Sustainable Overwintering Systems for Beef Cows on the Canadian Prairies: Challenges and Solutions

By

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ABSTRACT

The goal of this thesis was to provide an in-depth description of winter bale grazing (BG) for beef cows, including the impacts on animal, soil and forage productivity and the potential environmental costs and benefits. A winter trial with 60 pregnant beef cows was conducted over two, 21-day periods (P1 and P2) with the following treatments: drylot (DL), BG, and BG with supplementation (dried distillers grains with solubles; BGDG) at a rate of 8.3 kg cow^{-1} every three days. All treatments received low-quality (11% CP) forage *ad libitum*. Dry matter (DM) intake in P1 for the DL and BG systems was 13.4 and 12.2 kg cow^{-1} d^{-1} while average daily gain was 0.45 and -0.28 kg cow^{-1} d^{-1}, respectively. Enteric methane emissions (L d^{-1} and % GEI) were greatest from the BG system in P1. Forage DM yield decreased by 68% following application of manure from the BGDG treatment compared to a control field and was attributed to smothering by waste feed. Concentrations of residual soil extractable nitrogen (N) and phosphorus (P) were 15 and 2.5 times greater, respectively, at the centre of bale placement areas compared to a control. Detailed grid soil sampling revealed that 40 area-weighted mean extractable N and P samples, collected in a 4:1 ratio from waste feed affected and unaffected areas of the field, were required to determine field mean nutrient status without compromising precision. A system-scale nutrient budget model was used to determine efficiency of N and P inputs in BGDG and DL systems. Surpluses were 448 and 225 kg N ha^{-1} and 52 and 26 kg P ha^{-1}, and efficiency was 0.4 and -0.3% N and 8.7 and 12.1 % P for the BGDG and DL systems, respectively. This research provides scientific information regarding, DM intake, enteric methane and N and P surpluses from extensively overwintered beef cows. These studies suggest that in some production systems bale grazing may have increased enteric methane emissions and decreased nutrient utilization efficiency compared to DL systems. These results must be considered along with economic costs and benefits to more fully assess the sustainability of overwintering systems.

DEDICATION

I would like to dedicate this thesis to my grandparents, Shirley and Bill Jonas, who left this world before I completed this PhD program. Their daily encouragement and questioning as to when I was going to be done will forever be remembered and I wish they could be here to see it finally completed.

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FOREWORD

This thesis was written following a manuscript format and is composed of four manuscripts. The authors for the four manuscripts are as follows: Manuscript 1: G. R. Donohoe, K. M. Wittenberg, D. N. Flaten, and K. H. Ominski; Manuscript 2: G. R. Donohoe, D. N. Flaten, K. H. Ominski; Manuscript 3: G. R. Donohoe, D. Flaten, F. Zvomuya, K. H. Ominski; Manuscript 4: G. R. Donohoe, K. H. Ominski, D. N. Flaten. All manuscripts have been formatted based on the Canadian Journal of Animal Science guide for manuscript preparation and none have been submitted for publication at this time.

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ABBREVIATIONS

ANOVA	Analysis of Variance
y	year
d	day
h	hour
min	minute
kg	kilogram
g	gram
NH_3	ammonia
NH_4^+	ammonium
CH_4	methane
CO_2	carbon dioxide
N_2O	nitrous oxide
H	hydrogen
GHG	greenhouse gas
ns	not significant
na	not applicable
% GEI	percent gross energy intake
^oC	degrees Celsius
BG	bale graze
DL	drylot
DDGS	dried distillers grains with solubles
BGdg	bale graze with DDGS supplementation
BGcon	bale graze with no supplementation
SUN	serum urea nitrogen

BW	body weight
CP	crude protein
ADF	acid detergent fibre
NDF	neutral detergent fibre
DM	dry matter
DMI	dry matter intake
GE	gross energy
GEI	gross energy intake
ME	metabolisable energy
Mg	magnesium
Ca	calcium
K	potassium
N	nitrogen
P	phosphorus
Na	sodium
NE	net energy
NEm	net energy required for maintenance
NEma	net energy for maintenance available
NEcs	net energy for cold stress
NEg	net energy for gain
SE	standard error
SD	standard deviation
LCT	lower critical temperature

1.0 GENERAL INTRODUCTION

With sustainable food production at the forefront of Canadian and world politics, it is imperative to have a clear definition of sustainability as well as well-founded, accurate information regarding the impact of agricultural production systems on the Canadian landscape. The word sustainability has over 386 definitions reported in scientific literature (Rigby et al. 2001); one of which is that applied by the U.S. National Research Council (NRC) to agricultural production as “the means to meet the food, fibre, and fuel needs of society without negative effects on the economy, the environment and society” (NRC 2010).

Consumers are faced with a wide range of media reports regarding the sustainability of food products, including beef. Several studies have also suggested multiple benefits to human health and the environment through a reduction in red meat consumption (Ashton et al. 2012; Paola et al. 2015). Further, excessive energy and water consumption, greenhouse emissions and animal welfare are at the top of the list of environmental concerns associated with producing and eating beef (Fox and Ward 2008). The updated Canadian Food Guide which will be released in 2018 promotes plant-based diets as a means to promote environmental sustainability (Hui 2017).

On the Canadian Prairies and Northern Great Plains of the United States, beef production provides many socio-economic benefits including high-quality food for consumers from human inedible commodities, as well as economic activity for rural communities. With proper management, the use of forages and grazing lands in these production systems can provide many ecological benefits, including increased biodiversity of grasslands, protection from soil erosion, improved nitrogen cycling and sequestration of carbon (Schuman et al. 1999; Johnson 1961).

However, this region is also characterized by long, cold winter periods with increased feed requirements, where mechanical feeding of harvested forages and the use of supplemental feeds is often required to sustain animal productivity. As a result, winter feeding of beef cattle comprises a significant portion of the total cost of production for beef producers on the Canadian Prairies (Saskatchewan Forage Council 2011; Jungnitsch 2008; Kaliel and Kotowich 2002). To help reduce these costs, many producers across Canada have adopted alternative, extensive, winter management strategies, where animals are fed supplemental feeds on pasture or fields, instead of in a traditional confined, intensive management system (Sheppard et al. 2015). Studies have demonstrated increased soil nutrient status and forage productivity associated with these extensively managed systems, as well as increased recovery of imported nutrients (Jungnitsch et al. 2011; Kelln et al. 2012).

Extensive overwintering practices have also raised concerns from an environmental perspective, however. Reports of increased nutrient runoff from bale grazing sites (Chen et al. 2017) have resulted in debate over the development of government policies promoting extensive overwintering practices. The conflicting benefits and consequences associated with this particular management practice highlight the importance of ascertaining the full range of environmental and ecological implications of beef production systems to ensure public acceptance and environmental sustainability, as well as the economic viability of producers.

The goal of this thesis was to provide an in-depth description of bale grazing based extensive overwintering management practices, including the impacts on animal, soil and forage productivity and the potential associated environmental costs and benefits. The data collected were combined to develop an indicator, efficiency, to measure system sustainability. Gaps in knowledge and direction for future work were identified in order to promote continued evaluation of overwintering management practices and their impact on sustainability of the beef industry on the Canadian Prairies.

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2.0 LITERATURE REVIEW

This literature review describes the current status of the cow-calf sector of the Canadian beef cattle industry, overwintering practices used on the Canadian Prairies, and provides an overview of known scientific research conducted on beef cow overwintering systems as it relates to system sustainability. An in-depth review of enteric methane (CH_4) emissions is included, while other environmental concerns are briefly described.

2.1 Current Knowledge of the Sustainability of Beef Cow Overwintering Systems on the Canadian Prairies

2.1.1 Industry Statistics

The beef industry in Canada is a sizeable component of the Canadian economy, contributing $16 billion to Canada's annual GDP on average between 2012 and 2016 [Canadian Cattlemen's Association (CCA) 2017]. There were an estimated 10.6 million head of beef cattle in Canada in 2016 (CCA 2017). Cattle in the beef industry are distributed across three main sectors: cow-calf, back-grounding/stocker, and finishing/feedlot (Honey 2016). Each sector differs in terms of land and livestock management practices. In brief, calves are born and raised on cow-calf operations until they are weaned, at which time they are either placed on low-energy, forage-based back-grounding diets while they continue to grow or they are moved directly to feedlots where they receive high-energy, primarily grain-based, finishing rations until they reach desired weight and fat cover (Stats Canada 2012; Alberta Beef Producers 2013).

Grass-finished beef is characterized by use of forage-only diets from weaning until reaching finishing weight, which can take a longer period of time compared to the traditional feedlot system and may result in a different quality end product for consumers.

The cow-calf sector is by-far the largest sector of the industry, consisting of 3.8 million head of mature cows (CCA 2017). The Prairie Provinces (AB, SK, and MB) have 72% of the Canadian cow herd (CCA 2017). Manitoba had 12% of the beef cow herd in 2015 (Honey 2015). In Manitoba, 76% of the province's beef cattle inventories were located on cow-calf operations, 18% in back-grounding operations and the remaining 6% in feedlots (Honey 2015). This profile differs from Alberta which had 69% of the province's beef cattle inventories in feedlots (Alberta Cattle Feeders Association 2018).

The environmental impacts of beef production differ for the cow-calf and feedlot sectors as a consequence of inherent differences in the two production systems. Feedlots consist primarily of young, growing animals, fed high-energy diets, with a goal of achieving daily rates of gain in excess of 1.5 kg hd^{-1} for the least cost. As well, feedlots generally involve feeding in pens, where significant manure build-up can occur. The goal of cow-calf operations is to maintain the reproductive longevity of the mature cow herd in order to produce an annual calf crop. Forages (perennial and annual, tame and native) are the main source of feed for cow-calf and back-grounding operations throughout the year [Saskatchewan Forage Council (SFC) 2011].

In general, forages may be grown on land that is unsuitable for crops destined for human consumption (SFC 2011). These lands have few other economically sustainable uses in the market place and therefore, can be utilized by the cow-calf sector to provide nutrient dense calories that would otherwise be indigestible by humans. In addition, the cow-calf sector provides environmental goods and services by utilizing and conserving perennial forage and native range lands.

2.1.2 The Cow-Calf Sector

On average, the winter-feeding period in a cow-calf operation on the Canadian Prairies is 200 days, with 165 days of summer grazing per year (SFC 2011). Daily temperatures from November through March in Winnipeg, MB, Canada average -10.7°C, with a range of -4.9 to -16.4°C, although extreme minimum temperatures of -45°C have been recorded (Environment Canada 2013). Average annual snowfall is 114 cm in Winnipeg, Manitoba (Environment Canada 2013). Traditional, confined winter-feeding systems, in which cows are fed in corrals or small pastures (drylots) over winter also referred to as intensive winter management systems, were developed to ensure that cows would maintain productivity through harsh winter conditions. Costs associated with drylot feeding include infrastructure development and maintenance (i.e., corrals, wind shelters, water sources), bedding, feed production, transportation and storage, labour and equipment to feed animals, along with manure removal and application costs. Cows often have to be transported to and from the drylot locations as well.

2.1.3 Reducing Winter Feeding Costs

To reduce costs associated with overwintering beef cows in a drylot, many producers in Canada have adopted winter grazing management strategies. Also referred to as extensive overwintering, these practices typically involve feeding livestock on annually cropped fields or perennial pastures overwinter instead of within drylots. Sixty-nine percent of Canadian beef producers who grazed during the summer months reported using some form of winter grazing for at least a portion of the winter feeding period, with 82% of all beef producers still using drylots for winter feeding at some point during the year (Sheppard et al. 2015).

Of the Canadian producers who used winter grazing, 64% of respondents used more than one practice, including swath grazing (e.g., Aasen et al. 2004; McCartney et al. 2004; Karn et al. 2005; Baron et al. 2006, Legesse et al. 2012), bale grazing (Jungnitsch et al. 2011; Kelln et al. 2012a; Kelln et al. 2012b), stockpiled forage grazing (e.g., Adams et al. 1986; Willms et al. 1993; Baron et al. 2003; Baron et al. 2005), and crop residue grazing (Kelln et al. 2012a; Kelln et al. 2012b), as depicted in Figure 2.1. In Canada, bale processing or rolling bales is the most popular technique, used by 44% of surveyed producers who are using winter grazing techniques, followed by bale grazing at 42%, stockpiled forage grazing at 29%, swath grazing at 25%, standing corn grazing at 7% and crop residue grazing and other feedstuffs at 1.9% (Sheppard et al. 2015). Infrastructure required for these practices includes portable electric fencing, wind shelters, and winter watering sites. In addition to the feed, bedding may or may not be supplied to livestock on extensive grazing areas, depending on the field site location, time of year, grazing practice used and producer preferences.

Several studies have demonstrated the economic advantage associated with extensive grazing management practices (Table 2.1). Higher costs associated with drylot systems, as reported by Kelln et al. (2012b), have been attributed to increased labour and equipment due to the harvesting, transporting, storing and feeding of preserved feed (e.g., round bales) and manure handling costs. Bale grazing costs, were 92 to 96% of drylot costs (Kelln et al. 2012b), with costs associated with harvesting, storing and feeding of preserved feed (i.e. round bales), similar to a drylot but without the need for manure handling as the manure is left on the field. Interestingly, these authors reported that processed forage grazing was 94% of drylot costs although additional costs were required including machinery, labour, and fuel costs to process the round bales into rows for cows. Kelln et al. (2012b) examined several winter grazing strategies and found that straw and chaff grazing required supplementation and therefore was 118% of drylot costs. These authors hypothesized that a lower-cost supplement would have significantly lowered the cost of this practice (Kelln et al. 2012b). Willms et al. (1993) demonstrated the potential for significant cost savings in stockpiled forage grazing at 47% of drylot costs, for which no mechanical harvesting, feeding of forage or manure handling is required and the feed is grown on site. It is important to note that these costs do not include long-term gains or losses due to changes in productivity of livestock, forage or annual crops as a result of adoption of extensive overwintering management practices, and they do not include infrastructure costs.

