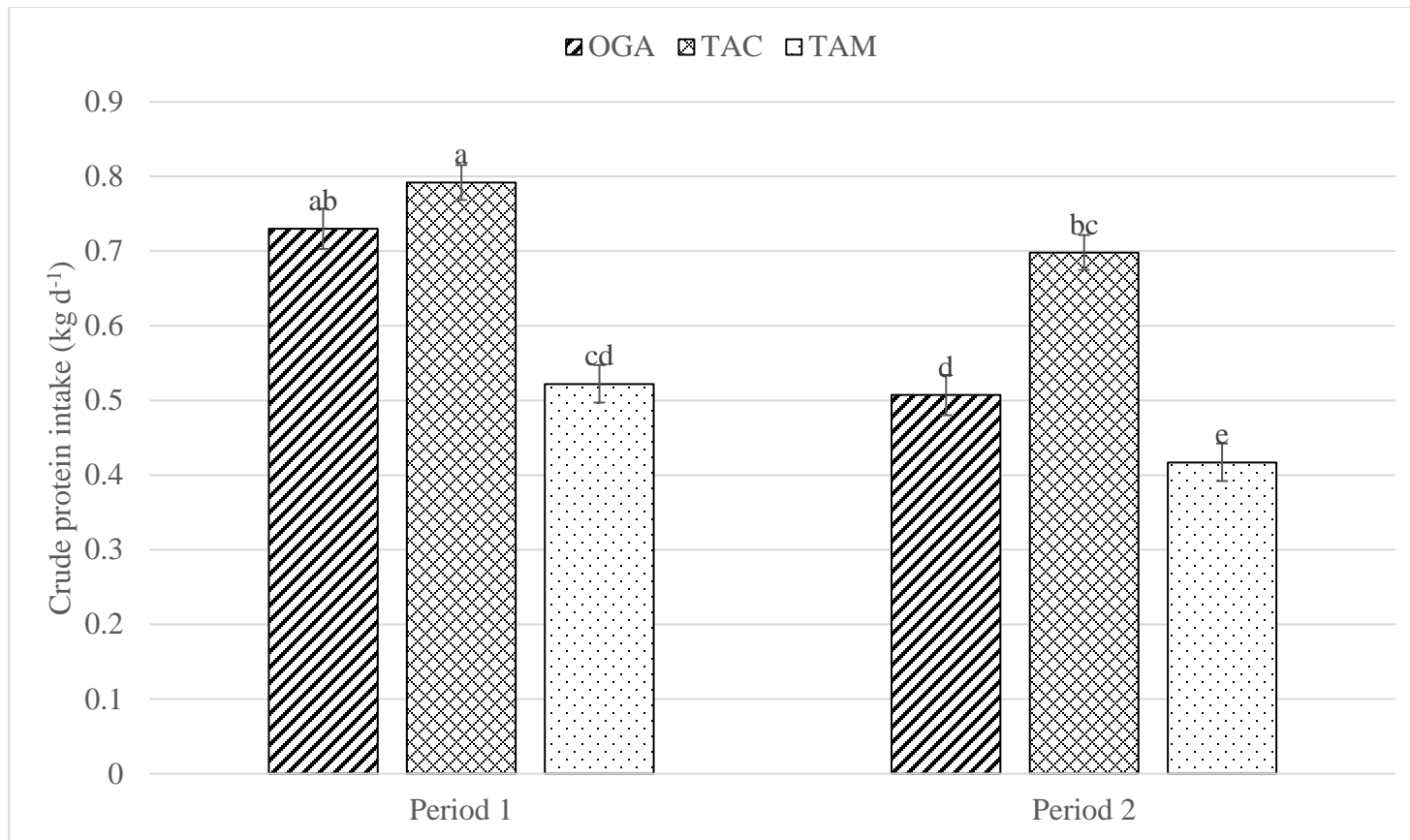


Figure 8. Crude protein intake of bred beef heifers grazing perennial stockpiled forages over two 28-d periods in the late fall and early winter; Forage treatments: OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

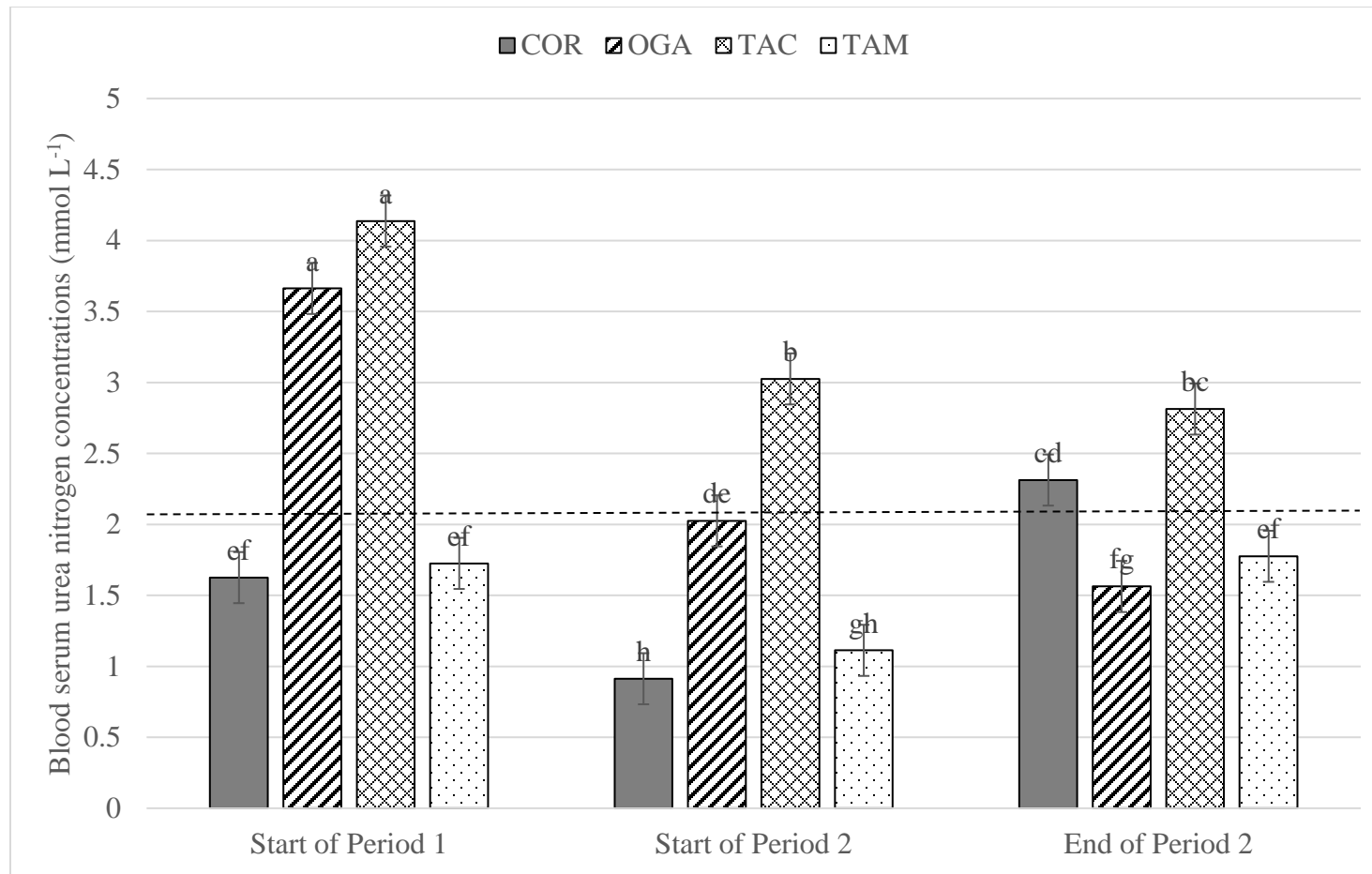


Figure 9. Serum urea nitrogen (SUN) concentrations in bred beef heifers grazing perennial and annual stockpiled forages in the late fall and early winter; Forage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

The minimum threshold for SUN levels in cattle is 2.1 mmol L⁻¹ (Hammond et al. 1994) depicted by the dotted line.

4.4.4 Methane and carbon dioxide output

Enteric CH₄ and CO₂ emissions are reported in Table 14 for Period 1 only as only 10 out of 32 heifers tested had successful gas collection in Period 2, as described in the Materials and Methods. In addition to the small sample size, heifers lost weight in Period 2 and therefore CO₂ emissions were not reported. There were no significant differences in CH₄ emissions, irrespective of unit of expression, between the stockpiled forage treatments (P>0.05; Table 14). Heifers grazing COR pastures had numerically, but not significantly (P>0.05) lower CH₄ (L min⁻¹), CH₄ (L d⁻¹) and CH₄ (L kg⁻¹ BW⁻¹) than the perennial treatments. No effect of treatment on CO₂ emissions was observed (P=0.881).

Table 14. Methane and carbon dioxide emissions of bred beef heifers grazing stockpiled perennial and annual forages in Period 1 in the late fall and early winter^z

	Treatment (T) ^y				<i>P-Value</i>
	COR (n=6)	OGA (n=6)	TAC (n=8)	TAM (n=4)	
CH ₄ (L d ⁻¹)	165.6 ± 21.48	211.3 ± 21.48	227.1 ± 18.60	235.4 ± 26.31	0.145
CH ₄ (L kg ⁻¹ BW ⁻¹)	0.31 ± 0.038	0.39 ± 0.038	0.41 ± 0.033	0.42 ± 0.047	0.196
CH ₄ (L kg ⁻¹ DMI ⁻¹)	-	32.9 ± 4.04	33.9 ± 2.47	32.6 ± 4.04	0.949
CH ₄ (kcal d ⁻¹)	-	2,325 ± 248.8	2,146 ± 152.3	2,200 ± 248.8	0.831
CH ₄ (% GEI)	-	7.48 ± 0.955	7.82 ± 0.585	7.79 ± 0.955	0.952
CO ₂ (L d ⁻¹)	2,437 ± 321.0	2,418 ± 393.1	2,688 ± 278.0	2,688 ± 393.1	0.881

^zWithin a row, means without a common superscript differ (P<0.05).

^yForage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

± SE was included with means when they differed from each other and were listed at the end of the means when they were the same.

4.4.4 Grazing behaviour

Time spent at windbreak shelters

As indicated in Table 15, a significant treatment x TOD interaction was observed ($P < 0.001$), as heifers in perennial forage treatments spent significantly more time at windbreak shelters during nighttime hours (51-73%) compared to daylight hours (19-34%). Heifers in COR pastures spent significantly less time at shelter during both daylight (3.6%) and nighttime (10.0%) than heifers in perennial forage treatments (Figure 10) while time spent at shelter did not differ between day vs night. During daylight hours, heifers grazing TAC pastures spent less time at the windbreak shelters than TAM but did not differ from OGA, nor did heifers grazing OGA pastures differ from TAM.

Time spent at water

As indicated in Table 15, significant interactions were observed for treatment x TOD ($P < 0.001$), TOD x period ($P < 0.001$), and treatment x period ($P < 0.001$). However, a significant TOD x treatment x period interaction for time spent at water was not observed. During daylight hours, heifers grazing COR (9.7%; Figure 11) spent more time at the water compared to OGA (4.4%), TAC (4.1%), and TAM (3.4%) which did not differ from each other. However, during nighttime heifers in all forage treatments spent the similar amount of time at water (COR 1.1%, OGA 4.9%, TAC 0.6%, and TAM 0.4%). In Period 1, heifers in all treatments spent more time at water during the day compared to the night and compared to day and night in Period 2 (8.8% vs 2.0%) with no difference between day and night in Period 2, as indicated in Figure 12. In Period 1, heifers in COR (9.2%), TAC (4.2%) and TAM (3.6%) spent more time at the water than in

Period 2 (COR 1.6%, TAC 0.5%, and TAM 0.2%; $P < 0.001$; Figure 13), whereas heifers grazing OGA spent more time at water in Period 2 (6.4%) than in Period 1 (2.9%).

Distance travelled

A significant interaction was observed for treatment x period ($P = 0.007$) and treatment x TOD x period ($P = 0.048$) but not treatment x TOD ($P = 0.682$) or TOD x period ($P = 0.107$). Significant interactions with period are expected given that heifers traveled a greater distance between the grazed area in the paddock and the water in Period 2 compared to Period 1 however, some treatments did not have to travel as far as others to reach available forage in Period 2 (Table 2). In Period 2, heifers in COR pastures did not have to travel as many of the heifers in the perennial pastures did (Table 2).

Table 15. Grazing behaviour of bred beef heifers grazing three perennial and one annual stockpiled forage measured by GPS grazing collars over a two, 28-d grazing periods in the late fall and early winter.^z (n=30^t)

	Treatment (T) ^t					<i>P</i> - <i>Value</i>	Time of Day (TOD)			<i>P</i> - <i>Value</i>	Grazing Period (P) ^x		SE	<i>P</i> - <i>Value</i>
	COR	OGA	TAC	TAM	SE		Day ^{xw}	Night ^{xw}	SE		1	2		
Time spent at wind break shelters (%) ^{xw}	7.0 ^c ± 2.5	39.0 ^b ± 2.6	43.0 ^b ± 2.5	54.0 ^a ± 2.6	-	<0.001	21.0 ^b	51.0 ^a	1.60	<0.001	-	-	-	-
Time at the waterer (%) ^v	5.4	4.7	2.3	1.9	1.30	0.293	5.4 ^a	1.8 ^b	0.80	<0.001	5.0 ^a	2.2 ^b	0.90	0.008
Distance traveled (m d ⁻¹) ^v	780.7	760.1	961.5	735.9	128.73	0.619	895.3 ^a	723.8 ^b	68.57	<0.001	699.0 ^b	920.1 ^a	72.30	<0.001
	<i>TxTOD</i> <i>P-Value</i>	<i>TODxP</i> <i>P-Value</i>	<i>TxP</i> <i>P-Value</i>	<i>TxTODxP</i> <i>P-Value</i>										
Time at windbreak shelters (%) ^{xw}	<0.001	-	-	-										
Time at the waterer (%) ^v	<0.001	<0.001	<0.001	0.142										
Distance traveled (m d ⁻¹) ^v	0.682	0.107	0.007	0.048										

^zWithin a treatment, within period, within Time of Day, within a row, means without a common superscript differ (P<0.05).

^xTime spent at wind break shelters (%) was only measured on d 20-27 of Period 2 (December 6-13, 2016) so therefore there was no Period fixed effect for this measurement.

^wDay = average daylight hours between Dec. 6-13, 2016 (08:30-16:40); Night = average nighttime hours between Dec 6-13, 2016 (16:40-08:30)

^vDay = Period 1 average daylight hours: (07:40-17:00) Period 1 average nighttime hours: (17:00-07:40). Period 2 average daylight hours: (08:20-16:40) Period 2 average nighttime hours: (16:40-08:20).

^tForage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

^t Due to collar availability, 30 heifers were fitted with collars during both grazing periods (OGA and TAM, n = 7; COR and TAC, n = 8).

± SE was included with means when they differed from each other and were listed at the end of the means when they were the same.

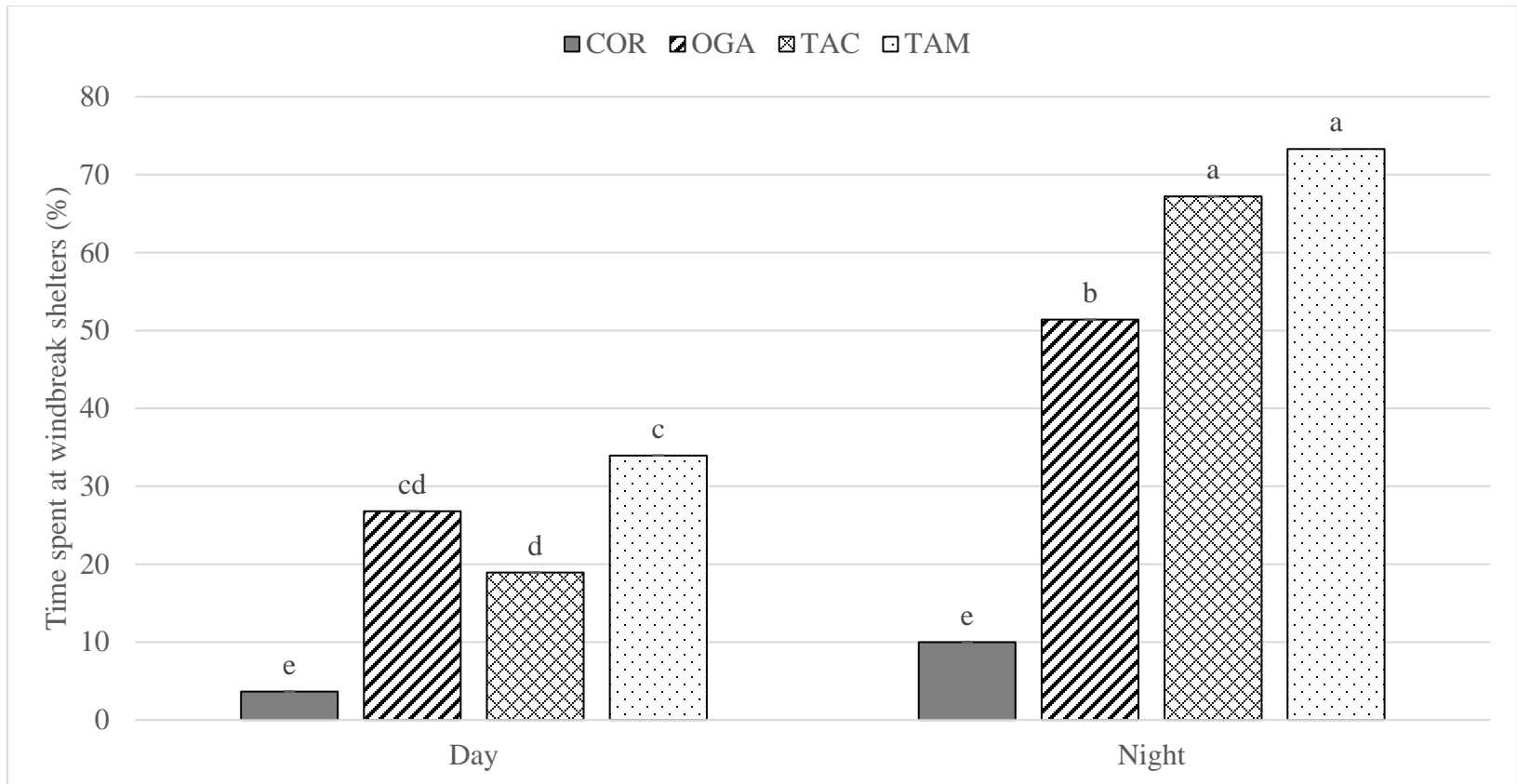


Figure 10. Length of time spent by pregnant beef heifers at the windbreak shelters during the day and at night while grazing perennial and annual stockpiled forages during an 8-d period in early winter (Treatment x Time of Day); Forage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