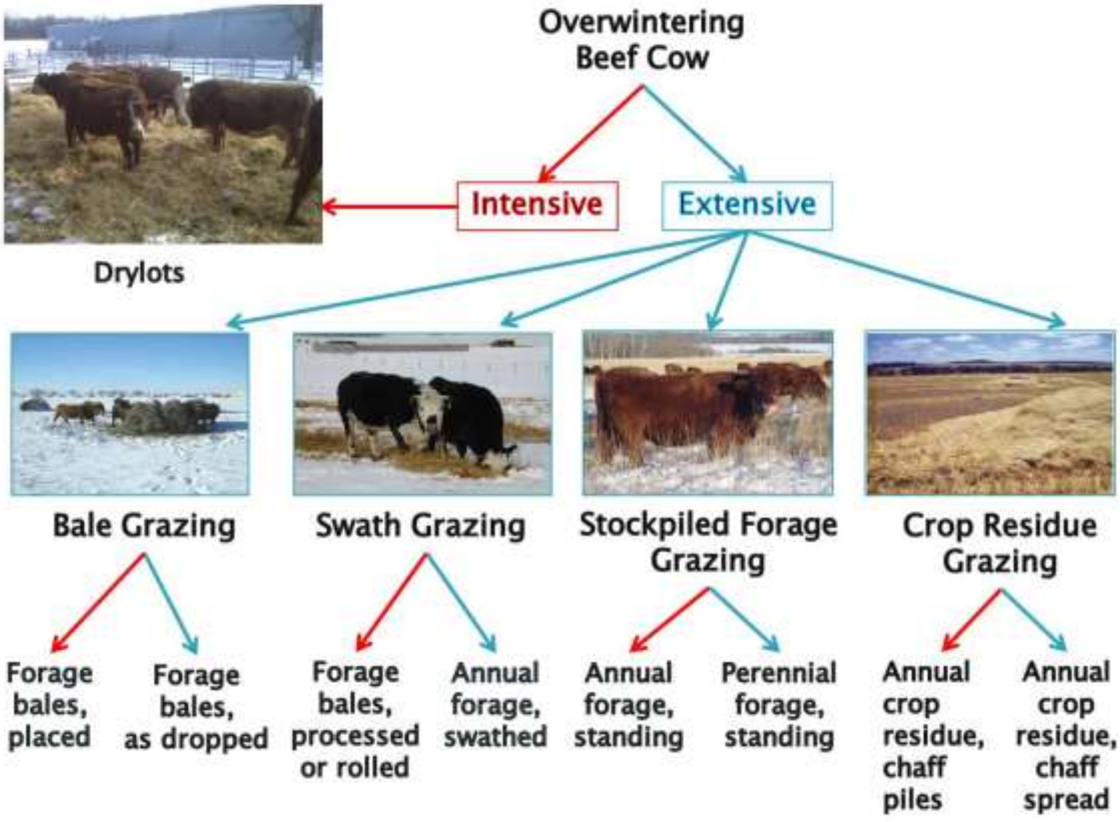

Figure 2.1 Description of common overwintering management practices for beef cows on the Canadian Prairies

Table 2.1 Cost of production of beef cow overwintering systems on the Canadian Prairies as reported in peer-reviewed literature

Reference and Year	**Beef Cow Overwintering System**					
	Drylot	Bale Graze	Swath Graze	Processed Forage	Straw Chaff Graze	Stockpiled Forage
				$\$\ cow^{-1}\ day^{-1}$		
Kelln et al. (2012b)	1.07	0.98	0.76	-	1.27	-
Jungnitsch (2008)	1.27	1.22	-	1.20	-	-
McCartney et al. (2004)	1.54	-	0.84		-	-
Willms et al. (1993)	0.78	-	-	-	-	0.37

2.1.3.1 Bale Grazing

Bale grazing is a practice by which large round bales (~400-600 kg bale^{-1}) are placed on either perennial pasture/hay or harvested annual crop land in a grid pattern, with a recommended spacing of 9 x 9 m [Manitoba Agriculture Food and Rural Initiatives (MAFRI) 2008] up to 12 x 10 m (Jungnitsch et al. 2011). These spacing recommendations would result in feed imports of 61.5 to 41.5 T ha^{-1}, respectively, if bales weighed 500 kg. Portable electric fencing is used to allocate enough feed for the herd for three to five d-periods throughout the winter. Waste feed in a bale grazing site has been recorded at 21% on average with differences attributed to feed quality (Jungnitsch 2008) and method of delivery. Waste hay in a drylot can be as high as 43% if round bales are fed without bale feeders in a drylot, and can be reduced to 5% with bale feeders (University of Missouri 2018). Bale grazing has advantages over most other extensive winter grazing practices, particularly in areas that receive large amounts of snowfall, as feed remains well above the snowpack.

However, transporting bales to a bale graze field site results in a large import of nutrients to a small location. Placement of 500 kg bales on a 10 x 10 m grid results in greater than a 12-

fold increase in forage density compared to that harvested from a forage field with a yield of 4000 kg ha^{-1}. If each imported bale had 85% dry matter, contained 9% crude protein and 0.11% phosphorus up to 612 kg of N ha^{-1} and 47 kg of P ha^{-1}would be imported to the site prior to consumption by cows. To decrease nutrient imports in feed, bale grazing can be practiced without placing round bales in a grid, but leaving them “as dropped” on a forage field. However, this practice requires a larger field size, making it impractical for large herds and difficult to use portable electric fencing to control the cows’ access to feed.

Waste feed and manure following bale grazing results in high variability in nutrient distribution and leaves circular patterns of waste feed and manure on field sites that can be visible in aerial photographs of the site for several years following grazing. These sites have localized areas of high nutrient content that may result in increased quantity and quality of forage for subsequent forage crops (Jungnitsch et al. 2011).

2.1.3.2 Swath Grazing

The practice of swath grazing typically involves cereal crops (i.e., barley, oats or triticale), legume crops or a mixture of the two, seeded later in the spring, cut at the soft dough stage and left in swaths for cattle to consume in the fall or over winter. Electric fencing is used to limit access to the swaths to reduce wastage. These crops have been shown to provide adequate feed quality through the winter months (Aasen et al. 2004).

Feed placement in rows may also be achieved using a bale processor to cut and spread baled forage (Jungnitsch et al. 2011) or by unrolling bales. As with bale grazing, several days of feed are allocated with a risk of importing excess nutrients to the site, depending on row spacing.

2.1.3.3 Stockpiled Forage Grazing

Leaving standing perennial forage for cows to graze in fall or winter is referred to as stockpile grazing. Some perennial and annual crops have been found to maintain relatively high nutrient content in their dormant stage with proper management (Baron et al. 2005). Common perennials used for stockpiled forage grazing include tame forage species such as brome grass varieties, alfalfa and creeping red fescue (Baron et al. 2005), as well as native pastures (Adams et al. 1986; Willms et al. 1993). Feed testing prior to grazing is important to ensure adequate nutrition is provided for livestock.

New varieties of corn with a lower heat unit requirement have expanded the area in which it can be grown and subsequently grazed in fall or winter (Baron et al. 2003). There is an advantage of using standing corn grazing in areas that receive large amounts of snowfall, as the corn and cobs stay well above the snow cover.

2.1.3.4 Crop Residue Grazing

Crop residue grazing is the practice of allowing cows to eat residue from annual crops (i.e., corn, wheat, barley, oats, and legume crops such as field peas) following harvesting. Crop residues can be gathered into piles or rows, or spread throughout the field. Cows can graze spread or rowed chaff through the fall and early winter periods before snowfall; however, piles are better for grazing during mid to late winter due to increased snow accumulation. However, piling chaff may require extra labour and equipment, as well. Beef producers can rent crop land or develop agreements with neighbouring crop farmers to access crop residues; a practice which can be particularly beneficial when feed shortages occur. As a consequence of the low nutrient density associated with crop residues, protein and energy supplementation may be required when crop residue grazing (Kelln et al. 2012b).

2.1.4 Animal Productivity

Over the winter-feeding period, providing adequate nutrition to cows is essential to ensure a successful calving and subsequent breeding season. Low energy diets pre-partum, may result in low birth weights and 105-d weights of calves, as well as lower pregnancy rates, compared to cows receiving moderate and high levels of energy pre-partum (Houghton et al. 1990). Research suggests that cows with adequate protein and energy supplementation during gestation have calves with improved weaning weights, heifer fertility, feedlot health and carcass composition (Stalker et al. 2006; Martin et al. 2007; Larson et al. 2009). Therefore, ensuring nutrient content and feed availability that meets animal requirements during the winter period is important for the long-term sustainability of extensive grazing systems.

Animal productivity in extensive management practices is more variable than intensive overwintering management as demonstrated in a three-year study in Saskatchewan comparing swath grazing, bale grazing, straw-chaff grazing and drylot overwintering systems (Kelln et al. 2012b). Cows in the drylot system had greater weight gains over a 21-d period in each of the three years. Swath grazing resulted in the largest body weight losses, ranging from -1.1 to -1.3 kg cow^{-1} d^{-1} followed by bale grazing, which had body weight changes ranging from -0.4 to -0.7 kg cow^{-1} d^{-1}. In year one, all three of the extensive systems resulted in average losses of body weight, whereas the drylot system resulted in gains of 9.1 kg cow^{-1}. Despite the changes in body weight, there were no significant differences in body condition scores (BCS) in years one or two. However, in year three, the drylot system had a significant increase of 0.2 BCS, compared to the bale graze and straw chaff systems which had a change of -0.1 BCS, with swath grazing being intermediate, with an increase of 0.1 BCS. No differences were found between winter feeding systems for calf birth date and weight, date of first born calf, date of last calf born, length of calving span, calving interval, or calving pattern.

Swath grazing also resulted in lower body weights when compared to drylot feeding in a three-year study by McCartney et al. (2004). However, no significant differences were found in changes in BCS, calving interval, length of calving span, calving pattern and cumulative open and cull rates between the two feeding systems. Conversely, Legesse et al. (2012) determined that when using extended winter grazing strategies, including stockpiled forage and swath grazing, cows gained more weight than in a drylot winter feeding system in four out of five years. Winter feeding system did not affect BCS or reproductive success, but cows in the drylot system had 1.8 x greater chance of being culled before turnout to summer pasture.

These trials indicate that more information regarding nutrient requirements for extensively managed beef cows is necessary to ensure that the energetic demands of these unique environments are met. There are no studies that monitor individual animal dry matter intake (DMI) during extensive overwintering, making it challenging to determine if weight loss during extensive overwintering is due to forage quality, decreased DMI, weather conditions, or other factors. Similarly, there is a lack of knowledge regarding increased activity associated with walking through snow packs to access water, exposure to extreme temperatures, increased wind exposure or other behavioral traits that arise in extensive wintering scenarios, which may affect animal nutrient requirements.

2.1.5 Nutrient Cycling in Crops and Forages

The impact of winter feeding systems on subsequent forage and crop production is an important consideration regarding winter site management and is typically not included in winter feeding costs as described in section 2.1.3 above. In a Saskatchewan study, Jungnitsch et al. (2011) reported that winter bale grazing and bale processing on a forage field resulted in 3.0 to 3.7-fold increase in soil inorganic N in the top 15 cm compared to an unfertilized control in the first spring following winter feeding. Forage dry matter (DM) yield for the next two growing seasons following bale processing and bale grazing was 3.3 to 4.7 times greater than an unfertilized control. Further, forage DM yield was greatest for the bale processing treatment, followed by bale grazing, with no significant difference between the control and spread manure or spread compost treatments, when manure and compost were spread at rates of 67.2 and 21.4 T ha^{-1}, respectively. These results indicate economic benefits of adopting extended grazing strategies due to increased forage production and decreased reliance on synthetic fertilizers.

Kelln et al. (2012a) also demonstrated that bale graze and swath graze systems resulted in significantly greater crop biomass yield compared to a straw-chaff overwintering system when barley was grown on a field site following extensive winter grazing treatments. No significant differences were found between bale, swath and straw-chaff grazing with regards to soil available N or soil extractable P at the 0-15 or 15-60 cm depths. Jungnitsch et al. (2011) and Kelln et al. (2012a) reported bale grazing and bale processing as superior overwintering systems in terms of their ability to capture soil nutrients and increase forage dry matter yield.

Both the Jungnitsch et al. (2011) and Kelln et al. (2012a) studies measured large variability in the distribution of soil nutrients and forage DM yield following bale grazing. Jungnitsch et al. (2011) reported that areas where bales were fed had increased urine and feces deposition and therefore high concentrations of N of P in surface soils, compared to other areas of the bale grazed field and compared to control and spread manure and compost-treated plots. As much as 600 kg inorganic N ha^{-1} and 240 kg P ha^{-1} (modified Kelowna method) were measured in the top

15 cm layer of soil in areas where bales were placed on the field, while measurements approaching 0 kg ha^{-1} available N and 20 kg ha^{-1} P were measured in areas away from bale placement locations. These “hotspot” areas of high soil nutrient status also had significant quantities of waste feed remaining on the soil surface that suppressed forage growth. Assessing field mean nutrient status of winter bale grazed sites with such extreme variability requires care in order to not undervalue or overcompensate for “hotspot” areas of the field. Random sampling a bale grazed field may prove to be difficult due to the visual variability resulting from waste feed deposition. Kelln et al. (2012a) and Jungnitsch et al. (2011) applied a grid-based sampling protocol to help reduce bias from hotspots; however, this process may be time consuming and costly. Protocols for soil and forage sampling winter bale graze sites are essential to ensure producers have an accurate measurement of available nutrients for subsequent crops and comply with provincial nutrient management regulations.

There is concern regarding extensive overwintering practices that result in large accumulations of soil nutrients, such as bale grazing. In provinces such as Manitoba, upper limits have been placed on accumulation of NO_3-N and Olsen P in agricultural soils for the protection of water quality. For example, in Manitoba, the upper limit for soil residual NO_3-N is 157 kg NO_3-N ha^{-1} (0-60 cm) in Water Quality Management Zone 1 soils. These limits decrease to 101 and 33.6 kg NO_3-N ha^{-1} for Zone 2 and 3 soils respectively, which include soils more typically used for beef cattle operations. Regulated limits for P in Manitoba are imposed when field mean Olsen P is greater than 60 mg kg^{-1} in the top 15 cm. Although the study by Jungnitsch et al. (2011) did not measure residual soil NO_3-N or Olsen P, field means of 146 kg available inorganic N ha^{-1} and 52 kg Modified Kelowna P ha^{-1} in the top 0-15 cm were reported. These results suggest that bale grazing on the same site annually may cause a large accumulation of soil nutrients. Variables that may affect soil nutrient accumulation following bale grazing include climate, soil type, bale spacing, size of bales, type and quality of feed, topography, and management before and after bale grazing. These variables must be considered when evaluating sustainability of extensive overwintering sites.

2.1.6 Ecological Implications of Overwintering Beef Cows

The majority of the published literature regarding winter grazing systems has focused on productivity and economic viability. To date, research published in peer reviewed literature regarding the consequences or benefits of these practices to the environment is limited.

Important ecological implications of note for overwintering beef cow systems may include: water quality, greenhouse gas (GHG) emissions, carbon sequestration, energy use, biodiversity, and resource conservation. This review provides a detailed account of enteric CH_4 emissions from overwintering beef cows, and briefly highlights notable references of other ecological implications of overwintering beef cows.

2.1.6.1 Water Quality

Increased nutrient runoff from bale graze winter sites compared to an equivalent ungrazed site has been measured for up to two years following winter feeding in southern Manitoba (Chen et al. 2017). This study found 3 to 11% of total N imported and 3 to 10% of total P imported was lost in runoff in the two years following bale grazing. Smith et al. (2011) determined that although intensive and extensive winter feeding sites had significantly greater concentrations of ammonium-N (NH_4^+-N) and orthophosphate (PO_4^--P) in runoff water compared to a control, runoff from the two overwintering systems did not appear different from each other, although they could not be compared statistically.

The studies by Chen et al. (2017) and Smith et al. (2011) show the potential for increased loss of nutrients to surface waterways from extensive overwintering sites. Several factors, including topography, depth of snowpack, and snowmelt/runoff conditions, impact potential nutrient loss to surface waterways (Liu et al. 2013). These authors demonstrated that annual variability in nutrient loss in runoff was large and volume of runoff was a critical factor controlling nutrients lost to surface water ways. The management of site location is therefore very important to consider when overwintering cattle, whether the overwintering system is intensive or extensive. Location of winter feeding sites in areas that do not drain directly to surface water bodies is essential.

2.1.6.2 Gaseous Losses: Greenhouse Gases and Ammonia

Gaseous emissions from winter feeding of beef cattle include three greenhouse gases: nitrous oxide (N_2O), CH_4 and carbon dioxide (CO_2). In addition, ammonia gas (NH_3), although not a direct source of greenhouse gas, is also emitted and is recognized worldwide as a harmful environmental air pollutant by the Gothenburg Protocol (United Nations Economic Commission for Europe 1999) and is a source of N loss from systems. Greenhouse gas emissions in the beef production system can originate from two main sources: i) enteric CH_4 from cattle associated with microbial fermentation of feedstuffs in the rumen and ii) microbial activity in soil and manure. Gaseous losses of ammonia can originate directly from manure and urine as well as from soil. Therefore, GHG and ammonia emissions can be affected by cattle management strategies during the winter-feeding period and crop/forage management of the land prior to or following winter feeding.

Enteric CH_4 emissions are estimated to contribute 63% of total beef production GHG emissions in western Canada, with 27% coming from soil and manure N_2O and the remainder from CO_2 and CH_4 from soil and manures (Beauchemin et al. 2010). These authors found that cow-calf operations contributed 80% of total GHG emissions from the beef production cycle.

Despite the large portion of GHG emissions reported to originate from the cow-calf sector, little peer-reviewed research has been published to date measuring gaseous emissions from mature beef cows over winter, particularly from extensive overwintering systems. This review focuses primarily on enteric CH_4 emissions and briefly highlights current knowledge of soil and manure GHG and ammonia emissions from overwintering systems.