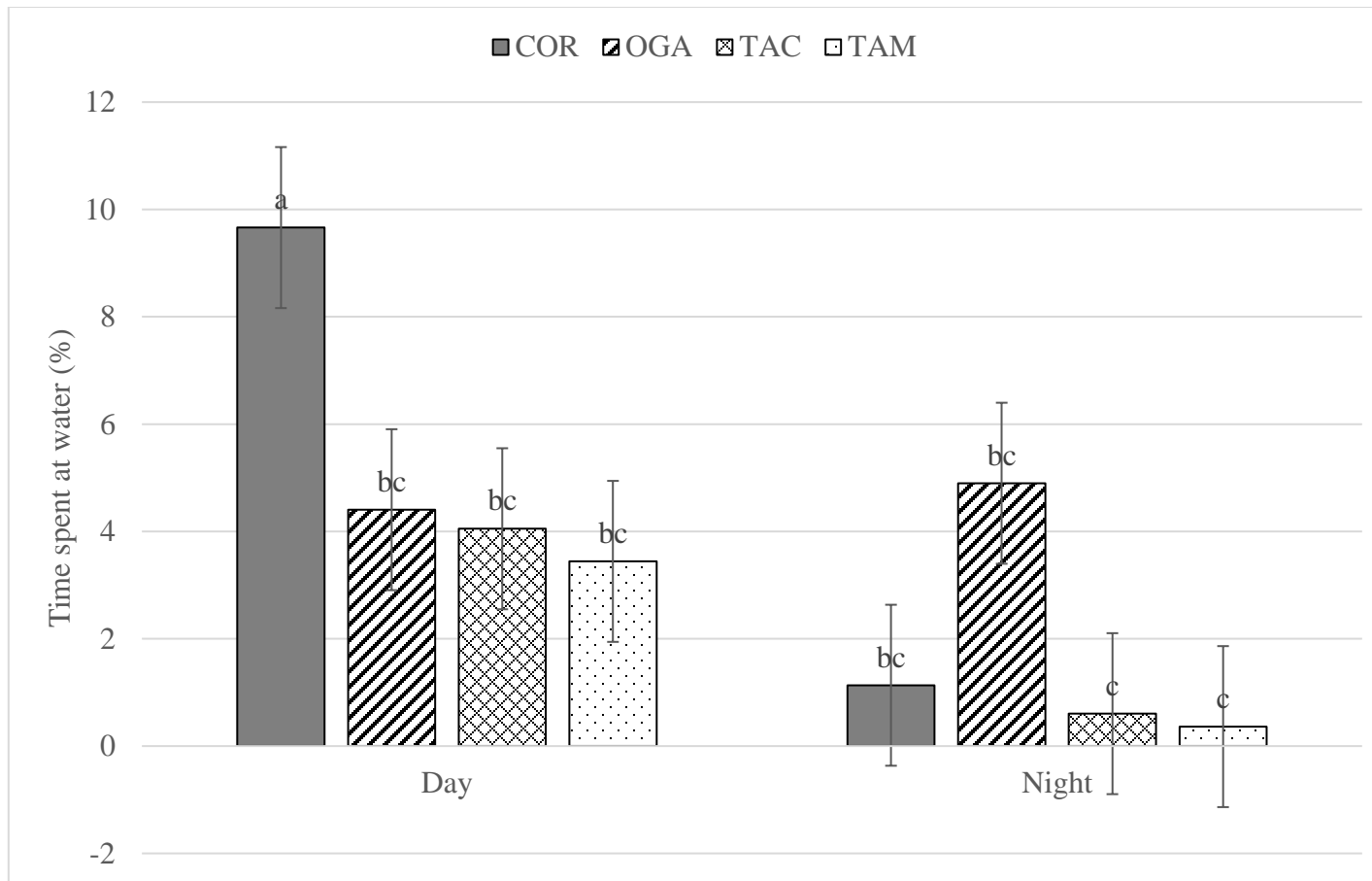


Figure 11. Length of time spent by pregnant beef heifers at water during daylight and nighttime while grazing perennial and annual stockpiled forages in both grazing periods (Treatment x Time of Day); Forage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

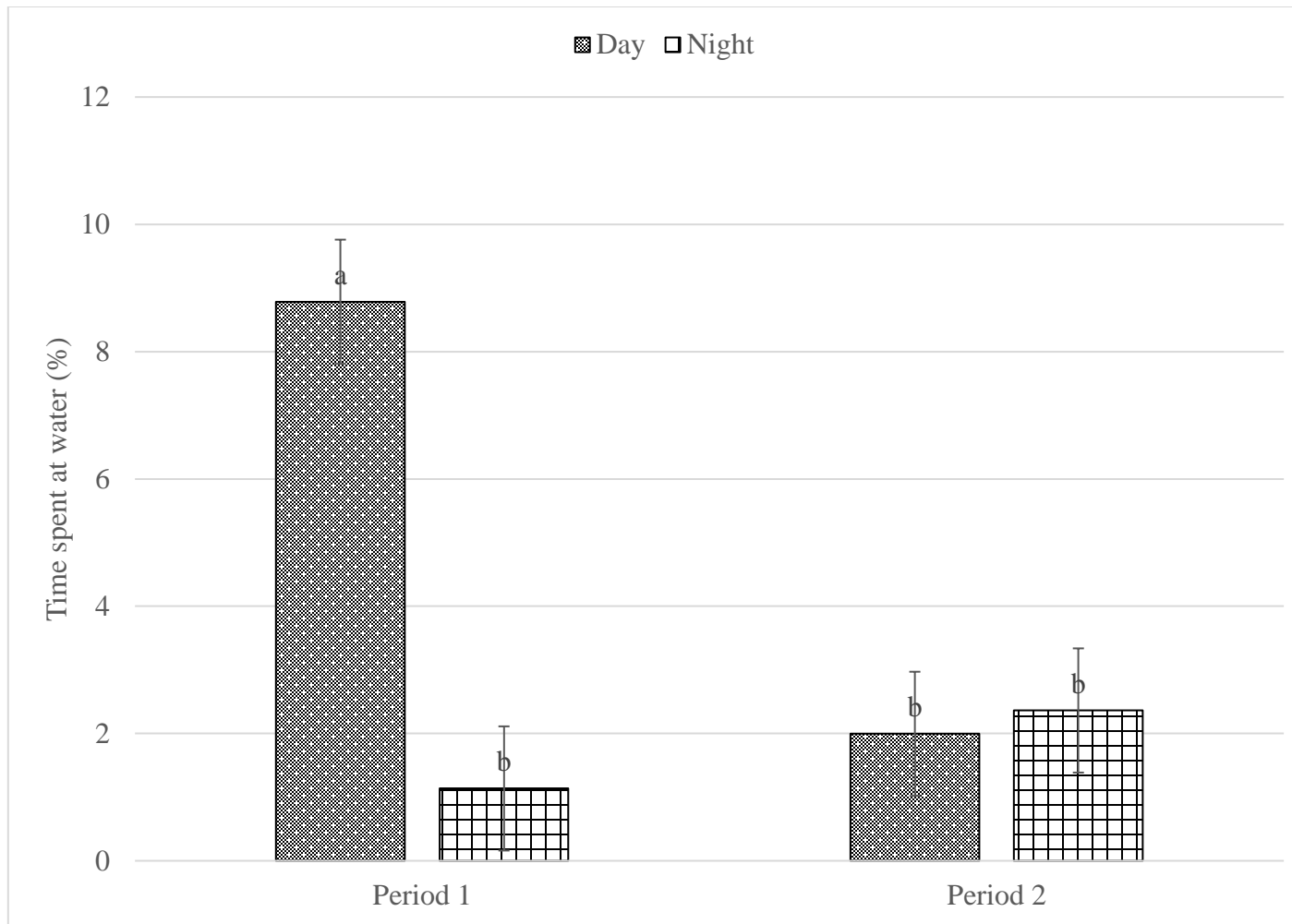


Figure 12. Length of time spent by pregnant beef heifers spent time at water during daylight and nighttime while grazing perennial and annual stockpiled forages in both grazing periods (Time of Day x Period)