2.1.6.2.1 Enteric Methane

Methane emissions from beef cattle occur as a by-product of microbial fermentation of feed in the rumen (90%) and large intestine, with a significant portion of the CH_4 produced absorbed and recirculated back to the lungs (Murray et al. 1976). Approximately 91 to 97% of CH_4 produced is emitted to the atmosphere via eructation and exhaled through the mouth and nose (Murray et al. 1976; Johnson and Johnson 1995). Ruminants cannot utilize CH_4; therefore, the formation and loss of CH_4 from a ruminant is also a form of energy loss, signaling inefficient digestive processes. Ruminants can lose 2-12% of their gross energy intake via CH_4 emission (Johnson and Johnson 1995). This is equivalent to 28 L CH_4 per kg DMI on average (Mathison et al. 1998).

Within the rumen, ingested feed (consisting of plant cell walls, proteins and starches) is hydrolyzed into amino acids and sugars by a multitude of microbial species (McAllister et al.

1996). These sugars are then fermented into volatile fatty acids, including acetate, propionate, and butyrate, which are utilized by the animal. The formation of acetate and butyrate result in H_2 and CO_2 as by-products, whereas the formation of propionate consumes H_2 and results in only H_2O as a by-product (Equations 1, 2 and 3; adapted from McAllister et al. 1996; Moss et al. 2000).

$$C_6H_{12}O_6 + 2H_2O \rightarrow 2C_2H_4O_2 \text{ (acetate)} + 2CO_2 + 8H \qquad \text{Eq. 1}$$

$$C_6H_{12}O_6 \rightarrow C_4H_8O_2 \text{ (butyrate)} + 2CO_2 + 4H \qquad \text{Eq. 2}$$

$$C_6H_{12}O_6 + 4H \rightarrow 2C_3H_6O_2 \text{ (propionate)} + 2H_2O \qquad \text{Eq. 3}$$

$$CO_2 + 8H \rightarrow CH_4 + 2H_2O \qquad \text{Eq. 4}$$

Anaerobic methanogens, part of the diverse community of microorganisms in the rumen, obtain their energy by reducing substrates, including CO_2, hydrogen, formate and acetate, to produce ATP, releasing CH_4 as a by-product (Equation 4; McAllister et al. 1996; Moss et al. 2000). The presence of H in the rumen can inhibit fermentation reactions by digestive microorganisms (McAllister and Newbold 2008). Methanogens are very efficient at ensuring that excess H is quickly utilized in order to maintain rumen microflora and the digestive process (Wolin and Miller 1988). Therefore, they are an essential part of rumen ecology. However, this process results in CH_4 formation. Large emissions of CH_4 from the cow-calf sector are due to the use of low-quality, forage-based diets for a large portion of the year. These lower-cost diets have high plant cell wall carbohydrate content (Small and McCaughey 2005) favoring acetate production and therefore increasing H and consequently CH_4. Feedlot animals are generally fed diets with large amount of concentrates, which increase propionate: acetate ratios in the rumen and thereby reducing production of CH_4 compared to forage only diets. In a review, Johnson and

Johnson (1995) reported losses of 6-12% GEI with forage-based diets and 2-3% GEI for concentrate-based diets, due to an increased ratio of propionate to acetate production.

Increasing the ratio of propionate to acetate in the rumen and reducing fermentation of plant cell walls are examples of processes that decrease H in the rumen and thereby reduce CH_4 production (Boadi et al. 2004a). Other management practices that may reduce enteric CH_4 emissions include improving animal productivity (e.g., Johnson et al. 1992; Kirchgessner et al. 1995; Johnson et al. 1996; Howden and Reyenga 1999); nutritional management strategies which include managing the type of carbohydrate fed, level of intake, feeding frequency, forage species and maturity, forage processing, forage preservation and grazing management (e.g., Johnson and Johnson 1995; Johnson et al. 1996; McAllister et al. 1996; McCaughey et al 1997; Harper et al. 1999; Benchaar et al. 2001; McGinn et al. 2009; Bernier et al. 2012;); manipulation of rumen fermentation including adding fats to the diet, ionophores and defaunation (e.g., Whitelaw et al. 1984; Mathison et al.1998; Moss et al. 2000; Johnson et al. 2002); direct inhibition of CH_4 by chemicals such as bromeothanesulphonate, chloride compounds, monensin and nitrate (Whitelaw et al. 1984; Lee et al. 2015; Vyas et al. 2018); probiotics (Eun et al. 2003); biological control including bacteriocins, archaeal viruses and immunization to methanogens (e.g., Hegarty 2001b; Klieve and Hegarty 1999); and genetic selection (Basarab et al. 2003). Increasing forage quality (Johnson and Johnson 1995), with starch or fat supplementation (McGinn et al. 2009) and decreasing frequency of feeding (Sutton et al. 1986) may be low-cost options for cow-calf producers to decrease enteric CH_4 emissions and meet increased energy demands of beef cattle during the winter months. Dried distillers grains with solubles (DDGS) has become a readily available, low-cost protein and energy supplement for beef cows. McGinn et al. (2009) found a

16.4% reduction in CH_4 emissions measured as % GEI, when DDGS was fed to growing beef cattle.

Enteric CH_4 emissions from beef cattle in free ranging environments can be measured using the sulfur hexafluoride (SF_6) tracer technique. Sulfur hexafluoride is contained in permeation tubes which are inserted into the rumen of a cow, where they continue to release SF_6 at a steady rate. To determine rates of exhaled CH_4 and CO_2, a portion of the exhaled CH_4, CO_2 and SF_6 from a cow is captured in evacuated canisters attached to the cow, through tubing that is attached to a halter and placed near the cow's nostils. The known steady state release rate of SF_6 from the permeation tubes is then used to determine rates of CH_4 and CO_2 exhaled that were captured in the canister. Using this technique, McCaughey et al. (1999) measured emissions ranging from 374 to 411 L CH_4 d^{-1} in mature beef cows grazing grass and legume-based forages in western Canada.

To date, CH_4 emissions have been modelled from beef cows swath grazing during late fall and early winter on the Canadian prairies using the IPPC Tier II method with feed quality and estimated gross energy intake as the model inputs (Alemu et al. 2017). Enteric methane has also been measured from non-pregnant beef cows overwintered intensively using the SF6 technique (Bernier et al. 2012). However, there are no studies that have measured CH_4 emission from pregnant beef cows in an extensive overwintering environment. It has been hypothesized that cold temperatures, which are typical during the winter months in prairie Canada, may lead to increased rate of passage of feedstuffs, thereby lowering enteric CH_4 emissions (Christopherson 1976; Kennedy and Milligan 1978; Christopherson and Kennedy 1983). In the only published study measuring CH_4 emissions from beef cows in confinement during the winter months in Canada, Bernier et al. (2012) confirmed this hypothesis. Three diet groups, fed a base-line low-quality forage (Control; 6% CP), with either 10% DDGS (9% dietary CP) or 20% DDGS (11% dietary CP) added, were fed in confinement with CH_4 emissions and individual DMI measured during thermal neutral conditions (fall) and replicated during the cold winter months. These authors observed a significant decrease in CH_4 emissions from intensively overwintered cows exposed to prolonged cold (256 L CH_4 d^{-1}) compared to cows fed the same low-quality, forage-based diets in thermal neutral conditions (331 L CH_4 d^{-1}).

In the same study, Bernier et al. (2012) determined that beef cows fed these low-quality forage diets did not increase DMI when exposed to cold temperatures, even when supplemented with dried distillers grains with solubles (DDGS). Dry matter intake did not differ between diets or seasons, with the exception that DMI in Control diets, which were energy and protein deficient, decreased due to cold exposure. This is contrary to other published literature in which cold exposure resulted in increased rate of passage and increased DMI (Kennedy 1985). Bernier hypothesized that the low-quality forage diets fed compromised the cows' ability to increase DMI to compensate for the increased demand for energy in the winter months. Methane emissions (% GEI) were increased by 18.5% in the Control diet when compared to the 20% DDGS diet across both seasons. Bernier et al. (2012) believed that the addition of protein to protein-deficient diets was the primary cause of decreased CH_4 emissions from mature beef cows receiving DDGS supplementation. The addition of protein has been cited as a means to improve utilization of poor-quality forages by improving microbial growth and fermentation as well as increasing DMI (Koster et al. 1996).

Extensive overwintering environments, with increased walking, foraging and cold and wind exposure, may increase nutrient requirements, particularly energy, compared to cows overwintering in an intensive environment. If low-quality forage diets do not meet rumen microbial protein requirements as well as energy requirements, there is limited opportunity to increase DMI to meet increased energy demands due to the inefficient functioning of the rumen microbial population, despite potential increased rates of passage noted in the winter months. The ratio of digestible energy to protein has been noted as important for optimal rumen function. When there is excess nitrogen relative to energy in the rumen, ammonia concentration increases, increasing transport of ammonia via blood flow to the liver where it is converted to urea. Urea in the blood stream is then either excreted in urine via the kidneys or is re-used by diffusing back through the rumen wall, or into saliva or milk (Hammond 1997). When protein is limiting in the diet, the recycling of urea via the blood stream back to the rumen is increased (and excretion of urea decreased), and overall urea concentration in the blood stream is decreased compared to diets with excessive nitrogen (Hammond 1997). Therefore, serum urea nitrogen (SUN) testing may be used as an indicator of dietary protein and energy status in cattle (Hammond 1997).

Low SUN values (< 2.1 mmol L^{-1}; Hammond et al. 1994) may indicate inefficient rumen microbial function and high recycling of rumen microbial protein. Hammond (1983a and 1983b) measured SUN concentrations in steers ranging from 0.93 to 3.96 mmol L^{-1} when diet CP concentration increased from 6% to 18%. For lactating dairy cows, SUN concentrations for cows fed balanced diets are expected to be in the range of 5.36 to 5.71 mmol L^{-1} (Baker et al. 1995); however, SUN concentrations greater than 6.78 have been associated with reduced fertility in dairy cows (Butler et al. 1998). Diets with similar protein intakes but differing energy intakes can also alter SUN. In a trial using bulls, Chase et al. (1993) found that diets which provided either 75% or 150% of maintenance energy requirements, but equal CP intake of 681 g d^{-1}, SUN concentrations averaged 2.00 and 7.03 mmol L^{-1}, respectively.

Other situations that can lead to increased SUN concentrations include increased proportions of rumen degradable protein in the diet, as opposed to protein degraded in the intenstinal tract. Protein digestion in ruminants is complex because of the demand of both rumen microbes and the animal for protein. Therefore, CP is only an estimate of the availability of dietary protein. The metabolizable protein system, including the use of rumen undegradable protein (RUP) and rumen degradable protein (RDP), which has been adopted by NRC, separates protein requirements into the needs of microorganisms and the needs of the animal. Barley, for example, has estimated RDP and RUP concentrations that are relatively equal (50%), whereas corn-based DDGS has a ratio of 32 to 68% RDP to RUP (NASEM 2016). Most forages have higher concentrations of RDP than RUD, e.g., alfalfa cubes (69: 31), bermudagrass hay (58: 42), oat hay (66: 33), peavine hay (70: 30), triticale hay (69: 31; NASEM 2016). Soybeans have a RDP: RUP ratio of 71: 29 and ear corn is 36: 64 (NASEM 2016).

Bernier et al. (2012) found that SUN concentration increased from 1.5 to 3.2 mmol L^{-1} by adding 10% DDGS to the base-line low quality forage, increasing diet CP from 6 to 9%. The added protein source was hypothesized to increase rumen microbial fermentation of the low-quality forage diet. However, CH_4 emissions did not decrease at this level of DDGS supplementation. When DDGS was increased to 20%, resulting in diet CP intake of 11% with 2.6 Mcal ME kg^{-1}, SUN increased to 4.4 mmol L^{-1} and CH_4 emission decreased. The diet with 20% DDGS had a ratio of of 51.6 g CP to Mcal ME. Gabler and Heinrichs (2003) considered the optimal ratio for productivity to be greater than 48.3 g CP per Mcal ME.

Dried distillers grains with solubles have been safely fed to beef cattle at levels up to 25% of DMI (Loy et al. 2007). Due to the fact that DDGS are low in starch and high in digestible fibre and protein, feeding large amounts of DDGS less frequently has been proposed as means to improve forage utilization (Loy et al. 2007), thereby potentially reducing CH_4 and also reducing labour by decreasing feeding frequency (Drewnowski et al. 2011). Feeding supplement more frequently throughout the day increases CH_4 emissions from cattle (Sutton et al. 1986). Reducing feeding times, such as feeding supplementation on alternate days or every third day, has been found to cause large daily fluctuations in DMI but overall, no significant differences in animal productivity, compared to animals fed daily (Drewnoski et al. 2011). However, no studies have been conducted to include measurements of enteric CH_4 emissions from alternate day feeding of supplements. Feeding supplements daily may result in increased labour and reduce the cost-effectiveness of extensive overwintering practices. Therefore, the potential for less frequent supplementation to improve sustatinability of extensive overwintering practices is at present a gap in literature which requires further research.

2.1.6.2.2 Soil and Manure

Measuring greenhouse gas and ammonia emissions from soil and manure during the overwintering period is difficult due to cold temperatures, snow pack and high variability in the distribution of nutrients over the pen or landscape. As such, little work has been conducted in the Northern Great Plains or Canadian Prairies on this topic. Manure from extensive overwintering systems differs from manure accumulated in a confined, intensive feeding system as it is characterized by patches of feces, urine and/or waste feed, deposited onto frozen soil or forage in the non-growing season, or directly onto a snow pack. This nutrient variability is further intensified by high-traffic areas, including wind shelters, watering sites and feeding areas. Manure from intensive overwintering generally contains a high proportion of straw or other high C bedding and these manure packs can remain thawed or experience frequent freeze-thaw fluctuations during the overwintering period (Boadi et al. 2004b). Factors which may influence gaseous emission from soil and manure in overwintering systems include variability in nutrient concentrations and form of nutrients in excreta, C:N ratios, soil type, topography, compaction and treading effects, soil moisture conditions, manure pack depth, depth of snow pack, speed of snow melt, number of freeze-thaw events, climate, and crop/forage management prior to overwintering and over the following spring and summer period.

Boadi et al. (2004b) measured N_2O, CH_4, and CO_2 emission using static vented chambers over the winter from manure packs of intensively overwintered steers. Temperature of manure packs averaged 4.3 +/- 0.5^oC throughout the winter. Emissions of CO_2 from the chambers throughout the study indicated that despite cold air temperatures, conditions within the manure pack were adequate for the microbial decomposition of manure and bedding to take place. These results demonstrate that bedding pack areas, which don’t freeze overwinter, could be significant sources of GHG emissions during the winter months. Edges of the manure packs, which ranged in temperature between plus and minus 1^oC, resulted in low GHG emission, indicating that cold temperatures were possibly inhibiting microbial activity in these areas.

Nitrous oxide emissions during the winter months have been reported from land previously used for summer pasture in the Northern Great Plains (Liebig et al. 2010). Emissions were evident during warming periods and spring thaw. Similar findings have been reported from arable crop land receiving liquid hog manure in eastern Canada (Wagner-Riddle et al. 2010).

Although there are no peer-reviewed publications examining gaseous emissions from extensive overwintering sites in North America, N_2O, CH_4 and NH_3 emissions have been measured from clay-silt soils in extensive winter feeding systems in Sweden using static vented chambers and acid traps (Salomon and Rodhe 2011). In that study, silage bales were placed on a forage field occupied by pregnant beef heifers (71 heifers ha^{-1}). Cumulative N_2O emissions were not different from high or low congregation areas compared to a control site for a period of 149-d after heifers were removed from the field. A study by Hynst et al. (2007) in the Czech Republic suggested that cattle overwintering sites were significant sources of GHGs due to small bursts of N_2O that occurred during the late fall and spring periods from high traffic areas. Average temperatures overwinter in both the Salomon and Rodhe (2011) and Hynst et al. (2007) studies were above 0^oC, reaching temperatures below 0^oC for only a few days at a time.