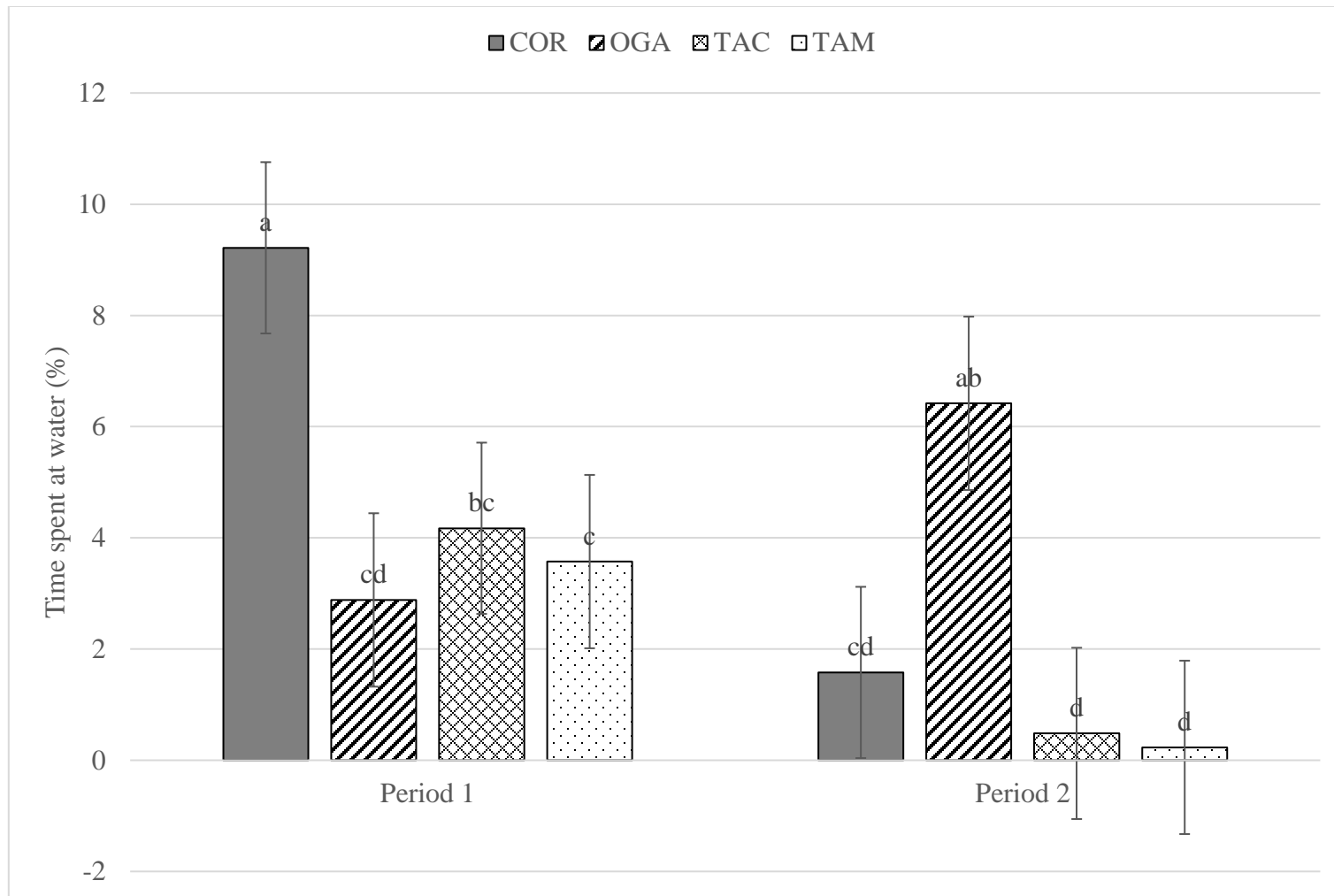


Figure 13. Length of time spent by pregnant beef heifers spent time at water during Period 1 and Period 2 while grazing perennial and annual stockpiled forages (Treatment x Period); Forage treatments: COR: Fusion corn, OGA: Killarney orchardgrass/Algonquin alfalfa, TAC: Courtney tall fescue/Algonquin alfalfa/Oxley II cicer milkvetch, and TAM: Courtney tall fescue/Yellowhead alfalfa/Fleet meadow brome.

4.5 DISCUSSION

4.5.1 Yield, plant height and nutrient composition of stockpiled forages

Intake and Performance pasture forage yield, plant height and nutrient composition data of annual and perennial stockpiled forages are discussed separately as significant differences were observed for yield and several nutrients' concentrations.

Selection of the forage species in this study were guided by an industry steering committee, as well as based on previous work demonstrating high yield and energy content of corn (Lardner et al. 2017; Hewitt 2018; Jose et al. 2020) which showed promise for stockpile grazing in the late fall and early winter when animal maintenance requirements typically increase with decreasing temperatures. The perennial forages were chosen for high CP concentrations and yield when grown in western Canada (Baron et al. 2004; Biligetu et al. 2014; Peng 2017; Hewitt 2018).

Forage yield

Performance pastures

Significantly greater yield associated with the COR treatment compared to the three perennial treatments (which did not differ) which was expected given the increased plant height (170 cm) of corn compared to the perennial species which had an average plant height of 48.8 cm (legumes) and 27.8 cm (grasses), as discussed in more detail below. In addition to plant height, COR also had a higher DM content and had not been harvested prior to grazing whereas the perennial pastures were harvested for hay in June prior to stockpile grazing to avoid advanced maturity, as well as weathering, leading to a decrease in quality before grazing. Hewitt (2018) observed that corn seeded in June and grown in western Canada had the highest forage yield

compared to other annual and perennial forage species including ‘Haymaker’ oats, ‘Hazlet’ fall rye, ‘Maverick’ barley, ‘Aubade’ westerwold ryegrass, ‘Golden German’ foxtail millet, ‘Fusion’ corn, ‘Mammoth’ soybean, ‘Killarney’ orchardgrass, ‘Courtenay’ tall fescue, ‘Fleet’ meadow brome, ‘Armada’ meadow brome, ‘Algonquin’ alfalfa, ‘Yellowhead’ alfalfa, and ‘Oxley II’ cicer milkvetch. Corn yields reported by Hewitt (2018) of 4,365 to 40,491 kg ha⁻¹ were greater than those reported here. Similarly, Lardner et al. (2017) reported corn yields of 9,400, 10,300 and 12,000 kg ha⁻¹ for three different corn varieties. Lower yields in the current study may be attributed to poor establishment, sandy, dry soil and high weed pressure leading to inconsistent plant density. These problems were addressed through reseeding twice in June and July (Table 1), the late reseeding dates would not have allowed the crop sufficient time to fully grow and mature before going dormant in the fall.

There were no differences in yield between the three perennial species in either the Intake or the Performance pastures. Biligetü et al. (2014) observed that small plot studies comprised of perennial binary forage mixes containing alfalfa (2,000 - 2,700 kg ha⁻¹) grown in Swift Current, Saskatchewan had increased yields compared to other legume/grass mixes or grass monocultures (1,000 - 2,100 kg ha⁻¹) containing cicer milkvetch or sainfoin. They did not take a first cut early in the growing season to initiate stockpiling as was done in the present study, but instead harvested yearly growth in two steps, early August and early September, over seven years. However, these are much lower yields compared to the grass-alfalfa mixes in the present study. In a 3-yr study, Kulathunga et al. (2016) reported an average forage biomass yield of 4,325 kg ha⁻¹ for meadow brome grass, and Algonquin alfalfa mix that was stockpiled and biomass measured in early September each year before grazing. This value is comparable to the DM yield in our study which ranged from 3,587 – 4,490 kg ha⁻¹.

Comparable yield between Period 1 and 2 suggests that the forage in all treatments were dormant at the beginning of Period 1 and did not change over the course of the study, or alternatively, were offset by grass growth after a killing frost. To reduce advancing plant maturity and weathering along with possible legume leaf loss, Kulathunga et al. (2016) swathed stockpiled perennial forage containing Algonquin alfalfa immediately before grazing was initiated in October. Potential leaf loss due to advancing plant maturity and weathering associated with inclusion of legumes should be a consideration when selecting forage species for extended grazing if they are to be utilized after a killing frost. Based on visual observation in the present study, alfalfa plants had significant leaf loss at the onset of the study.

Intake pastures

Standing DM forage yield is important when extended grazing to ensure sufficient forage yield to meet increasing maintenance nutrient demands of the grazing animals associated with cold. Lack of a significant difference in DM yield of COR in the Intake pastures compared to the perennial species may be due to a consistent increase in yield of all perennial Intake pastures (Table 9) compared to the Performance pastures (Table 8), whereas the COR pastures had very similar yield between the Intake and Performance pastures. Heifers were randomly assigned to Intake and Performance paddocks at the onset of the trial. As observed in the Performance pastures, changes in forage yield were also not apparent between grazing periods in the Intake pastures. The observed increase in DM yield cannot be attributed to differences in management (i.e., fertilization) or precipitation as the Intake and Performance pastures were adjacent to each other. Other factors which may have impacted yield include topography (low lying areas as visibly observed) and differences in weed pressure leading to variability in plant density and yield. All perennial (Intake

and Performance) were harvested at the same time in June to ensure the same duration of re-growth in all treatments. Alternatively, COR pastures were not harvested after seeding. Although there was not a significant yield difference, COR DM yield was numerically greater, providing higher DM yield ha⁻¹ than the three perennial forage treatments. Biomass for grazing remained stable over the course of the study, suggesting that treatments were not adversely impacted by weather.

Plant height – Intake and performance pastures

Plant height in stockpile grazing systems can be an important factor to determine forage accessibility after significant snowfall. If forages cannot maintain an upright position during the grazing period, forage DMI may be impacted due to an inability to access forage. Taller grass height for TAC and TAM in both the Intake and Performance pastures compared to OGA ($P < 0.05$), can be attributed to the presence of tall fescue. Tall fescue is a taller grass than orchard grass which was included in the OGA treatment Hewitt (2018). This is consistent with findings from Hewitt (2018) who reported that when grown under Manitoba conditions, Courtenay tall fescue was typically taller (30 - 34 cm) throughout the summer and early fall when included in stockpile forage mix treatments compared to those containing orchard grass (27 - 32 cm).

The decrease in height for grasses and corn from Period 1 to Period 2 may be attributed to two days of freezing rain at the end of Period 1 which bent over the tops of the corn and grass plants (plant height samples taken mid-way through Period 1 and early Period 2). A further reduction in plant height from the start to finish of Period 2 was likely related to 20 cm of snowfall (Table 5) received in the last two weeks the trial. In both cases, plants were flattened under the

weight of the precipitation (Table 6 and 7) but since yield was measured at the start of Period 2, these effects of precipitation were not evident in the yield measurements.

Legume height was primarily measured by alfalfa height due to poor establishment of cicer milkvetch in TAC. Differences in legume height were not apparent for the performance pastures but were evident in the intake pastures. Differences between TAM, OGA and TAC were not expected. Two alfalfa species were used with Yellowhead alfalfa seeded in TAM and Algonquin seeded in the OGA and TAC treatments. Hewitt (2018) found that both Yellowhead (22 - 32 cm) and Algonquin (23 - 32 cm) alfalfa had similar heights at October harvest. Although these two species of alfalfa have different fall dormancies with Yellowhead having a greater fall dormancy compared to Algonquin, the exceptional growing conditions (above average temperature and moisture) may mitigate any impact of dormancy. It may be that the alfalfa was influenced by competition from the grass species in the mix or weed pressure.

The decrease in COR height observed in both the intake and performance pastures from Period 1 to the end of Period 2 may be also attributed to freezing rain and increased snow cover, as described above, causing the tops of the plants to bend or break off. However, the corn was still readily accessible for the heifers to graze above the snow at the end of Period 2, unlike the grass species, which were not as easily accessible under snow. Since forage DMI was measured prior to receiving snowfall in Period 2, it was not possible to determine if the presence of snow affected forage DMI. Baron et al. (2003) found that corn height and yield were decreased by wind and overwintering effects in Alberta. Therefore, despite the negative impact of snow and wind, COR was better suited for stockpile grazing in the early winter in Manitoba compared to the perennial species based on plant height as COR biomass was well above snow throughout the trial unlike the perennial treatments, particularly OGA.

Nutrient Concentration

Performance pastures

Protein requirements for pregnant replacement heifers (550 kg BW, gaining 0.80 kg d⁻¹) require a dietary CP concentration of 10.7% (Alberta Agriculture and Rural Development 2011). The CP concentration was highest in TAC (10.9%) followed by OGA (9.08%), COR. (6.76%) and TAM (6.51%) which would indicate only TAC was meeting CP requirements for the heifers. These CP concentrations are consistent with Biligetu et al. (2014) who found that grass mixes with alfalfa had the highest CP concentration compared to grass monocultures, grass-cicer milkvetch mixes and grass-sainfoin mixes. These authors also reported that meadow bromegrass, crested wheatgrass and green needlegrass had the lowest CP concentration of the grass species, which is consistent with our study in that TAM (containing meadow bromegrass) had the lowest CP of the perennial mixes even though it contained alfalfa. The decrease in CP concentration from Period 1 (9.00%) to Period 2 (7.46%; Table 10), may be associated with advanced weathering (Yu et al. 2003) and leaf loss of alfalfa which was visually apparent in all perennial treatments but does not account for the observed decreased in CP concentration in COR pastures.

The observed treatment x period interaction which resulted in a small but significant increase in NDF concentration for TAM may be attributed to increased weathering and alfalfa leaf loss of the plant (Mueller and Orloff 1994) from Period 1 to Period 2 which has been reported elsewhere (Baron et al. 2004; Biligetu et al. 2014). Unlike TAM, OGA and TAC were able to maintain quality in terms of NDF concentration from Period 1 to Period 2. However, all perennial treatments were over 60% NDF concentration which may reduce forage DMI as described by

Ominski et al. (2006). Alternatively, COR had a significantly lower NDF which may be due to taller plants with more leaf material further into the field that was grazed in Period 2 compared to Period 1.

Biligetü et al. (2014) also reported an increase in the NDF concentration of 7 grass and 3 legume species when harvested in September compared to August which was likely due to increased maturity of the stands. Similarly, in a 3-yr study, Kulathunga et al. (2016) observed an increase in NDF concentration from 61.8% in October to 66.8% in December in a stockpiled alfalfa/meadow brome grass perennial mix in Saskatchewan as plants weathered and broke down after being swathed immediately prior to grazing in October. These values are comparable in magnitude to those observed in TAM over a similar sampling period.

Energy requirements for pregnant replacement heifers (550 kg BW, gaining 0.80 kg d⁻¹) require a dietary TDN concentration of 56% (Alberta Agriculture and Rural Development 2011; National Research Council 2016). The energy concentrations of the treatments in the present study (COR = 72%, OGA = 45%, TAC = 55%, and TAM = 54%; Table 10) which indicates that only COR met energy requirements of the heifers, but TAC and TAM slightly below requirements. As expected, energy concentration (TDN, DE, ME, NE_{main}, and NE_{gain}) was highest in COR compared to the perennial forage treatments, due to the high starch concentration of the grain and higher ratio of seed (grain) to stem and leaves relative to the perennial forages (McCartney et al. 2009; Jose et al. 2020). Of the perennial treatments, energy concentration of OGA was lower than both TAC and TAM. Hewitt (2018) also reported that energy concentration (TDN) in corn was higher than all perennial grasses and legumes.

The required mineral concentrations required for pregnant beef heifers (550 kg BW, gaining 0.80 kg d⁻¹) are Ca = 0.40%, P = 0.20% and Mg = 0.20% (Alberta Agriculture and Rural

Development 2011; National Research Council 2016). This means that all three perennial stockpiled forage treatments exceeded requirements for Ca, P and Mg except for OGA which had the P concentration of 0.18% (Table 10). In the performance pastures, COR was significantly lower in Ca and Mg than all the perennial pastures but there was no difference in P concentrations and COR did not meet heifer requirements for Ca (0.12%) and Mg (0.14%; Table 10). This would indicate that heifers grazing COR would require a different mineral program than heifers grazing the stockpiled perennial forages to meet requirements.

Intake pastures

The CP concentration of the forages in the intake pastures was very similar to the performance pastures in that CP was highest in TAC (10.90%), intermediate in OGA (9.08%), and lowest in TAM and COR. Unlike the performance pastures, CP concentration in the intake pastures although numerically different was not significantly different between periods. Performance and intake pastures received the same seed, fertilizer, field management, precipitation and were adjacent to each other so differences in CP may be attributed to field variation in establishment of seeded species as well as weed pressure. The high CP content could be since it contained Oxley II cicer milkvetch which had better leaf retention during the grazing periods than alfalfa did.

The NDF and ADF concentrations were higher in perennial forages compared to COR in both grazing periods and OGA was higher than the other two perennial treatments. Hewitt (2018) reported similar NDF concentrations in corn (41.7 - 64.2%) over two years and three plot sites when harvested at a comparable stage of maturity. In addition, corn NDF in that study was lower than perennial forages (Hewitt 2018).

The energy concentration (TDN) was highest in COR compared to all three perennial treatments. Further, TDN concentration in all perennial treatments decreased from Period 1 to Period 2 as would be expected as the plants mature. However, COR increased in TDN from Period 1 to Period 2 which may be associated with plant density throughout the field due to uneven establishment resulting in variability in cob development and therefore starch/energy concentration. Hewitt (2018) and Biligetu et al. (2014) reported decreased TDN in perennial forages as the plants matured from September to October and August to September, respectively.