2.1.6.3 Resource Conservation

The ability to conserve nutrients, including energy, and water is an important ecological implication of a management strategy, particularly for those nutrients that are not renewable, such as P. Increased nutrient capture and resource conservation can decrease cost of importing nutrients in the form of fertilizer or feed, decrease potential environmental losses of nutrients via gaseous losses and to water ways, as well as, improve the social acceptance of a management strategy. Jungnitsch et al. (2011) conducted the only overwintering study that addresses N and P capture as a benefit of extensive winter grazing strategies. Recovery of added N in forage harvested was 45%, 30%, 9% and 5% for bale processing, bale grazing, spread raw and composted manure, respectively, while recovery of added P in forage harvested was 32%, 21%, 5% and 3%, respectively. Haas et al. (2002) examined nutrient balance (i.e., nutrients in and out of a pen where beef bulls or suckler calves were raised for 84 d) on an organic beef operation, and found 16 to 36% N efficiency and -7 to 22.5% P efficiency. Sheldrick et al. (2003) found that recovery of manure nutrients from cattle systems around the world was 14% and 25% for N and P, respectively. Nutrient capture and efficiency can be used to develop indicators to help measure environmental sustainability in beef cattle production systems.

2.2 Measurements of Sustainability

As indicated throughout the review, there can be both ecological benefits and consequences for the same management practice, as cattle systems can affect many parts of the landscape and ecosystem. For example, practices that reduce enteric CH_4 can consequently increase emissions of soil and manure GHG's and ammonia (Bernier et al. 2014; Donohoe 2011). Practices that increase nutrient intake to mitigate enteric CH_4 emissions, such as supplementation with protein and energy, can lead to increased excretion of N and P. Increased excretion of N has been shown to result in both increased soil N_2O and CH_4 emissions, as well NH_3 emissions (Jarvis et al. 1995; Bolan et al. 2004; Donohoe 2011). Assessing the environmental sustainability of cattle production systems, particularly overwintering sites, can therefore be complex. Furthermore, measuring sustainability involves determining not only the environmental, but the economic and social sustainability as well, adding further layers of complexity.

Direct measurements, such as those described throughout this review, enable us to determine any singular cost or benefit of a management practice. They can include physical and biological measurements collected in the field or data collected via a survey. These measurements are a necessary first step to understand how a system functions. However, these measurements are time consuming and costly, requiring extensive sample collection, sample processing and data analysis. As management practices, climate and soil type can vary from farm-to-farm, direct measurements are appropriate at the research level to determine factors which influence biological processes. Once baseline factors have been determined, simulation models can be used as a means to scale up and make predictions from the direct measurements

Simulation models consist of a series of equations that describe a biological system (Fumagalli et al. 2011). Inputs for these models include direct measurements, biological measurements and survey data. They are a good tool for scaling up environmental impacts of farm management practices on a regional or national scale, or over time. For example, models can be used to determine the contribution of the beef industry to Canadian GHG emissions (Beauchemin et al. 2010), or to determine potential P reductions in waterways associated with a change in management practice and may include the economic viability associated with it (Rotz et al. 2002). North America appears to be the leader in the development and use of simulation models, and examples of models currently available to use for beef cattle systems include the Integrated Farm Systems Model (IFSM; Rotz et al. 2015), whole farm GHG model (HOLOS; Janzen et al. 2006) and Life Cycle Analysis (LCA; Andreini and Place 2014).

However, there are several challenges associated with the use of simulation models to assess the sustainability of agricultural management practices. Firstly, most simulation models are designed to measure and address only the biophysical components of a system. Some models, such as the IFSM, have both an environmental and economic component; however, none have incorporated a means to measure social sustainability. As well, simulation models are not always adaptable to accommodate new management systems or changing climates, as the models were developed with regional data and management practices. For example, none of the models listed above currently incorporate equations and coefficients developed from direct biological measurements of extensive beef cattle production systems during a typical Canadian Prairie winter period. Modifications to ensure that the model is capable of adapting to different locations, climates and management scenarios may require extensive programing and model re-evaluation, which is not always possible for users and difficult to explain to end-users.

Outputs from simulation models, along with biophysical measurements, can be used to form indicators of sustainability. Indicators are a tool used to measure the sustainability of agricultural management practices and are defined as variables that supply information about other variables which are difficult to assess (Fumagalli et al. 2011). The use of a balanced set of indicators, or an index, can be used to carry out sustainability assessments. Indices have been widely used in Europe and South America (van Passel and Meul 2012).

Indices were designed to assemble data from environmental, economic and social aspects of sustainability by using a platform that values each criterion in accordance to the community or end-user values. The platform can be easily adapted as views and values change. In this manner, indices are able to simplify complex biological systems into an output that is presentable and understandable at both the farm and policy levels (Meul et al. 2008). Van Passel and Meul (2012) describe several farm and policy level indices that have been published in peer reviewed journals. These indicator-based assessment and monitoring tools have been used not only to compare the sustainability of agriculture management practices, but also to help farmers monitor management practices over time and to help administrators evaluate policies intended to improve sustainability of farms (van Passel and Meul 2012).

Indicator-based assessments are not without flaws. Validation of indicators is one of the major areas of concern. In most cases, only expert opinion has been used to determine the accuracy and accountability of indicators (Fumagalli et al. 2011; Meul et al. 2008). Scientific validation in the region of use is a necessary step in validation of an indicator as described by

Salvano et al. (2009) when phosphorus (P) indices that were developed in the U.S. performed poorly for conditions in southern Manitoba, Canada. Therefore, as with simulation models, caution must be exercised in interpretation of results when using indicator-bases assessments (Rigby et al. 2001).

Some examples of sustainability indices used at the farm level include those reported by: Rigby et al. (2001) who compared the sustainability of conventional to organic farming practices in the U.K., Fumagalli et al. (2011) who compared the sustainability of arable crop farms and dairy farms in northern Italy, and Meul et al. (2008) who compared the sustainability of Flemish dairy farms using the MOTIFS framework. The Food and Agriculture Organization of the United Nations (FAO) has established a set of sustainability indices guidelines called the Sustainability Assessment of Food and Agriculture systems (FAO 2012). These guidelines are intended to help agri-food industries and farms monitor sustainability using a worldwide excepted set of standards.

Nutrient use efficiency is an example of an indicator that can describe some aspects of the sustainability of beef cow overwintering practices. Measurement of nutrient inputs and outputs from a management practice can be used to assess the efficiency of a farm to use imported nutrients, which is important from an economic perspective. Nutrient use efficiency can also determine which management practices may lead to a build-up of nutrient pools that are vulnerable to environmental loss, which is important from an environmental perspective. Depending on the questions posed, including kg beef, milk or forage produced per unit of nutrient added. Further, area and economic value can be added into the model as well. This single indicator of efficiency can therefore be used at the farm level to help improve economics of production, and at the policy level to indicate environmental sustainability. The value placed on nutrient use efficiency in an index of multiple indicators to measure sustainability depends on the values of the end-users of the index; the importance of potential nutrient loss to water and air from nutrient accumulation, the importance of economic sustainability of the farm, and the resulting impact these benefits or consequences may have on their community.

As there are no indicator-based sustainability assessment systems in place for the evaluation of farm management practices in Manitoba, or western Canada, the development of such an indicator-based evaluation tool may be an important first step in determining the sustainability of farm management practices such as extensive overwintering. Developing suitable and effective indicators to describe overwintering beef cow systems that are relevant to the western Canadian production environment is an important part of building an evaluation tool.

An example of a platform currently being used in the U.S. to help producer's link environmental, economic and social implications of dairy production is the Pro-Dairy Program in New York (Cornell University 2018). This platform helps producers monitor profitablility, meet environmental regulations and provides training and skill development for families and employees. Accurate information and relevant indicators regarding the environmental and economic impacts of overwintering beef production are a necessary first step for the development of a comparable program on the Canadian Prairies.

2.3 Conclusions

Cow-calf production is an important component of the Canadian beef industry and of the Canadian economy. On the Canadian Prairies, overwintering beef cows presents a variety of biophysical challenges in terms of developing sustainable management strategies. The overwintering period is challenging in terms of our ability to take measurements as we contend with cold temperatures. The type of overwintering management practices used on any given farm in a given year can be variable, as well. Although we know there are potential benefits from extensive overwintering strategies for improving soil nutrient status and forage productivity, these benefits are not consistent through the field site, making measurement challenging. As well, these benefits to forage and soil productivity have not been assessed relative to the benefits or consequences for animal productivity. Sustainability of overwintering management strategies is dependent on many factors including soil types, feed supplements, bale spacing and bale quality, and post-grazing management strategies. Water quality and recovery of N and P are currently the only two measurements of environmental sustainability from extensive overwintering in the literature, and recovery of N and P was the first attempt to look at sustainability indicators from these systems.

2.3.1 Gaps in Knowledge

To assess the impact of overwintering systems on the sustainability of beef cattle production, the following gaps in knowledge must be addressed and these gaps form the basis of the hypotheses for this thesis:

- Individual animal DMI for beef cows fed low quality forages in extensive winter management systems
- Greenhouse gas emissions, including both enteric and soil and manure emissions, from intensive and extensive management systems for beef cows fed low quality forages
- Soil and forage response to extensive overwintering in different locations, soil zones and climates

- Protocols for measuring soil and forage nutrient status following extensive winter management
- Development of indicators to measure impact of extensive overwintering on sustainability of cow-calf operations

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3.0 RESEARCH HYPOTHESIS AND OBJECTIVES

3.1 Hypothesis Statements

1. Energy requirements of cows in an extensive overwintering management system will be greater than in an intensive system. Cows will be unable to increase DMI due to the low-quality forage diets fed (Christopherson 1976; Bernier et al. 2012) and this will result in similar DMI for intensive and extensive treatments. It is hypothesized that this increased demand for energy and no increase in DMI will result in increased CH_4 emissions from extensively overwintered cows due to compromised microbial growth associated with asynchrony of protein and energy.
2. Bale grazing has been found to increase soil nutrient status of N and P as well as increase mean subsequent forage yield (Jungnitsch et al. 2011) and crop yield (Kelln et al. 2012a) in the first two years following bale grazing. It is hypothesized that bale grazing will increase soil nutrients, increase forage yields and increase forage quality, as a result of deposition of waste feed and feces to the field site over the winter months. These depositions decompose over time and release N and P to soils, as well as, help conserve soil moisture (Jungnitsch 2008). These increases in forage yield, quality and soil nutrients will be concentrated around bale placement areas (Jungnitsch et al. 2011).
3. Areas of increased soil fertility associated with bale feeding locations can result in high variability in soil nutrient status (Jungnitsch et al. 2011). Rather than random sampling, a systematic sampling protocol that considers the area impacted by bale feeding areas compared to areas not impacted is necessary in order to accurately assess and describe field

mean nutrient status of a bale grazed field and to identify and describe the intensity of hotspots. These data can be used to model variability for future management and regulation development.

4. Bale grazing results in a large import of nutrients in the form of feed to a relatively small area of land. These imported nutrients can be recovered in the cows themselves via increased weight gain and body composition change, through subsequent forage or crop yields and through available nutrients remaining in the soil for succeeding crops. The ability of a management system to recover imported nutrients, such as N and P, will increase the sustainability of the farm. As bale grazing is anticipated to increase forage and crop yields and soil nutrient status, it is hypothesized that bale grazing will have greater efficiency of N and P compared to an intensive overwintering system that involves spread drylot manure.

3.2 Thesis Objectives

1. Expand our capacity to assess the sustainability of cattle overwintering systems in the eastern Canadian Prairies by measuring animal, soil and forage response to drylot vs. bale-grazed beef cattle overwintering systems:
    a. Measure DMI, animal productivity, and enteric methane emissions for pregnant beef cows fed low-quality forages in bale graze and intensive drylot overwintering systems
    b. Measure soil nutrient status and forage response over two years following bale grazing on highly fertile clay soils in a subhumid climate

2. Develop an efficient and effective soil sampling protocol to address the large biophysical variability in soil nutrient status following bale grazing to ensure accurate assessment of the impact of bale grazing on soil nutrient status from both environmental and agronomic perspectives
3. Develop a nutrient budget spreadsheet for measuring N and P balance and efficiency as indicators of environmental sustainability of bale grazing and drylot overwintering systems for beef cows

3.3 References

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4.0 MANUSCRIPT 1

COW RESPONSE TO EXTENSIVE VS. INTENSIVE OVERWINTERING PRACTICES

4.1 Abstract

Cow dry matter intake, rumen efficiency and performance in drylot (DL) and bale grazing (BG) overwintering systems were compared during two, 21-d periods. Both treatments received forage-based diets, and the BG system included two supplementation strategies: non-supplemented (BGcon) and supplementation every third-day with dried distillers grains with solubles (DDGS; BGdg). Dry matter intake was measured in the BGcon system with the alkane marker technique and in the DL with the GrowSafe system. Over the first 21-d period (P1) intake in the BGcon and DL were similar, at 12.2 and 13.4 kg DM d^{-1}, respectively. Enteric CH_4 emissions in P1 were greater for BGcon compared to DL when measured as L d^{-1}, L kg BW^{-1}, L kg DMI^{-1}, and % GEI. Cows in BGcon had a negative average daily gain (ADG; -0.28 ± 0.17 kg d^{-1}) during P1. Similar CH_4 emissions were measured (L d^{-1}) for BGdg and DL in P1, with statistically similar values for BGdg and BGcon. In Period 2, BGdg had the lowest CH_4 emissions (L d^{-1}), while the DL and BGcon were statistically similar. Serum urea nitrogen (SUN) concentrations were greatest for BGdg. Cows in the DL had $2^{o}C$ increase in air temperatures measured in close proximity to the cow compared to cows in the BG treatments. Differences in ADG and CH_4 emissions between DL and BGcon treatment may be associated with low protein to energy ratios in the diet combined with increased energy expenditure associated with cold temperatures and increased wind exposure in the BGcon treatment.

4.2 Introduction

Beef production has been referred to as the most unsustainable form of livestock production in terms of land use, consumption of irrigation water, impact of reactive nitrogen in the environment and production of greenhouse gases (Eshel et al. 2014). To address these concerns, beef producers must identify and adopt management practices that are not only economically viable, but environmentally sustainable and socially equitable.

On the Canadian Prairies, the greatest cost of beef production is incurred during the winter months (Lardner et al. 2005) when cattle are exposed to average daily temperatures below 0^{o}C for 5 months of the year, with extreme temperatures as low as -45.0^{o}C (Government of Canada 2017). This economic driver has moved producers towards less intensive management of beef cows overwinter, where cattle are managed on frozen and snow-covered fields to reduce manure handling and labour costs associated with daily feeding in corrals. Fifty-eight percent of producers surveyed across Canada used a form of these extensive overwintering practices for at least a portion of the winter months, with 42% winter grazing round bales, also known as bale grazing (Sheppard et al., 2015).

The short-term economic advantages of bale grazing in terms of reduced equipment and labour costs have been proven (McCartney et al. 2004; Kelln et al. 2012), as has increased soil nutrient status and forage productivity, suggesting long term benefits of bale grazing in terms of increased feed production for cows (Jungnitsch et al. 2011). The sustainability of these practices in terms of animal productivity and environmental sustainability in perennial forage systems have not been fully characterized. Previous studies indicate that these practices are not without challenges. Increased nutrient runoff to waterways from a winter bale grazed system on annual cropland has been observed, (Chen et al. 2016) as well as weight loss in cattle in extensive overwintering systems, including bale grazing (Kelln et al. 2012), indicating that supplementation to forage-based diets may be necessary, depending on weather and snow fall.

The observed decrease in animal productivity in extensive overwintering environments, compared to intensive overwintering, suggests winter rations formulated to meet nutrient requirements in the latter scenario may not always meet the demands of increased exposure to environmental conditions and increased activity required for foraging, walking for water or utilizing snow as a water source in extensive systems. Winter conditions such as depth of snow pack, snow pack quality, temperature, and wind exposure can vary from year-to-year and site-to-site. Cattle in these variable, extensive winter systems may benefit from protein and energy supplementation to forage-based diets in order to maintain productivity during harsh winter conditions. Recent research suggests that cows with adequate protein and energy supplementation during gestation result in calves with greater weaning weights, heifer fertility, feedlot health and carcass composition (Stalker et al. 2006; Martin et al. 2007; Larson et al. 2009). In fact, > 85% of producers practicing extensive winter grazing used a form of supplementation in addition to a forage-based diet (Sheppard et al. 2015). However, supplementation must be delivered strategically based on the goals of the operation to ensure that it is cost effective and enhances animal performance (Funston et al. 2010), and, does not compromise environmental sustainability. For example, protein and energy supplementation via dried distillers grains with solubles (DDGS) decreases ruminant eructation of the greenhouse gas (GHG) methane (CH_4), from intensively overwintered beef cows (Bernier et al. 2012) but increased excretion of labile nutrients in urine and feces, increasing risk to surface and ground water (Bernier et al. 2014).