The mineral profile of the forages showed that COR was lower in Ca and Mg than all the perennial forages. Potassium was also lower in COR than TAC and TAM. Lower mineral concentrations, particularly Ca, will have implications on the mineral selected while grazing stockpiled pastures. The higher Ca concentration in the perennial pastures, likely associated with the presence of alfalfa, will require a 1:1 Ca:P mineral, whereas the COR pastures with low Ca concentration will require a 2:1 Ca:P mineral to meet the minimum Ca:P ration of 1.5:1 required for beef cattle diets.

Based on the nutrient profiles of the forages examined in this study, TAC was the superior perennial forage based on high CP concentration which met heifer requirements and lower NDF content than the other perennial forages but may require energy supplementation when winter weather conditions begin to avoid loss of animal condition. However, based on high energy concentration and biomass yield COR outperformed the perennial forages although the CP and Ca concentrations of COR were too low to meet heifers' needs and would require supplementation.

4.5.2 Forage intake and animal performance

Forage and nutrient intake

Although significant differences in forage DMI were not observed between treatments, advancing plant weathering as measured by increased NDF in OGA, TAC and TAM performance pastures, resulted in lower forage DMI (kg d^{-1}) in Period 2 compared to Period 1. Ominski et al. (2006) also demonstrated that steers consuming an all-forage alfalfa-grass silage mix diet (60.8% NDF) had significantly lower DMI than steers fed diets containing 53.2%, 51.2% and 46.4% NDF. All three perennial forage treatments in the present study had NDF concentrations over 60% which may have been why forage DMI (% BW) was only 1.40%, 1.21%, and 1.32% compared to the assumed industry standard of 2.4% (National Research Council 2016). Heifers in the present study also selectively grazed throughout both grazing periods to avoid the dormant, dried stalks of the alfalfa plants but instead selected for the grasses and remaining alfalfa leaves (based on visual observation). Intake heifers were also offered 1 kg of n-alkane dosed pellets from days 1-13 of each period which could impact DMI of forages in their respective pastures causing their forage DMI to be lower than expected due to the pellet consumption. In the present study, differing plant height between treatments did not appear to affect forage DMI in either grazing period. Further, since forage DMI was measured before significant snowfall occurred, it is not possible to determine if significantly decreased plant height due to heavy snowfall affected forage DMI of heifers stockpile grazing in these conditions.

Similarly, forage CP intake of the heifers grazing perennial forage treatments was closely related to the forage CP concentration of the forages in each respective treatment. More specifically, TAC had higher forage CP intake than OGA and TAM due to higher forage CP concentration compared to the other two perennial forages. The decrease in forage CP intake for

all treatments in Period 2 compared to Period 1 is due to a decrease in both forage CP concentration and DMI. This is consistent with findings elsewhere (Blair 2015) where diets highest in CP also had the highest forage CP intake. However, based on visual observation in the present study, heifers selectively grazed in all perennial pastures and did not typically consume the over mature, dead alfalfa plant stalks whereas these were included and accounted for in the forage samples taken.

Forage digestible energy intake (DEI) was closely related to the DE concentration of grazed forages. Although forage DMI (kg d^{-1}) of heifers grazing OGA was comparable to TAC and TAM, a lower DE concentration in OGA pastures led to lower forage DEI intake when compared to the other two perennial forage treatments. Lower forage DE intake in Period 2 compared to Period 1, may be attributed due to the decreased forage DMI (6.58 vs 7.28 kg d^{-1}) during Period 2.

Body weight and ADG

The significant treatment x period interaction observed for BW indicates that all heifers did not respond in the same way across the four treatments and two grazing periods. The increase in BW from Period 1 to Period 2 in all treatments and subsequent loss from the start to end of Period 2, suggest that nutrient profile of the forages was sufficient to support growth when heifers were within the thermoneutral range for cattle. However, when extreme cold temperatures ($< -18^{\circ}\text{C}$; Table 6) were coupled with snow during Period 2, heifers in all perennial treatments ended up with lower BW at the end of Period 2 than at the start of Period 2, suggesting the need for supplementation during this period of time. Young (1989) reported that Canadian researchers have found that feed requirements for overwintering beef cows are increased by 30 to 70% due to

adverse winter conditions ($<-20^{\circ}\text{C}$) for pregnant beef cows over maintenance requirements when the cows are in their thermoneutral zone. The energy requirement for a pregnant beef heifer increases from 56% TDN at thermoneutral conditions to 62-65% TDN when cold stressed (Alberta Agriculture and Rural Development 2011; National Research Council 2016). In the current study, the greatest loss in BW and the lowest ADG (-0.72 kg d^{-1}) was apparent for heifers grazing OGA which can be attributed increased nutrient demand associated with poor winter weather conditions and a lower nutrient profile (lower CP/TDN and higher ADF/NDF) compared to all other treatments. The OGA Intake and Performance pastures had the lowest TDN concentration during Periods 1 and 2 compared to the other perennial pastures (TAC and TAM) and COR. The energy concentration of TAC and TAM did not differ; however, the CP concentration of TAC was significantly greater than TAM and may have attributed to the numerically (-0.10 vs. -0.53 kg d^{-1}) but not significantly different ADG between the two treatments. Unlike heifers grazing perennial pastures, those grazing COR had a similar BW at the end of Period 2 compared to the start of the trial two months prior. The energy concentration of the COR pastures, regardless of the unit of measure, was higher compared to the three perennial forages in both periods. Nonetheless, increased CP in TAC may have accounted for comparable gains between the two treatments. However, lower CP and TDN in TAM pastures resulted in lower ADG compared to COR. Jose et al. (2020) concluded that pregnant beef cows grazing standing corn in Saskatchewan (October to January) maintained BCS and tended to have greater BW increase over the 3-year trial compared to cows grazing swathed barley and offered barley hay in drylot.

The protein (CP g d^{-1}) to energy (ME MJ d^{-1}) ratio in cattle diets have been shown to be important in optimal ruminal efficiency by affecting rumen microbial function (Illius and Jessop 1996) and that diets with an inadequate ratio may have lower rumen metabolic efficiency as a

result of insufficient protein for rumen microbes to function optimally. Gabler and Henrichs (2003) identified that a ratio greater than 202 g of CP per MJ of ME is optimal for ruminal feed efficiency in ruminants within their thermoneutral zone. The protein to energy ratios for forage intake in the present study were 133 for OGA, 138 for TAC and 80.5 for TAM and since forage DMI and CP intake were measured at the start of each grazing period, the heifers did not experience cold stress during this time. Since forage CP intake and forage DMI were not measured for COR heifers, a ratio could not be calculated for this treatment. All three perennial forage treatments were lower than the identified threshold in Gabler and Henrichs (2003) indicating that bred heifers in all three treatments were at a suboptimal rumen efficiency during the trial, especially TAM. Donohoe (2019) observed that cows fed grass hay (8.8% CP) either in drylot or while bale grazing during winter in Manitoba both had low protein to energy ratios (167 and 178 in Periods 1 and 2 respectively) while cows supplemented with dried distillers grains with solubles (DDGS; 30.3% CP) had a CP:ME ratio of 241 in both periods. However even with a CP:ME > 202, Donohoe (2019) found that the cows fed DDGS in addition to the grass hay did not differ in BW or ADG compared to the other two treatments when grazing during January and February in Manitoba when minimum daily temperature was outside their thermoneutral zone (<-20°C; Young et al. 1989) during some period of the trial.

Negative ADG in Period 2 (-2.00 kg d⁻¹) compared to the positive ADG in Period 1 (1.36 kg d⁻¹) reflect the changes in BW and demonstrate that extreme winter weather conditions (Table 5, 6, 7) in Manitoba can compromise performance in pregnant beef heifers. Some of this loss may have been associated with gut fill due to reduced DMI. The extreme winter weather conditions (<-18°C and >15cm of snowfall in the present study; Table 5 and 6) which is outside the thermoneutral zone of pregnant cattle (Young et al. 1989) resulted in increased maintenance

requirements, and when coupled with advancing stage of pregnancy, led to increased nutritional requirements beyond that supplied by all treatments, indicating that supplementation was required.

Previous work in western Canada has demonstrated that pregnant cows can graze stockpile grass or grass-legume pastures during the winter without losing condition (Baron et al. 2016; Kulathunga et al. 2016). For example, Baron et al. (2016) reported that cows grazing stockpiled perennial forage (meadow bromegrass, CP = 78 g kg⁻¹ DM⁻¹, NDF = 514 g kg⁻¹ DM⁻¹) in Alberta maintained condition from November to March without supplementation with similar forage nutrient profiles but did not experience the same drastic change in temperature as was experienced in Period 2 of the present study. However, loss in BW and negative ADG in pregnant heifers grazing stockpiled perennial forages in late fall/early winter reported here, suggest the potential need for supplementation. Kulathunga et al. (2016) offered rolled barley supplemented at 0.2% and 0.01% BW d⁻¹ to mid-gestation pregnant cows grazing treatments 1) stockpiled meadow bromegrass and alfalfa pastures and 2) fed meadow bromegrass-alfalfa hay bales in drylot, respectively when temperatures dropped to or below -18°C to -23°C to maintain cow weight and condition. Cows in both treatments gained weight during that study and maintained BCS, with no difference in weight between treatments.

Serum urea nitrogen

Urea nitrogen concentration in the blood serum can be used as an indication of the protein status of the animal and is influenced by the dietary CP concentration through absorption of excess ammonia following CP breakdown in the rumen (Hammond, 1994). In the current study, there was significant treatment x period interaction as TAC was the only treatment consistently above the

minimum SUN threshold amount of 2.1 mmol L⁻¹ (Hammond, 1994) at all three sampling times. The SUN concentrations in Period 1 and the start of Period 2 can be explained by the forage CP concentrations as COR and TAM had lower forage CP concentrations compared to TAC and OGA and both were above the minimum threshold in Period 1. Decreased CP intake in Period 2, led to decreased SUN concentrations in all perennial treatments with only heifers grazing TAC above the minimum threshold. However, at the end of Period 2, SUN concentrations in heifers grazing COR and TAM increased compared to the start of Period 2. When CP intake does not meet requirements, muscle tissue can be metabolized in lieu of dietary CP (Huntington et al. 2001; Chimonyo et al. 2002). Chimonyo et al. (2002) found that draft cattle fed low dietary protein mobilized tissue reserves to supplement deficient dietary protein levels. Mobilization of muscle leads to increased N in the blood stream (Huntington et al. 2001) and therefore may account for the increased SUN concentrations in heifers grazing COR and TAM from the start of Period 2 to the end of Period 2. However, SUN concentrations were lower for OGA heifers and did not change for TAC heifers during this same period of time and both treatments also lost weight in Period 2. Bernier et al. (2014) demonstrated that low SUN values may be the result of an increase in N excretion during extreme cold as fecal NH₃-N concentrations were 25% higher in cows exposed to prolonged cold (-17.7°C) as compared to thermal neutral conditions (7.3°C). Although all heifers were grazing at the same location with the same ambient temperature, COR heifers who had wind protection from their available forage may be expected to respond differently due to decreased heat loss from windchill. Further, pastures adjacent to the COR pastures may have been exposed to temperatures and snow accumulation that differed from COR as a consequence of the microclimate created by the COR stand. Nonetheless, it is evident that heifers stockpile grazing COR, OGA and TAM, require protein supplementation to achieve the minimum SUN threshold.

4.5.3 Methane and carbon dioxide emissions

There were no differences between the perennial forage treatments and the annual forage treatment, however COR heifers had numerically but not significantly lower CH₄ output than the three perennial forage pastures. It is well documented that plant species such as corn and cereals with a higher starch concentration have lower CH₄ emissions compared to cattle eating a low starch diet (Beauchemin et al. 2008; Beauchemin et al. 2020). Benchaar et al. (2001) reported that a ration consisting of 30% alfalfa hay and 70% 45:55 corn grain:soybean meal supplement produced 23% less CH₄ (%GEI) compared to a 100% alfalfa hay diet indicating increased rumen metabolic efficiency when fed concentrates compared to a forage-only diets. However, in the current study the animals were eating the whole corn plant, ingesting the high fibre stalk and leaves along with the whole cob grain, thus decreasing the starch concentration of the diet.

4.5.4 Grazing behavior

Time spent at shelter

The GPS collar data provides strong evidence that standing corn provides shelter for heifers grazing stockpiled forages as they spent less time at the windbreak shelters (7%) compared to the heifers grazing perennial grass and legume forages (39-54%; P<0.001; Table 15). During periods of cold (below -18°C; Table 6), it was apparent based on visual observation that on days when windspeed was higher, the heifers spent more time at the windbreak shelter than days when there was little to no wind. This is consistent with work by Houseal and Olson (1995) in which cattle consistently choose microclimates on pasture that provided shelter and relief from cold stress while

grazing native range in Montana during winter months. Olson and Wallander (2002) also found that beef cows will utilize any shelter (manmade or natural) in order to conserve energy during harsh winter weather in Montana. Their findings were similar to those in the present study as they also observed cattle chose to conserve energy and avoid excess cold stress by remaining behind the wind fence on very cold windy winter days rather than spending time spent grazing as was also seen in OGA, TAC and TAM treatments. Increased time at shelter at night is likely associated with decreased nighttime temperatures ($<-17^{\circ}\text{C}$; Olsen and Wallander 2002) or days when windspeeds exceeded 10 km hr^{-1} . Since heifers in COR pastures spent more in the paddock rather than behind the windbreak shelter, it can be speculated that the physical height of the corn plants created a favorable microclimate that reduced cold stress. Therefore, COR heifers did not have to choose between energy conservation (seeking shelter from extreme winter weather) and energy loss (traveling away from shelter to available forage), unlike heifers in OGA, TAC and TAM. Although the corn height was significantly lower at the end of Period 2 compared to its height at the beginning of the trial, it served as a wind barrier throughout heavy snowfall and blizzard conditions for the heifers to continue grazing during this time.

Time spent at water

Cold stress and choosing to seek shelter instead of accessing water sources may also impact animal performance (Young et al. 1989; Olson and Wallander 2002) so time spent at water was measured in the present study to gain a better understanding of how often cattle will seek water over shelter while extended grazing. Heifers in the COR pastures spent significantly more time at the waterer in Period 1 but did not differ from the other treatments in Period 2. Visual observation supports the GPS data, as it was apparent that COR heifers preferred to rest by the water more than

the other treatments in Period 1. The heifers grazing perennial pastures had grass to lay on, compared to the corn pastures that had only corn stubble and mud/dirt to lay on except in the area adjacent to the waterer which had grass cover. The decrease in time spent at water in Period 2 for all treatments likely was due to the lack of shelter around the water so less time was spent at water during cold temperatures that occurred in Period 2. This is consistent with Olson and Wallander (2002) who reported that cows sought shelter during harsh winter weather rather than feed or water to conserve energy. Additionally, cattle were able to consume snow while grazing which would reduce the amount of water needed from the heated waterer.

Distance travelled

Research utilizing GPS collars to track distance travelled is typically examining animal behaviour and grazing patterns on a large pasture or range (Rawluk et al. 2014; Bailey et al. 2018) instead of small intensively managed paddocks that were utilized during the present study. A treatment x period interaction and treatment x TOD x period interaction ($P < 0.05$; Table 15) occurred with increased distance travelled from Period 1 to Period 2 which was expected due to use of the strip grazing during the trial with the new forage allocation increasing in distance from water and shelter resulting in increased distance travelled. Therefore, interactions involving period were not explored in the currently trial. Heifers in TAC had to travel further to available forage in Period 2 compared to other forage treatments due to the larger size of forage allocation space for this treatment due to lower forage yield compared to TAM and COR (Table 2). Increased distance traveled during daylight hours and nighttime may be attributed to increased grazing activity during the day. Dunn et al. (1988) also reported significantly less activity and movement during 19:00-

07:00 each day than during both 07:00-13:00 and 13:00-19:00 while grazing native rangeland in Montana.

4.6 CONCLUSIONS

The hypothesis that perennial grass-legume stockpiled pastures can support pregnant beef heifers without any difference between forage treatments was confirmed, however, differences were observed in the nutrient profile of the stands as TAC pastures had higher CP followed by OGA, and TAM/COR pastures. In addition, TAC and TAM pastures had higher TDN concentration than OGA. Although nutrient profiles differed, forage yield did not differ between grass-legume treatments. As hypothesized, COR pastures had a lower CP concentration than OGA and TAC, while yield and TDN were greater and NDF concentration lower than all three perennial forage treatments. However, increased TDN concentration did not result in increased rumen fermentation efficiency in COR heifers as measured by enteric CH₄ emissions in Period 1. Finally, heifers grazing corn pastures spent less time at shelters during periods of cold due to increased protection offered by the taller corn stand compared to the perennial pastures, as was expected.

Bred beef heifers grazing all four stockpiled forage treatments gained weight and were able to successfully stockpile graze in the late fall (Period 1), however all treatments lost weight when temperatures fell to < 18°C in Period 2. Heifers grazing COR and TAC lost less weight than OGA while TAC and TAM had comparable loss. Although heifers grazing COR spent more time grazing than those on the perennial treatments who had to choose between grazing and conserving heat and energy behind the windbreak fences, this resulted in a marginal numerical but not statistical difference in ADG.

In conclusion, of the perennial species, TAC had higher CP and TDN, lower ADF and NDF compared to OGA and TAC. In addition, TAC appeared to maintain quality over time compared to OGA which had higher ADF and NDF as well as lower TDN in Period 2 compared to Period 1. Mineral profile of TAC was also superior to COR. Although heifers in all treatments lost weight when weather conditions declined in Period 2, heifers grazing TAC and TAM lost less weight than heifers grazing OGA from the start of the trial to the end of Period 2. Compared to the perennial grass-legume pastures, COR had lower CP, ADF and NDF but higher TDN, leading to a marginally positive ADG when averaged across both periods with superior performance compared to TAM and OGA and comparable to TAC. In addition, increased plant height and less time at shelter suggest that COR offered sufficient shelter to reduce non-grazing time compared to the perennial grass-legume treatments. As heifers in all forage treatments lost weight in Period 2 when heavy snowfall and cold temperatures occurred, it is evident that during periods of cold, growing bred heifers require supplementation to maintain a positive energy balance. An economic analysis is necessary to determine if corn, with its higher input costs, is a viable option compared to perennial grass-legume stands such as TAC and TAM.