Delivering supplement to cows daily increases labour, input and equipment costs, potentially reducing the economic incentive of extensive overwintering management. Several studies have been conducted examining the effect of reduced supplementation frequency on cow productivity and rumen function. Drewnoski et al. (2011) found that supplementation with soybean hull and corn gluten meal could be reduced to as little as two times weekly without negative impacts on animal productivity. Feeding DDGS three times weekly to growing heifers in intensive systems resulted in daily gains that were similar to cows supplemented three times weekly with dried rolled corn or dried rolled corn with corn gluten meal (Loy et al. 2008). Reduced feeding frequency of DDGS may be a potential practice to reduce costs and improve animal productivity in extensive winter systems.

Literature regarding animal efficiency and nutrient utilization associated with extended grazing is limited as a consequence of the challenges of measuring animal intake in grazing systems (Undi et al. 2008). At present, there are no published measurements of individual animal intake from beef cows in extensive overwintering systems, making it difficult to predict digestive and metabolic responses to overwintering management strategies and evaluation of cow nutrient requirements. Techniques that have been utilized in other extensive overwintering studies to estimate forage intake include equation-based strategies (Mertens et al. 1987; Kelln et al. 2012) and the measurement of waste forage remaining following grazing (McCartney et al. 2004; Kelln et al. 2012). The National Academies of Sciences, Engineering and Medicine (NASEM) Beef Cow Nutrient Requirements Model 2016, specifically equation 10-5, is the recommended equation to predict DMI for pregnant beef cows on low-quality forage diets.

Objectives of this research were to: 1) examine the potential of the alkane technique, the waste feed recovery method and the Beef Cattle Nutrient Requirements Model 2016 to estimate individual animal intakes in an extensive overwintering environment; 2) examine differences in DMI, enteric CH_4 and carbon dioxide emissions, energy expenditure, serum urea nitrogen concentration, body weight and near animal temperatures in cows overwintered in an intensive vs extensive winter bale grazed system, and 3) to determine if protein and energy supplementation via DDGS can improve the sustainability of extensive overwintering practices by increasing animal productivity and decreasing enteric CH_4 emissions.

4.3 Materials and Methods

4.3.1 Overwintering Trial

The trial was designed in accordance with the guidelines set out by the Canadian Council on Animal Care (1993). The overwintering trial was conducted with an intial 14-d adaptation period (Adaptation P1) followed by two, 21-d periods (P1 and P2) from 3 January to 2 March 2011, with a second, 17-d adaptation period between P1 and P2, at the University of Manitoba's National Centre for Livestock and the Environment (NCLE) Cattle and Forage Research Facility (lat. 49.65N, long. 97.12W). Sixty, non-lactating, pregnant, commercial Simmental-Red Angus and Simmental-Gelbveih cross beef cows, averaging 5 ± 2 years of age, weighing 606 ± 35 kg and in their second trimester of pregnancy, were divided into six groups of similar total body weight. All cows had previous experience in extensive overwintering environments. Groups were randomly assigned to either an intensive drylot (DL) or extensive winter bale graze (BG) management system in an incomplete block design; two groups of cattle were allotted to the DL and four groups to the BG systems.

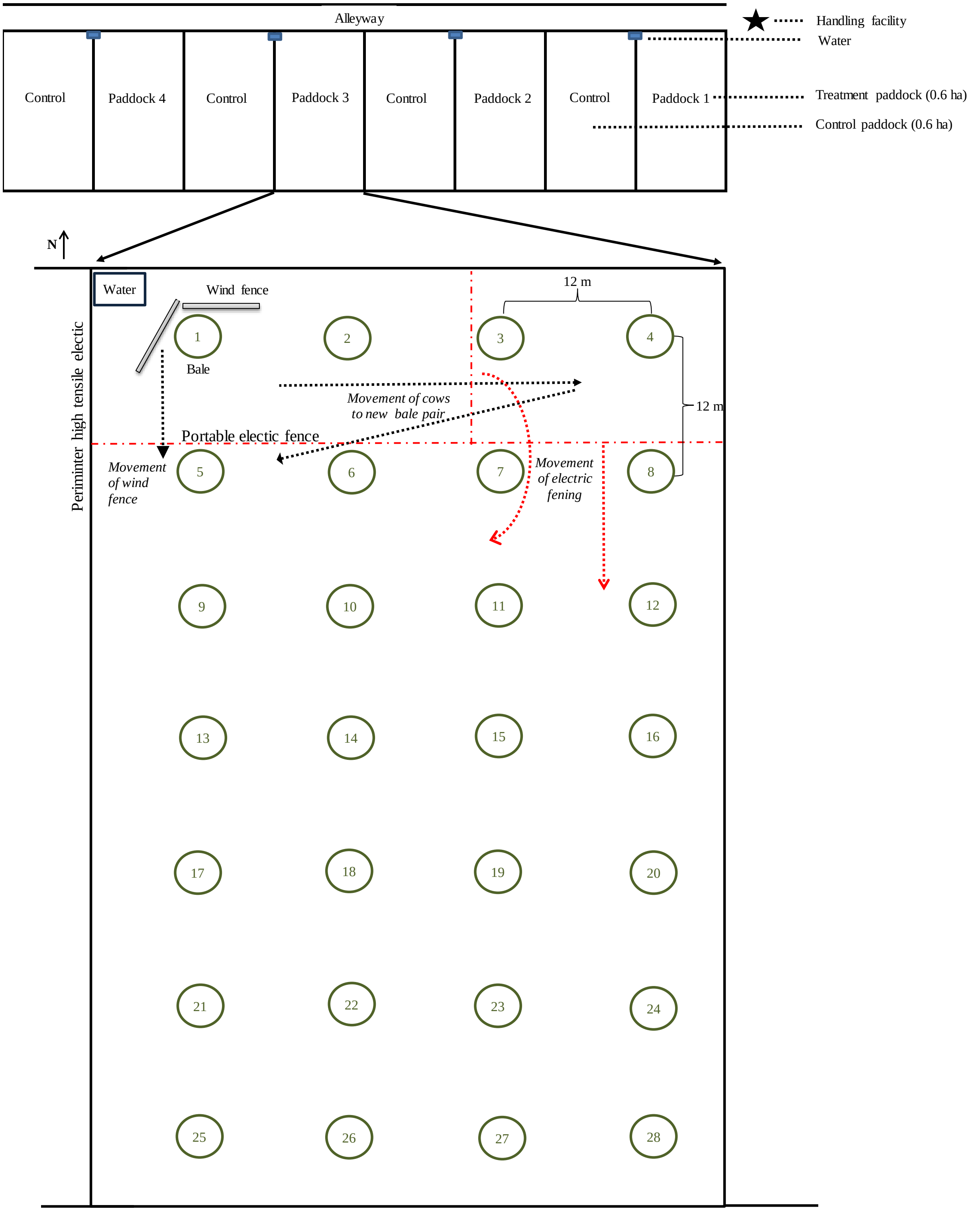

Figure 4.1 Layout of extensive management system including bale placement and movement of cows, electric fencing and wind shelters throughout the trial

The intensive DL system consisted of two drylot pens that were partially covered with a lean-to roof structure. Each pen contained four GrowSafe feeder nodes (GrowSafe Model 4000E feed monitoring system, GrowSafe Systems Ltd., Airdrie, AB) and a winterized water bowl (Richie Industries Inc., Conrad, IA, USA). Pens were bedded with barley (*Hordeum vulgare*) straw as needed throughout the trial.

The extensive BG system consisted of four paddocks of tame forage, each 0.6 ha in size, fenced with four-strand, high-tensile wire electric fencing (Figure 4.1). To reduce the possibility that cattle could graze residual standing forage leading to consumption of differing forage qualities, the site was mowed to 10 cm in height in late October prior to the start of the trial. Each paddock was equipped with a winterized water system (Richie Industries Inc. Conrad IA USA) and two, 10-m portable windbreak panels. No additional bedding was provided to cows and no hay feeders were used.

Diets in both management systems consisted of low-quality, wild grass hay, fed *ad libitum*, from a single source and stored as round bales weighing 511 ± 51 kg (Table 4.1). All cows were adapted to diets in the drylot pens for 14 d (Adaptation P1), with cows assigned to the BG system receiving hay in the form of round bales in the drylot pens, and cows assigned to the DL system receiving hay chopped to a length of 15 to 20 cm in the GrowSafe bunks. Throughout the study forage was delivered to cows in the DL in such a manner to ensure that cows had free-choice access to hay throughout the day. Hay delivered was of sufficient quality and quantity to meet nutrient requirements for beef cows in their late second and early third trimesters of pregnancy using historic climate data according to using Cowbytes©, beef cattle ration balancer program (V.4.6.8, Alberta Agriculture, Food and Rural Development).

Two of the four paddocks of cows in the extensive BG system were supplemented with DDGS (BGdg) at a rate of 8.3 kg cow^{-1} fed every third-day (Table 4.1) while the remaining two BG paddocks received a hay-only diet (BGcon), similar to the intensive DL system. Distillers grains was a 50:50 blend of wheat and corn, fed in two, portable, steel-framed, plastic-lined feed bunks, four meters in length.

Bales of hay were placed in the four BG paddocks on a 12 x 12 m grid with four bales to a row (Manitoba Agriculture Food and Rural Initiatives 2008; Jungnitsch et al. 2011), resulting in 1774 cow d ha^{-1} stocking density assuming 12 kg d^{-1} forage intake, as fed basis. Cows assigned to the BG system were moved to the BG paddocks following adaptation P1, representing d 1 of P1. Cows were allotted two bales at a time using portable electric fencing and moved to new set of bale pairs when depth of waste feed remaining across the diameter of both bales was less than 10 cm in depth. Windbreaks were moved simultaneously as cows received access to a new row to ensure wind protection was nearby.

Due to concerns of negative weight gains and low serum urea N (SUN) status at the end of P1, diets were adjusted to increase energy and protein intake in the hay only diet treatments (DL and BGcon) by providing supplementation in the form of barley, fed daily at a rate of 1.2 kg DM d^{-1} (Table 4.2). Barley was delivered daily on an individual animal basis in rubber buckets to cows in the DL. In the BGcon paddocks, barley was fed in portable feeding troughs similar to those used to feed DDGS supplementation. Cows in both DL and BGcon management systems were adapted to the change in diet over 17 d (Adaptation P2).

4.3.2 Measurements

4.3.2.1 Weather

Ambient temperature and precipitation events, as well as wind speed and wind direction, were monitored at the nearby Trace Gas Manitoba (TGAS MAN) Greenhouse Gas Field Emission Site, located approximately 1.2 and 1.4 km west of the BG and DL field sites, respectively. Meteorological equipment and measurement techniques used are available from the Soil Ecology Laboratory of the University of Manitoba (2018).

4.3.2.2 Body Weights and BCS

Body weights were recorded on d 1, 9, 10, 11, 14, 15, 16 and 21 of each period and scales were calibrated at the beginning of each period. Body condition scoring, using a five-point system (Edmonson et al. 1989), was conducted at the start and end of each period.

4.3.2.3 Intake

GrowSafe feeding events were used to measure individual animal intake from cows in the DL over both periods. Sum of daily feeding events were averaged for each cow from d 7 through 13 and d 13 through 19 in each 21-d period and used to estimate DMI and GEI during CH_4 collection. An average of the 13-d period was used to determine overall average DMI intake per period.

Individual animal intakes from the BGcon paddocks in P1 (i.e., hay only diets) were measured using the alkane technique (Elwert et al. 2008). Dosing with alkanes was accomplished with n-alkane controlled release capsules (Captec Alkane CRC, Nufarm Health and Sciences, Auckland, New Zealand). According to manufacturer’s instructions, boluses were administered on d 1, and fecal sampling occurred within d 7 through 15, with release of alkanes from the bolus to be completed by d 21. Boluses were inserted into the rumen of eight cows per paddock. Release rate from boluses were either 328.90 or 363.00 mg d^{-1} C_{32}, depending on the batch number, provided by the manufacturer. If a fecal sample could not be obtained on the first day of sampling, the cow was re-sampled the following day. Fecal grab samples were collected on d 9 and 14 of P1, as well as on d 10 and 15 for samples that were missed on the first collection day. Fecal grab samples were frozen at -20°C for subsequent DM and n-alkane analysis. Samples of hay were analyzed for alkane concentration before the start of the trial to determine alkane profiles.

Calculations to determine DMI using the alkane technique were obtained from Elwert et al. (2004). Concentration of alkanes in feeds and feces (mg kg^{-1}) were determined by comparing the ratio of the peak areas of the external standards (in the feeds and feces) to the ratio of the external standard alkane concentrations in the standard solution. Peak areas were corrected for any discrimination, assuming a linear discrimination depending upon the chain length of the alkanes. The content of natural alkanes was calculated from the ratio of natural alkane to C_{34} and the known amount of C_{34} in the internal standard added to the sample.

The concentration of alkanes found in hay and feces was then used to determine DMI using the following formula:

$$\text{DM intake (kg d}^{-1}\text{ DM)} = \text{Intake} = \mathrm{F}i / \mathrm{F}j \times \mathrm{D}j / (\mathrm{H}i - \mathrm{F}i / \mathrm{F}j \times \mathrm{H}j)$$

where Hi and Fi are the herbage and fecal concentrations of the odd chain alkane, Hj and Fj are the herbage and fecal concentration of the even chain alkane, and Dj is the dosed even-chain alkane. The ratios of C_{31} to C_{32} were used, and the dosed rates of C_{32} from the two batches of alkane boluses of 328.9 and 363.0 mg d^{-1} were used in the calculations.

Table 4.1 Average nutrient and alkane composition (DM basis) of feedstuffs

	Feedstuffs[a]				
	Hay		DDGS		Barley
n[b]	*10*		*2*		*1*
Nutrient					
DM (%)	84.6	(3.10)	94.8	(3.19)	94.0
CP (%)	8.8	(0.76)	30.3	(0.02)	16.2
NDF(%)	62.3	(2.29)	38.8	(0.68)	19.2
ADF (%)	37.6	(1.42)	14.0	(0.58)	5.2
Ca (%)	0.54	(0.05)	0.12	(0.01)	0.11
P (%)	0.11	(0.01)	0.99	(0.02)	0.48
K (%)	0.71	(0.17)	1.26	(0.02)	0.54
Mg (%)	0.27	(0.02)	0.37	(0.01)	0.16
GE (Mcal kg^{-1})	4.25	(0.03)	5.31	(0.02)	4.39
NEma[c] (Mcal kg^{-1})	1.31[d]	(0.02)	1.52[e]	(0.01)	2.06[e]
n-Alkanes (mg kg^{-1})					
C_{24}	1.7	(0.55)			
C_{25}	11.9	(9.33)			
C_{26}	5.4	(2.97)			
C_{27}	22.5	(3.53)			
C_{28}	4.8	(0.71)			
C_{29}	78.7	(6.27)			
C_{30}	2.7	(0.45)			
C_{31}	100.1	(16.4)			
C_{32}	1.5	(0.21)			
C_{33}	31.3	(7.90)			
C_{34}	388.0	(56.7)			
C_{35}	0.5	(0.62)			
C_{36}	1.9	(0.95)			

[a] Standard deviation of the mean given in parentheses

[b] Where *n* for hay is the number of composited samples of hay analyzed representing hay delivered to the BG paddocks and DL treatment over P1 and P2; where *n* for waxed DDGS and barley is the number of composited samples analyzed for each period fed

[c] Net energy for maintenance available in feed delivered

[d] Calculated using the Beef Cow Nutrient Requirements Model 2016 (NASEM 2016)

[e] Table 18-1 (NASEM 2016)

Intake in the BG paddocks was also measured using the waste feed recovery (WFR) method described by McCartney et al. (2004) and used later by Jungnitsch et al. (2011). In the spring following bale grazing, total waste feed from four bale sites was collected. Feces were hand separated from the waste hay and DM weights of both feces and waste hay determined. Measurements of waste hay were compared against their initial bale weights to determine an average percentage of waste hay per treatment. For each paddock, initial bale weights (DM basis) were multiplied by the average percentage of waste hay and subtracted from initial bale weight and divided by the number of days cows had access to the feed and by the total number of cows per pen to get an estimate of daily hay intake per cow. If supplement was delivered, the daily rate of supplement (DM basis) was also added to the calculation.