5.0 GENERAL DISCUSSION

Extending the grazing season in western Canada has been practiced using multiple management strategies (McGeough et al. 2018) including stockpile grazing of both perennial and annual forages, swath grazing, and bale grazing. Many of these strategies have been proven successful in feeding beef cows over the winter in western Canada (Baron et al. 2016; Kulathunga et al. 2016; Jose et al. 2020). However, much of the work conducted to date has compared management strategies (stockpile grazing vs hay fed in drylot or swath grazing) in grazing settings or compared forage species in plot-settings with more limited research conducted to investigate the effects of different forages species using the same management strategy in a western Canadian production environment (Schoonmaker et al. 2003; Kulathunga et al. 2016; Baron et al. 2016). Identifying forage mixes that can be used in extended grazing strategies is important to ensure producer success in implementing these strategies to support and maintain cow/heifer performance and pregnancy while reducing cost of production to ensure economic viability of the operation (Kelln et al. 2011). Performance of heifers/cows while stockpile grazing can vary greatly as a consequence of adverse weather conditions including drought/excess precipitation and extreme cold, leading to inconsistent forage yield and quality, and snowfall accumulation.

The objectives of the present study were to compare perennial and annual forage species in stockpiled grazing environments and their impact on: 1) yield, nutrient profile and plant height; 2) animal performance including DMI, BW, ADG, SUN, rumen metabolic efficiency as measured by CH₄ production; and 3) animal activity and behavior including distance traveled, time spent at shelter and water.

5.1 Stockpile grazing bred beef heifers in western Canada

A number of researchers (Baron et al. 2003; Biligetu et al. 2014; Lardner et al. 2017; Peng 2017; Hewitt 2018) have conducted valuable small plot trials examining perennial and annual forages and their suitability for stockpiled forage in western Canada, primarily based on nutrient profile in late fall. Their work helped to fill knowledge gaps by indicating potential forage species that could be well suited for stockpile grazing. Our data demonstrates that the legume-grass perennial species examined differ in nutrient profile and therefore selection should depend not only on the environmental constraints of the farm (i.e., soil type, annual precipitation, etc.) but also on the time of grazing and the class of animals grazed. Although several studies have demonstrated that cows are able to graze in winter conditions in western Canada (Baron et al. 2016; Kulathunga et al. 2016; Jose et al. 2020), the potential to graze pregnant heifers has not been previously examined. Heifers have greater nutrient requirements compared to cows as they are not only maintaining a fetus but also still growing themselves. Our data suggests that heifers can gain weight when grazing OGA, TAC, TAM or COR stands early in the fall/winter grazing season therefore reducing the cost of production. However, for stockpile grazing of bred heifers in Manitoba to be successful supplementation or a change in feeding management strategy such as grazing earlier in the fall before alfalfa loses leaf material and quality is compromised, moving animals into drylot confinement or a different extended grazing strategy is needed with a higher forage nutrient profile. The merit of supplementation is supported by Kulathunga et al. (2016) who successfully stockpile grazed bred beef cows during winter months in Saskatchewan. Supplementation was needed to meet the increased nutrient requirements associated with cold and changes in physiological status associated with pregnancy. Therefore, the current study adds new information to a body of research in western Canada by comparing heifers grazing different forage species under more typical fall conditions and more extreme winter conditions.

This study also provided unique information regarding animal grazing behavior during subzero temperatures and using GPS data re-enforces need for either natural or constructed wind shelters to improve animal well-being and performance. It was evident that COR heifers spent significantly more time than the perennial treatments at the waterer as they preferred grassy area surrounding the waterer compared to the corn stubble on areas they had already grazed. Therefore, it is important that heifers grazing corn pastures have an area to rest which does not require increased travel distance and energy expenditure. Further, heifers grazing COR spent less time at wind shelters than heifers grazing perennial grass and legume pastures when winter weather conditions declined. This evidence supported is by Olson and Wallander (2002) who found that cows grazing winter range pasture in Montana, actively sought out shelter in harsh winter weather ($<-17^{\circ}\text{C}$) to minimize energy loss rather than grazing to maximize energy gain. Visual observation in the current study also demonstrated that heifers grazing perennial grass-legume forage used shelter to a greater extent on days when cold temperatures were coupled with increased wind speed. Energetic savings may potentially be realized in grazing by placing a moveable wind fence close to the grazing area, especially when there is sufficient snow to meet water requirements, minimizing energy spent in traveling long distances to a waterer.

5.3 Future research

It was evidenced in the present study that further research is required surrounding stockpile grazing as an extended grazing method in western Canada, and more specifically, Manitoba, which is known to experience extreme cold temperatures during the winter months. The present study was a snapshot over three months that exhibited that stockpile grazing can be successful in late fall but did not examine if supplementing on pasture during harsh winter weather could enable heifers

to continue stockpile grazing later into the winter, forage regrowth the following spring (yield, height, and quality), or reproductive success of the bred heifers and their offspring. A more comprehensive assessment of the success of stockpile grazing bred beef heifers should be determined through a multi-year study which includes the long-term effects of late season grazing on forage vigor and longevity in the stand. This information is valuable to beef producers who may be considering seeding a perennial forage stand to utilize for stockpile grazing to avoid seeding forage species that will not survive or be productive long-term for their grazing needs. Multi-year small plot studies surrounding stockpiled forages in western Canada (Biligtu et al. 2014; Hewitt 2018) examined yield and quality over time but forages were harvested in either late summer (August) or fall (September or October) but did not examine late season growth (November and December) on forage regrowth the following spring.

Another area of future research to be explored is the impact of nutrient deficiency while stockpile grazing on both cow and offspring in the short and long term. A review by Funston et al. (2012) concluded that inadequate maternal nutrition may not affect short term performance of the cow (BCS, ADG) and her calf (birth and weaning weight) but may also have long term negative effects on, heifer fertility, susceptibility to chronic health problems and carcass outcomes. However, there is limited research regarding the fetal programming associated with nutrient deficiency in extended grazing environments in the late fall and early winter in cold climates such as western Canada.

Another area that requires further investigation is an economic assessment of stockpile grazing using different annual and perennial forage species. For example, in the present study, COR had favorable outcomes in terms of higher forage yield and energy concentration but had increased inputs compared to the perennial species. Previous research has compared different

extended grazing strategies to each other (Kelln et al. 2011; Kulathunga et al. 2016; Jose et al. 2020) but an economic comparison within stockpile grazing of different forage species has not yet been completed.

6.0 GENERAL CONCLUSIONS

From this study it can be concluded that:

- Stockpile grazing both perennial forage mixes and standing corn in the late fall can be a successful extended grazing strategy for cattle producers in western Canada before temperatures drop below -18°C and more than 15 cm of snow accumulation. Based on high TDN and yield COR was the preferred forage for stockpile grazing. Of the perennial forages TAC had the highest CP and low NDF concentrations and therefore was the preferred perennial forage for stockpile grazing.
- Plant height of perennial forages can be reduced once snowfall starts to accumulate in the early winter. Increased snow accumulation as the winter progresses may impact DMI, however it did not in this study but DMI was measured in Period 2 before more than 5 cm of snowfall fell.
- Grazing a higher concentrate and lower CP annual forage such as corn did not improve rumen metabolic efficiency measured via enteric CH_4 emissions in Period 1 of bred beef heifers compared to grazing perennial legume and grass forages statistically, but it did trend towards improving efficiency numerically. Lack of significance may be attributed to large variation and a relatively small sample size.
- Heifers lost weight in the second grazing period in which severe cold temperatures coupled with high winds occurred suggesting that all treatments require supplementation
- Heifers grazing stockpiled perennial forages in the early winter require wind protection via either a man-made structure or wind fence or trees. However, standing corn offers wind protection such that heifers did not seek additional protection away from available feed, especially during the day.

Recommendations:

- Producers should ensure selected forages that are seeded and intended for stockpile grazing are compatible with their soil and landscape to ensure optimal forage yield and quality at the time the forage is to be grazed (early fall, early winter or spring) and for the class of animals (cows vs heifers) that will be grazing it.
- Producers should ensure that all nutritional requirements for their bred cows and heifers are met when practicing extended grazing strategies to avoid body condition loss and ensure reproductive success. This can be accomplished by forage and feed testing, matching forage quality with animal requirements and monitoring animal condition throughout the extended grazing season. A strategy should be in place to provide protein or energy supplementation, if necessary, especially once animals become cold stressed in the winter months to ensure optimal performance.
- Producers should have a backup plan in place if significant snowfall or freeze-thaw cycles limit access to stockpiled forage pastures in the winter months. This may include feeding harvested feed (hay, silage, etc.) either on pasture or in confinement where there is adequate wind protection for the animals.
- Stockpile grazing can be a successful extended grazing strategy for western Canada in the late fall with proper animal management coupled with sufficient forage yield and quality.

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