The Beef Cow Nutrient Requirements Model 2016 was used to estimate DMI along with net energy in feed delivered (NEma), available N in feed intake, net energy requirements for maintenance (NEm), net energy required for cold stress (NEcs), net energy required for pregnancy (NEpreg), cow lower critical temperature (LCT) and microbial protein requirements for maintenance (MPm) over P1 for DL and BGcon treatments (NASEM 2016). The LCT is defined as the temperature below which cows are no longer in a thermoneutral zone and temperatures below the LCT can trigger increased energy requirements. Cow inputs were set at 606 kg initial body weight and day one of period one as 183 d of gestation, with average hide thickness, hair coat, and no effect of mud. Solution type for the model was set as empirical. Mean daily temperatures and humidity for both intensive and extensive models were obtained from TGAS MAN. For the intensive treatment, wind speeds were set at 5 km h^{-1} in accordance with Block et al. (2001), while for the extensive treatment TGAS MAN mean daily windspeeds were used.

4.3.2.4 Methane and Carbon Dioxide

The sulphur hexafluoride (SF_6) technique was used to measure enteric CH_4 (Boadi and Wittenberg 2002; Boadi et al. 2002; Johnson et al. 2004) as well as CO_2 (Stewart et al. 2008) from all treatment and diets combinations. The SF_6 technique is based on the steady release of SF_6, an inert and non-toxic tracer gas, from a permeation tube inserted in the rumen. Using the known release rate of SF_6 from the permeation tube and the molar masses of SF_6, CH_4 and CO_2, the ratio of SF_6 to CH_4 or CO_2 were used to determine enteric emission of CH_4 and CO_2.

Briefly, steel permeation tubes (12.5 x 40 mm) with a known release rate of SF_6 gas were placed in the rumen of cows in all treatments, with a speculum, 8 d prior to CH_4 measurements to ensure SF_6 concentration in the rumen had reached equilibrium. Permeation tubes were filled with 99% pure SF_6 gas with a minimum starting weight of 0.28 after initial fill and were then weighed over a minimum of eight weeks to determine accurate release rates prior to placement. The following selection criteria were used to choose valid permeation tubes: (i) minimum half-life (tube expiration is considered at 50% loss of SF_6 gas from the permeation tube) exceeding the second CH_4 sampling event in P2, (ii) a minimum flow rate of 350 ng min^{-1} of SF_6 from the permeation tube, and (iii) a maximum variation of 11% in flow rate of the permeation tube.

A specialized nylon cattle harness fitted with 900-mm capillary tubing (128 µm internal diameter) was placed on cows on d-8 of each period, and then attached to a stainless steel collection sphere (130 mm diameter) that had been pre-evacuated (Boadi et al. 2002). Gases entered the collection system via a nose piece attached to a 15 µm filter as the animal exhaled and eructated. The apparatus was removed after approximately 24 h of collection on d 9, and again another halter and collection sphere placed on d 9 and removed on d 10. This was also repeated on d 14 to 16 of each period, resulting in two consecutive 24 h measurements of CH_4

and CO_2 twice within each period. These three-day CH_4 collection events corresponded to DDGS feeding cycle d 2, 3 and 1, respectively, and the halter and canister apparatuses were removed prior to feeding DDGS on d 1. A maximum of eight measurements were collected per group on a given day, depending on the availability of functioning canisters. Two collection devices were placed in each management system during each collection period to collect background gas concentrations.

Methods of CH_4 and SF_6 analysis and calculation were similar to those described by Boadi and Wittenberg (2002) and Boadi et al. (2002) and CO_2 analysis was as described in Stewart et al. (2008). Post-collection, the collection spheres were pressurized with nitrogen gas to 68.9 kpa prior to transport for gas analysis. Gases were analysed using gas chromatography (GC; Varian CP-3800; Varian, Mississauga, ON; Boadi et al. 2002). Instrument calibration was performed using the following prepared standard gases: quality control (QC) gas (200 ppm $CO_{2,}$ 2 ppm $CH_{4,}$ with the balance $N_{2;}$ Praxair Distribution Inc.; 9501-34 St., Edmonton, AB), CO_2 gas (1599 ppm; Praxair Distribution Inc.; 9501-34 St., Edmonton, AB), CH_4 (102 ppm ± 5%; Scotty Analyzed Gases; Air Liquide America Specialty Gases LLC; Plumsteadville, PA), and SF_6 (20.67 ppm ± 10%; Scott-Marcia; Riverside CA). Gases were calibrated against 100 ppm CH_4, 1600 ppm CO_2, and 50 ppm $CH_{4,}$ and the QC gas calibration occurred every 10 samples to ensure continued accuracy of the gas analysis. Following calibration, gas sample concentrations were determined with the following equation:

$$CH_4 \text{ (L min}^{-1}\text{)} = \text{permeation tube } SF_6 \text{ release rate x } [CH_4] / [SF_6]$$

Concentrations of CH_4 and SF_6 are represented in the equation as $[CH_4]$ and $[SF_6]$ respectively and were adjusted for the removal of background concentrations of CH_4 and SF_6. The following criteria were used to remove data from the data set: (i) integrity of equipment during collection (i.e., equipment failure of harness, tubing, etc.), (ii) final pressures of collection spheres must fall between a range of 200 mmHg to 650 mm Hg to be accepted, and, (iii) SF_6: CH_4 ratio was not consistent for a particular cow over time, suggesting that the permeation tube was not releasing SF_6 gas at a steady rate.

Energy expenditure (EE) was then calculated from CO_2 emissions from cows with a positive ADG as described by Sahlu et al. (1988), using the following equation:

$$\text{EE (MJ kg BW}^{0.75}\text{ d}^{-1}\text{]) = (4.39 x CO}_2\text{ (L kg BW}^{0.75}\text{ d}^{-1}\text{) + 13.91) * 0.0041868}$$

4.3.2.5 Serum Urea Nitrogen

Blood samples to measure SUN were collected from cows on d 9 and 14 from all treatments, as well as on d 11 and 16 from cows in BGdg paddocks to further map variation as a result of every third-day feeding, via tail vein puncture into 10 mL serum separator vacutainers (BD Canada, Mississauga, ON). Serum urea N for all days was analyzed using a colorimetric test with a Vitros 250 (Ortho Clinical Diagnostics Inc., Pub. No. P2-9, Rochester, NY), with values averaged from d 9 to 11 and d 14 to 16 for BGdg cows. Analysis was conducted by Veterinary Diagnostic Services (Manitoba Agriculture, Food and Rural Initiatives, Winnipeg, MB). Serum urea N concentrations of less than 2.1 mmol L^{-1} were considered below normal nitrogen status for beef cows (Hammond et al. 1994).

4.3.2.6 Feed Analysis

All bales used in both extensive and intensive management systems were individually weighed and sampled with a handheld electric corer, with fifteen cores collected per bale. Cores were thoroughly mixed and sub-sampled and stored at -20°C. A subsample of DDGS and barley was collected weekly and stored at -20°C, and thoroughly mixed and composited prior to analysis.

Hay, DDGS and barley samples were dried in a forced-air oven at 60^{o}C for at least 48 h to determine DM content and then ground through a 1 mm screen (Cyclotec Tecator 1093 Sample Mill, Foss Analytical, Denmark). Hay samples from bales fed within 7 d around CH_4 collection events were composited for each extensively grazed paddock, for a total of eight samples. For the intensive treatment, one composited sample for each period to represent hay bales fed in the DL was analyzed, for a total two samples. Dried samples were analyzed for moisture, 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) was analyzed using a Par 6300 Automatic Isoperibol Calorimeter (Moline, IL). Alkanes were analyzed as described in Moshtaghi Nia and Wittenberg (2002).

4.3.2.7 Near-Animal Temperatures

Near-animal temperatures from extensive and intensive treatments were collected every 30 min over a 13-d period during P2, 17 February to 1 March, using iButtons (Maxim Integrated, San Jose, CA), which were placed in a nylon mesh bag attached to a collar around a cow’s neck, hanging approximately 7 cm from the cow’s chest area. A total of 18 cows were used to determine treatment means, including 7 from the DL and 11 from the BGcon and BGdg paddocks.

4.3.2.8 Post-Trial Animal Productivity Measurements

Cows were kept and managed as a group following the end of the trial and measurements including percentage of live calves born, pregnancy rate and calf weaning weights were recorded.

4.3.3 Statistical Analysis

Statistical Analysis Software (SAS) version 9.2 (SAS Institute Inc. 2000) was used to perform all statistical analyses. PROC Mixed was used in a two-way analysis of variance using a Bonferoni test for multiple comparison of means ($P < 0.05$) to compare treatment means of DMI, GEI, CP intake, CH_4 (L d^{-1}, L kg BW^{-1}, L kg DMI^{-1} and % GEI), SUN, BW, ADG and BCS from cows in the two DL pens over both periods, as well as for cows in P1 in the DL (measured via GrowSafe) and BGcon (measured via the alkane technique) treatments. Period 1 was the only period when individual animal intakes were measured from the BGcon treatment. All measurements collected from cows throughout the period were considered as individual replicates.

A repeated measures test in Proc Mixed was used to determine differences between temperatures recorded by iButtons using Treatment (T) and Day (D) and T by D, with D as the repeated variable and T (Cow) as the subject of the repeated variable. The variance-covariance structure was set as “type=arc(1)” to account for the unequal variances that were found from day-to-day as well as to help account for a decreasing covariance between days over time that was observed. The “ddfm = satterthwaite” option was also used to correct for unequal variances when testing the model. Differences between day and night time temperatures recorded by iButtons were also examined, with day and night temperatures determined by sunrise and sunset times. Proc Mixed was used to examine a three-way analysis of variance between T, D and time of day (Time), including interactions of T by D, T by Time, D by Time, with D as the repeated variable and T(Cow) as the subject of the repeated variable. Again, the ddfm = satterthwaite and type=acr(1) options were used. Two data points were removed from the iButton dataset that had studentized residuals that were more than four standard deviations away from the mean. These two temperatures were recorded on a day with above normal temperatures (greater than 0^{o}C).

Proc Mixed was used to perform a two-way analysis of variance for CO_2, CH_4 (L d^{-1}, L kg BW^{-1}), EE, SUN, BW, ADG and BCS across both periods for the BGcon, BGdg and DL treatments. In this analysis, BGdg samples taken on d 3 as well as d 1 were used in order to obtain an average concentration or emission rate for the 3-d DDGS feeding cycle. One cow in the BGdg treatment was removed from the trial on day 9 of P1 due to temperament. Data points that had studentized residuals greater than three standard deviations from the mean were removed from the dataset.

Natural log transformed means were used to compare data with non-homogenous distribution of residuals including GEI, CP intake, CH_4, CO_2 and EE comparisons. Probability was set at $P < 0.05$. The “ddfm = satterthwaite” option was also used to correct for unequal variances when testing the models for all analyses, as large difference in the residual distribution were found between intensive and extensive treatments.

4.4 Results

4.4.1 Weather

Mean daily temperature in P1 was -20.0^{o}C and average wind speed was 9.8 km h^{-1}, with a mean minimum temperature of -25.7^{o}C, mean maximum temperature of -15.4^{o}C and mean relative humidity of 80.2% (Figure 4.2). Mean daily temperature in P2 was -14.9^{o}C and average wind speed was 17.0 km h^{-1}, with a mean minimum temperature of -21.0^{o}C, mean maximum temperature of -9.6^{o}C and mean relative humidity of 79.1%. Temperatures in P1 and P2 were similar to the long-term climate normals for Winnipeg, MB, which included mean daily temperatures of -16.4^{o}C in January and –13.2^{o}C in February (Government of Canada 2017). Precipitation in P1 was above the 19 mm normal for Winnipeg in January (Government of Canada 2017), as 28.5 mm was received in the form of snow over the 21-d period. Period 2 precipitation was well below normal, with 13.8 mm expected over the month of February (Government of Canada 2017) and only 1.8 mm received over 21 d. In general, climate was more favourable in P2 compared to P1.

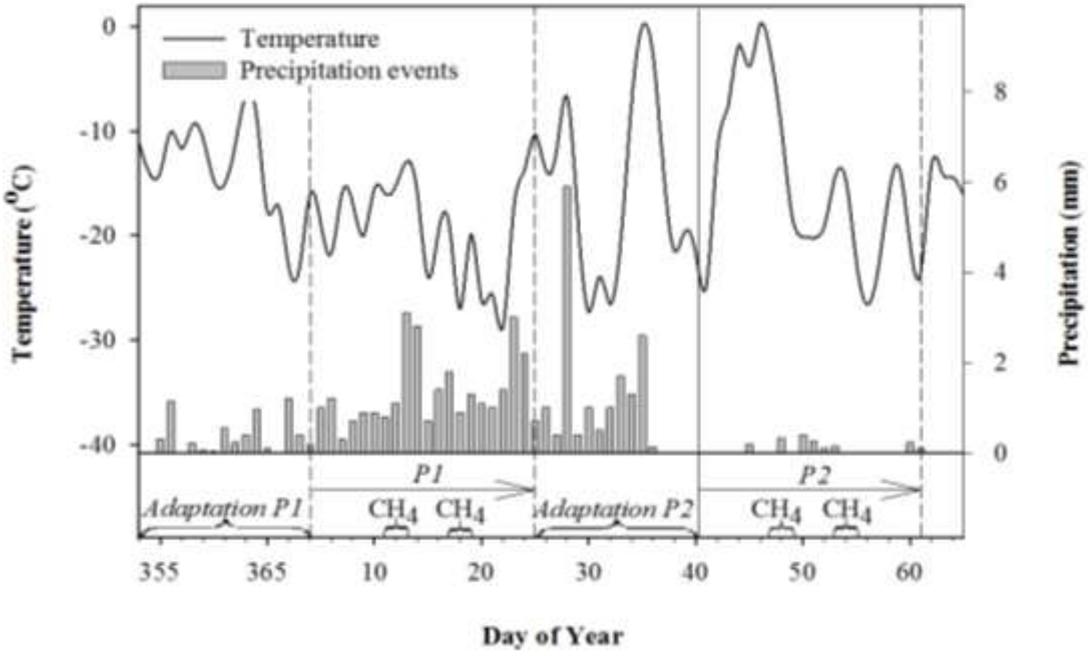

Figure 4.2 Ambient average daily temperature and daily precipitation events from day of year 356 (22 December 2010) to 61 (2 March 2011), along with a chronology of activities throughout the trial including adaptation periods (P) and three-day methane (CH$_4$) collection events

4.4.2 Intake

Average waste feed measured using the WFR method was 21.2 ± 5.2 %. Estimated hay intake using the WFR method (hay delivered minus waste feed, divided by the number days and number of cows) and averaged over both periods was 14.3 ± 1.7 kg DM d^{-1} for BGcon, and 14.0

± 2.9 kg DM d^{-1} for BGdg, respectively. When expressed as a % of BW, hay intake was 2.3 ± 0.3 and 2.2 ± 0.5 % for the BGcon and BGdg treatments, respectively, measured using the WFR method.

Intake measured with the GrowSafe system within the replicated DL pens in P1 (13.4 kg DM d^{-1}; data not shown) was significantly lower than in P2 (14.7 kg DM d^{-1}; $P < 0.01$, SEM = 0.42). There were no significant differences in DM (kg d^{-1} and % BW), CP or GE intake between the intensive (DL) and extensive (BGcon) treatments in P1 using the GrowSafe and alkane techniques (Table 4.2). Dry matter intake estimated by the Beef Catte Nutrient Requirements Model 2016 for cows of comparable weight, physiological status and raised under similar environmental conditions was 12.0 kg cow^{-1} d^{-1}.

4.4.3 Differences Between Cows Overwintered Intensively vs. Extensively

Average daily gain was greater for intensively overwintered cows (DL) compared to extensively overwintered cows fed the same diet (BGcon) while no differences in BCS occurred between the two treatments in P1 (Table 4.2). Serum urea nitrogen concentrations were greater ($P = 0.0046$) for cows in the BGcon treatment (Table 4.2), although all cows in both DL and BGcon treatments had inadequate SUN measurements (< 2.1 mmol $L^{-1;}$ Hammond et al. 1994) throughout P1.

Methane emissions in P1 were significantly greater from BGcon compared to the DL treatment when measured as L d^{-1}, L kg BW^{-1}, L kg DMI^{-1} and as % GEI (Table 4.2). Carbon dioxide emissions averaged 5126 ± 2704 and 7526 ± 3118 L CO_2 d^{-1} in the DL and BGcon treatments, respectively. A large number of cows had negative ADG in the BGcon paddocks in P1; therefore CO_2 emissions expressed as EE could not be calculated for P1 for these animals

(Stewart et al. 2008), leaving too few measurements to be analyzed for significant differences between treatments.

Table 4.2 Mean dry matter (DM), crude protein (CP), and gross energy (GE) intakes, enteric methane emission, serum urea nitrogen (SUN) concentration, and body weight (BW) and body condition (BCS) scores for cows overwintered intensively (DL) and extensively (BGcon) over 21 d in P1

Measurement	Intensive	Extensive	*P* values
Intake	*GrowSafe*	*Alkane*	
n[a]	*40*	*30*	
DMI *(kg d^{-1})*	13.4 ± 0.52	12.2 ± 0.58	0.13
DMI *(% BW)*	2.27 ± 0.07	2.12 ± 0.08	0.29
CP Intake *(kg d^{-1})*	1.11 ± 0.04	1.07 ± 0.05	0.59
GEI *(Mcal d^{-1})*	56.6 ± 2.18	51.8 ± 2.45	0.15
Body Weight			
n[a]	*20*	19	
Initial BW *(kg)*	626 ± 1.0	611 ± 1.0	0.74
ADG *(kg d^{-1})*	0.45 ± 0.17a	-0.28 ± 0.17b	<0.01
BCS			
n[a]	20	19	
Initial BCS	3.6 ± 0.04	3.6 ± 0.04	0.61
Change in BCS	-0.14 ± 0.03	-0.09 ± 0.03	0.30
Methane (CH_4) emission			
n[a]	*19*	*19*	
CH_4 *(L d^{-1})*	320 ± 13.7b	376 ± 13.7a	<0.01
CH_4 *(L kg BW^{-1})*	0.53 ± 0.02b	0.64 ± 0.02a	<0.01
CH_4 *(L kg DMI^{-1})*	23.8 ± 2.37b	36.0 ± 2.33a	<0.01
CH_4 *(% GEI)*	5.36 ± 0.42b	7.81 ± 0.40a	<0.01
Serum urea nitrogen	*20*	*19*	
SUN *(mmol L^{-1})*	0.87 ± 0.07b	1.15 ± 0.07a	<0.01

± Standard error of the mean

a-b Least squared means within a row with the same letter are not different ($P \geq 0.05$)

[a] Where *n* is equal to the number of replicate measurements

Total NE requirements in P1 predicted using the Beef Cattle Nutrient Requirements Model 2016 ranged from 14.5 to 17.4 Mcal d^{-1} for the extensive treatment (BGcon) and 14.5 to

15.8 Mcal d^{-1} for the intensive treatment (DL; Figure 4.3 a and b), and increased with day of gestation and cold stress. Net energy for maintenance available (NEma) from hay intake measured in the intensive and extensive treatments was 17.6 ± 6.3 and 16.0 ± 3.4 Mcal d^{-1}, respectively. Figures 4.3a and b demonstrate that, depending on level of intake on a given day during P1, NEm may not have been met in both the extensive and intensive treatments. The ability to meet NEm requirements was more difficult in the extensive (BGcon) treatment due to the added NE requirements for cold stress, compared to the NEm requirements for the intensive (DL) treatment.

For the hay only diets for both DL and BGcon treatments in P1, the Beef Cattle Nutrients Requirement Model 2016 calculated protein supplied via hay intake to be 1076 g CP d^{-1}, while requirements for maintenance and pregnancy were predicted to be 490 increasing to 509 g MP d^{-1} as days of gestation increased. Microbial crude protein supplied by the diet was estimated to be 670 g d^{-1}. Predicted ADG for pregnancy started at 0.23 and increased to 0.29 kg cow^{-1} d^{-1} over P1.

The impacts of temperature and wind speed on cow LCT are depicted in Figure 4.3a and b. Extra NE required for cold stress occurred on days when cow LCT was greater than the mean daily air temperature, as depicted in Figure 4.3a. When wind speed was constant, set at 5 km h^{-1} for the intensive (DL) treatment in P1, LCT was also fairly consistent and there was no extra energy required due to cold stress (Figure 4.3b). Net energy for cold stress was not associated with the coldest day of the period, and appeared to be entirely influenced by windspeeds that were greater than 12.5 km h^{-1}, which occurred on five days during P1 in the extensive (BGcon) treatment (Figure 4.3a).

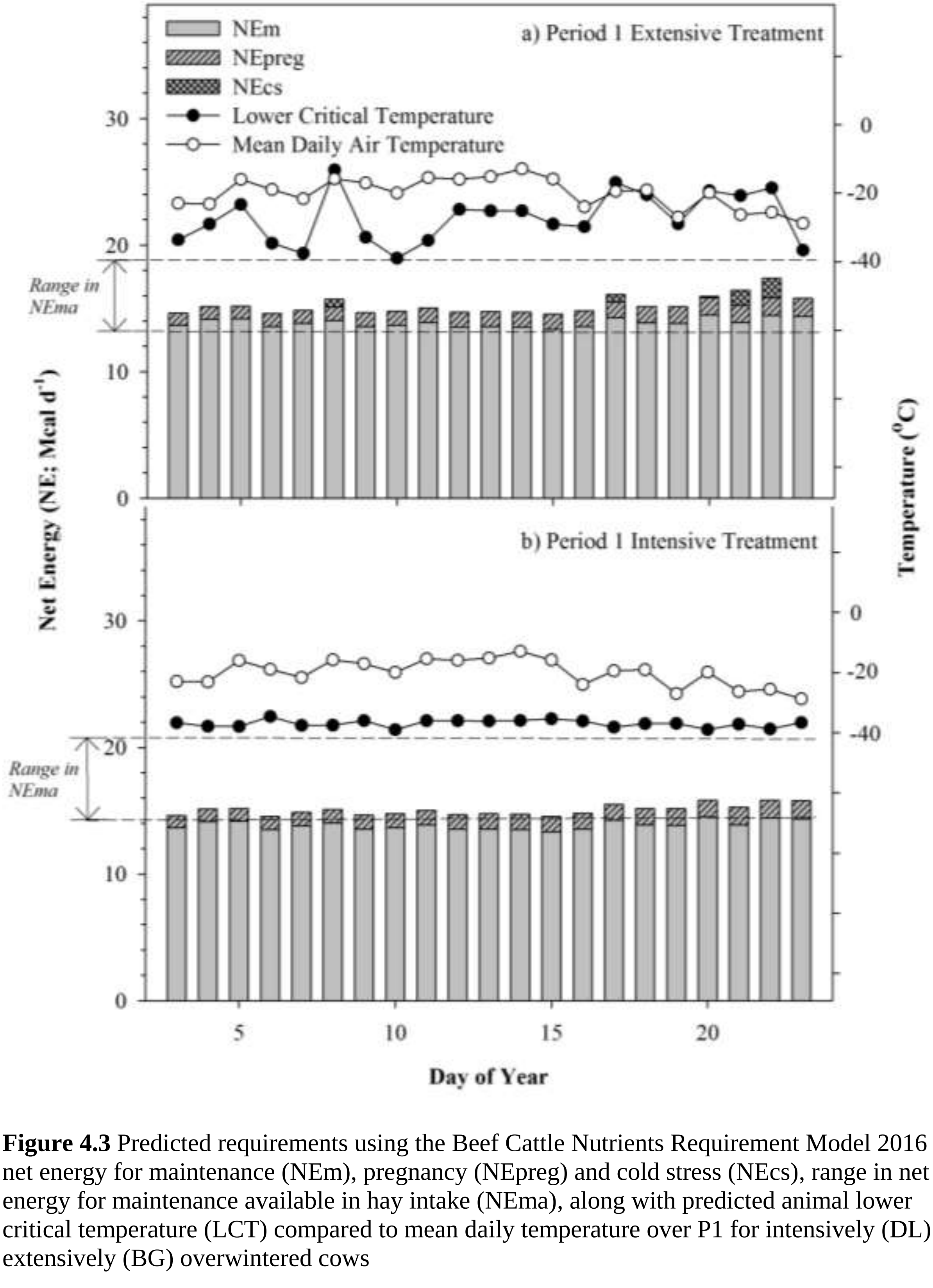

Figure 4.3 Predicted requirements using the Beef Cattle Nutrients Requirement Model 2016 for net energy for maintenance (NEm), pregnancy (NEpreg) and cold stress (NEcs), range in net energy for maintenance available in hay intake (NEma), along with predicted animal lower critical temperature (LCT) compared to mean daily temperature over P1 for intensively (DL) and extensively (BG) overwintered cows

4.4.4 DDGS Supplementation

When compared across all treatments over both periods, average daily gain was greatest for cows in the DL and lowest for cows in the BGcon treatment, with the BGdg treatment not significantly different than either (Table 4.3; Figure 4.4). Weight loss in the DL during the P2 adaption period was attributed to changes in management associated with feeding the barley supplement which was delivered daily on an individual animal basis. Body condition scores did not change significantly over the trial for any treatments, which was to be expected considering the short duration of the trial.

A period by treatment interaction revealed that enteric CH_4 emissions from the DL and BGdg treatments were not different from each other in P1 when measured as both L d^{-1} and L kg^{-1} BW (Table 4.3; Figure 4.5). However, cows in the BGcon treatment had significantly greater emissions than the DL in P1 when measured in L d^{-1}, and significantly greater than both DL and BGdg treatments when measured as L kg BW^{-1}. In P2, enteric CH_4 emissions from cows in the BGdg treatment were significantly less than both BGcon and DL treatments when measured in L d^{-1} and kg BW^{-1}, while there was no difference in emission between DL and BGcon. There was also a trend for cows in the BGcon and BGdg treatments to have decreased emissions in P2 compared to P1, while the emissions increased numerically in the DL treatment from P1 to P2 (Figure 4.5).

Carbon dioxide emissions were not different between periods or treatments, however, a period by treatment interaction occurred, which was the result of a significant difference between DL and BGcon in P1 which did not occur in P2 or between any other treatment by period combination (Figure 4.6). Energy expenditures measured over both P1 and P2 were 0.27 ± 0.02

and 0.28 ± 0.02 Mcal kg^{-1} $BW^{0.75}$ d^{-1} in the DL and BGcon treatments, respectively, with intermediate BGdg values, and with no significant differences between periods or treatments.

Serum urea N concentrations were greater for cows in the BGdg treatment compared to both BGcon and DL treatments. As well, P2 SUN concentrations were greater than P1 (Table 4.3). Cows in the BGdg treatment had a high variation in SUN concentration between days, increasing to greater than 5 mmol L^{-1} 24 h post DDGS feeding and dropping to less than 3 mmol L^{-1} by 72 h post DDGS supplementation (data not shown).

In both management systems, iButton temperatures near the cows were greater (warmer) than ambient air temperatures with differences attributed to the effect of the animal’s body. Near animal temperatures in the extensive management systems averaged 2^{o}C colder than those in the intensive management system (P<0.0001; Figure 4.7). Overall, day-time temperatures were significantly greater ($P < 0.0001$) than night time temperatures. Average day and night time temperatures of -8.9 and -14.3^{o}C, respectively were warmer ($P < 0.0001$) near the cows in the DL, compared to the extensvie treatments (-11.5 and -16.4^{o}C, respectively).

4.4.5 Post-Trial Animal Productivity

Mean calf weaning weights in the fall of 2011 were similar between treatments, ranging from 261 ± 27 kg in the BGdg treatment to 275 ± 31 kg in the BGcon treatment. Cows overwintered intensively had slightly lower calving success rates at 90 % compared to 100% for extensively overwintered cows. As well, cows from the DL treatment had a 79% conception rate compared to 89 and 95% in the BG and BGdg treatments, respectively.

Table 4.3 Mean body weight and body condition score, methane and carbon dioxide emission and serum urea N concentration, measured from pregnant beef cows fed low-quality forage and overwintered intensively (DL) or extensively (BG), with (BGdg) or without (BGcon) DDGS, over two, 21-d periods

	Period (P)		Treatment (T)			*P* value		
	1	2	DL	BGcon	BGdg	P	T	PxT
Body Weights (BW) and Body Condition Scores (BCS)								
n^a	59	59	40	40	39			
Initial BW (*kg*)	610*b* ± 4.8	618*a* ± 4.8	605 ± 8.0	609 ± 8.2	622 ± 8.2	<0.01	0.29	0.01
ADG ($kg\ d^{-1}$)	0.02 ± 0.09b	1.08 ± 0.09a	0.79 ± 1.0z	0.32 ± 1.0y	0.54 ± 1.0zy	<0.01	<0.01	0.14
Initial BCS	3.6 ± 0.02a	3.5 ± 0.02b	3.5 ± 0.03z	3.6 ± 0.03z	3.5 ± 0.03z	<0.01	0.04	<0.01
Change in BCS	-0.12 ± 0.02b	0.13 ± 0.02a	-0.01 ± 0.02	0.01 ± 0.02	0.01 ± 0.02	<0.01	0.72	0.66
Methane (CH_4)								
n^a	*72*	*72*	*48*	*36*	*46*			
CH_4 ($L\ d^{-1}$)	353 ± 13	354 ± 12	352 ± 16z	402 ± 18z	306 ± 17y	0.56	<0.01	<0.01
CH_4 ($L\ kg^{-1}\ BW$)	0.57 ± 0.14	0.53 ± 0.53	0.57 ± 0.02z	0.59 ± 0.02z	0.49 ± 0.02y	0.05	<0.01	<0.01
Carbon dioxide^y (CO_2)								
n^a	*26*	*70*	*38*	*26*	32			
CO_2 ($L\ d^{-1}$)	8198 ± 553	7588 ± 338	8104 ± 514z	7480 ± 616z	8095 ± 549z	0.71	0.04	0.01
EE^b ($Mcal\ kg^{-1}\ BW^{0.75}\ d^{-1}$)	0.29 ± 0.02	0.29 ± 0.01	0.27 ± 0.02	0.32 ± 0.02	0.28 ± 0.02	0.44	0.28	0.36
Serum urea N (SUN)								
n^a	59	59	40	40	39			
SUN ($mmol\ L^{-1}$)	1.94 ± 0.11b	2.26 ± 0.11a	1.0 ± 0.15y	1.4 ± 0.15y	3.9 ± 0.11z	0.04	<0.01	0.67

± Standard error of the mean

a-b Least squared means within a row with the same letter are not different ($P \geq 0.05$)

z-y Least squared means within a row with the same letter are not different ($P \geq 0.05$)

[a] Where n is the number of replicate measurements.

[b] Cows with negative ADG removed from the data set

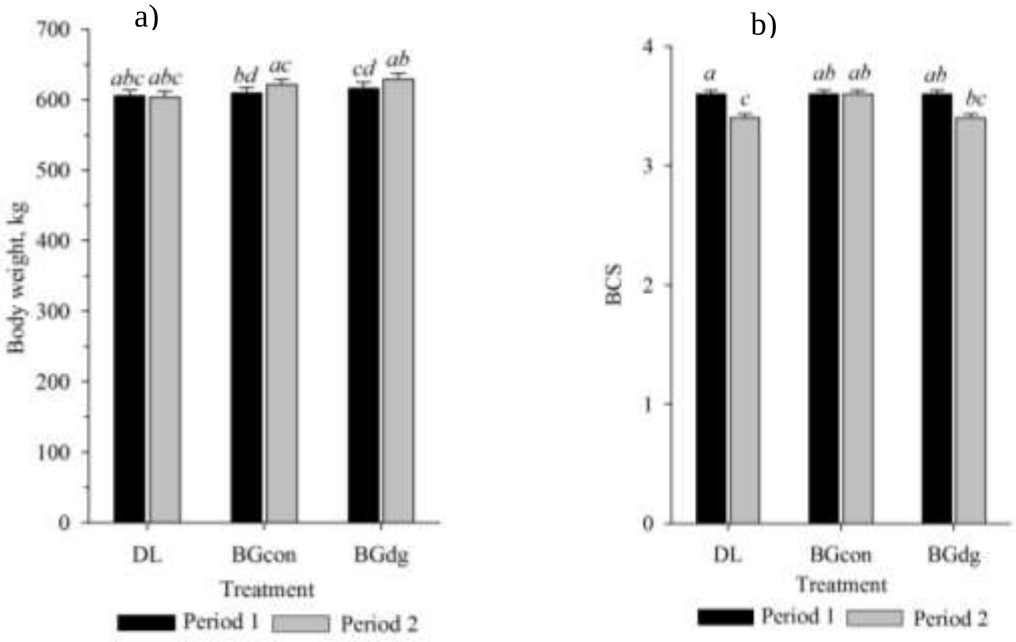

Figure 4.4 Mean period initial body weights (a) and body condition scores (b) of pregnant beef cows fed low-quality forage and overwintered intensively (DL) or extensively (BG), with (BGdg) or without (BGcon) supplementation with DDGS, as measured over two, 21-d periods during the winter of 2011

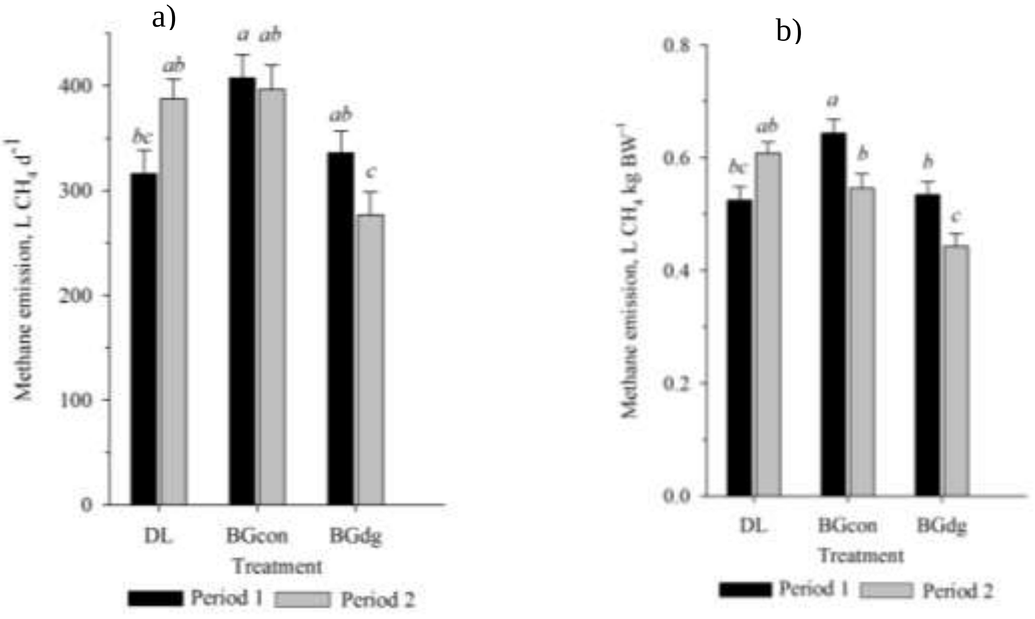

Figure 4.5 Mean methane emission measured in (a) L d^{-1} and (b) L kg BW^{-1} from pregnant beef cows fed low-quality forage and overwintered intensively (DL) or extensively (BG), with (BGdg) or without (BGcon) supplementation with DDGS, as measured over two, 21-d periods during the winter of 2011

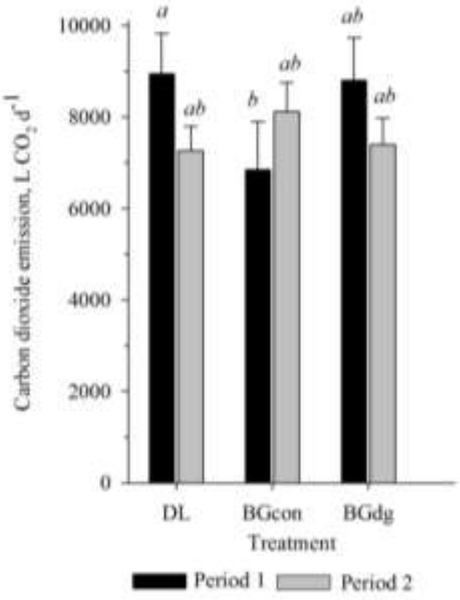

Figure 4.6 Mean carbon dioxide emissions of pregnant beef cows fed low-quality forage and overwintered intensively (DL) or extensively (BG), with (BGdg) or without (BGcon) supplementation with DDGS, as measured over two, 21-d periods during the winter of 2011

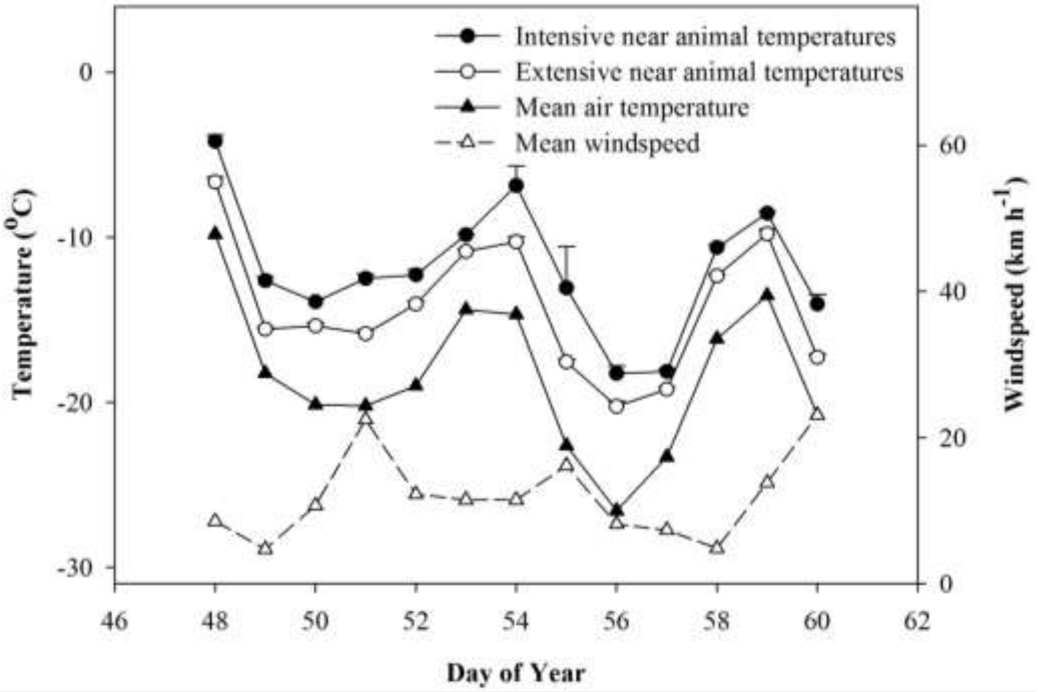

Figure 4.7 Mean iButton temperature near the cows, average daily ambient temperature and wind speed the intensive (DL; n=7) and extensive (BG; n=11) management systems over 13 d. Error bars represent standard error of the mean

4.5 Discussion

4.5.1 Measuring Intake in Extensive Overwintering Environments

Individual animal intakes measured with the GrowSafe system provided a basis for assessing the effectiveness of the alkane technique, the WFR method and the Beef Cow Nutrient Requirement Model (NASEM 2016) to estimate DM and nutrient intake for pregnant beef cows in cold environments. The difference in DMI between P1 and P2 in the DL may be attributed to the addition of barley (1.2 kg DM d^{-1}) to the diets in P2. Further, this comparison also suggests that intake of forage was not affected by the addition of barley and that animals were not substituting forage for barley.

Statistically similar intakes for the DL and BGcon treatments in P1 (Table 4.2) suggest that the alkane technique was an effective technique to measure DMI in the extensive overwintering system receiving a hay only diet, and this study is the first to provide individual animal intakes from a beef cow extensive overwintering system.

As measured DMI for both the DL and BGcon treatments were similar to the estimated intake generated by the Beef Cattle Nutrients Requirement Model 2016, 12.0 kg d^{-1}, it is suggested that the model was successful at predicting hay intake for both extensively and intensively overwintered beef cows. This is contrary to the findings of Block et al. (2010) who found that the NRC Model (2000), which was based on the same calculations and assumptions as the 2016 model, overestimated DMI of pregnant beef cows overwintered intensively.

Feed waste of 21% from the bale feeding areas was similar to the value of 21% waste feed found in Jungnitsch (2008). There was a 2.2 kg cow^{-1} d^{-1} increase in P1 intake for the BGcon treatment when measured with the WFR method, compared to the alkane technique.

Potential over-estimation of DMI by the WFR method may be significant due to factors such as hay loss from the site due to wind or in snow melt runoff, or human error in collecting hay and separating fecal matter. Although the WFR method likely overestimated intakes, covariance was similar between intakes measured with the WFR method for the BGcon and BGdg treatments, ranging from 6 to 9%, suggesting that the method was a reasonably consistent estimation of intake in the extensive system. Although not capable of providing accurate individual animal intakes, the WFR method may be a good tool to evaluate differences between similar treatments.

4.5.2 Differences Between Intensive and Extensive Overwintering

Extensive overwintering environments have several unique features. Animals in extensive environments do not have access to a heated bedding pack. Boadi et al. (2004) found bedding pack temperature averaged 4.5 ± 0.5^{o}C overwinter, with temperatures reaching as high as 8^{o}C in the deepest parts of the pack. The 2^{o}C difference measured in near animal temperatures between DL and BG treatments may be an indicator of the difference in manure pack heat and/or the difference in wind exposure.

Although cows overwintered extensively had access to windbreaks, depending on wind direction, these windbreaks may not have always been effective in protecting cows from prevailing winds while consuming forage. Cows may not have been eating as frequently on windy days or for shorter durations due to exposure to wind, unlike cows in the DL who were protected from the wind on all sides in the farm yard. This is important to note because on some days cows may not have been eating enough to meet NE requirements. The DMI SD was 2.3 kg DM cow d^{-1} measured with the alkane technique in P1 for BGcon, while SD was 2.4 kg DM cow d^{-1} for DMI measured with the GrowSafe system in P1, suggesting similar variability in intake.

Studies on animal behavior in Sweden indicated that cows on pasture spent more time ruminating and lying down, and less time eating during inclement and cold weather than during warm weather (Graunke et al. 2011). In that study, cows congregated together during cold, windy and/or wet weather to alter their micro-climate to a 2^{o}C average increase in temperature compared to the most exposed area of the field. Also, cows didn't always utilize supplied wind protection objects to escape cold and wet weather and preferred to congregate together for protection from the elements (Graunke et al. 2011). The 2^{o}C difference in microclimate observed by Graunke et al. (2011) is similar to the 2^{o}C near animal temperature difference observed with iButtons between the DL and BG treatments in the current study. It is possible that the 2^{o}C difference demonstrates the lack of ability of cows in the BG treatment to alter their microclimate to the same extent as cows in the DL. Literature suggests 1 Mcal NE d^{-1} is associated with a 10^{o}C change in temperature [National Research Council (NRC) 2000].

Cows in extensive overwintering environments may also experience increased physical activity depending on distance between feed and water sources and depth of snow pack, and therefore may have greater energy expenditure compared to cows in intensive systems. In this study, drylot pens were 0.04 ha while BG paddocks were 0.6 ha, and cows were required to walk a maximum of 168 m from the far end of the BG paddock to the water trough. Previous studies indicate that cows grazing in the warm season travel to the water source twice per day, while in the winter travel to water was limited to once per day (Broom and Fraser 2015). Given that walking has an energetic cost of 0.24 Mcal km^{-1} (Agricultural Research Council 1980), it is estimated that no more than 0.24 Mcal d^{-1} was expended to walk to the water source in this study, particularly in P1 when cows were still grazing at the end of the paddock closest to the water trough. However, the effect of depth of snow pack on energy expenditure while walking to the water source or to wind protection is unknown.

Using snow as a water source can also increase energetic expenditure. Degen and Young (1990) suggested that, theoretically, cows would require 10.7 to 15.3% of their daily ME intake to convert an equivalent volume of snow to water to meet animal requirements. In this study, that would equate to 2.8 to 4.0 Mcal d^{-1}. If cows in the current study preferred to eat snow as a water source instead of walking to the water source, this energy expenditure may be an important consideration. In fact, Degen and Young (1990) observed that cows with access to water also ate some snow to complement their water intake. However, in the same study, measurements of rectal temperature and metabolic heat production showed no differences between cows with water or snow as the water source in a thermal neutral environment, suggesting that the heat produced in the rumen for digestion was adequate to melt small quantities of snow without requiring additional energy (Degen and Young 1990). Degen and Young (1980) determined that cows with a water source made one or two trips to the water trough to ingest a large quantity of water to meet water demands, while cows with snow as the water source ate small quanties of snow throughout the day in between foraging. The energy required to heat these small quanities of snow was hypothesized to be small compared to heating large quantities of snow or large volumes of cold water.

In this study, although not significantly different, EE was consistently numerically lower in the DL compared to extensive treatments, with an average of 0.27 compared to 0.32 Mcal kg^{-1} $BW^{0.75}$ d^{-1} for the DL and BGcon treatments, respectively. This suggests that there were greater demands for energy in the BG treatment. The reduced sample size due to the negative ADG in Period 1 in the BGcon treatment made it difficult to determine if these differences in EE were significantly different. The increased energy requirements due to increased walking and foraging, snow depth, wind exposure, and using snow as a water source, are not currently accounted for in nutrient requirement models and require more investigation.

Forage delivered was intended to supply cows in all treatments with the nutrients and energy necessary to meet or exceed maintenance and production requirements in cold temperatures and on windy days. The negative ADG observed in P1 in the BGcon treatment suggests that nutrient requirements were not met and that, despite hay available for consumption, cows were not able to increase intake to meet increased demand for nutrients, as was seen in Bernier et al. (2012). As described, the Beef Cattle Nutrient Requirement Model 2016 (NASEM 2016) estimates intake and nutrient requirements based on the users inputs of weather such as temperature, wind, humidity, previous temperature and humidity, as well as animal information such as diet composition and intake, breed, animal body weight, age, days of gestation, along with hair depth, hide, hair coat, and mud depth. Figure 4.3 demonstrates the use of the Beef Cattle Nutrient Requirements Model 2016 to predict NE required for maintenance, pregnancy and cold stress based on the recorded daily weather conditions in P1 of the bale grazing trial. According to the predicted requirements in Figure 4.3, the amount of hay ingested may not have met animal requirements for the BGcon treatment on several days of P1. The alkane technique standard deviation suggests that on some days, DMI may have been up to 2.3 kg lower than the Period mean DMI. For cows in the BG treatment, this would have resulted in more days where NE requirements were not met. The DL treatment, with a slightly higher NEma and lower NE requirements, would have been able to meet NE requirements on a greater number of days. These factors, combined with the uncertaintly regarding energy required for increased walking and foraging in deep snow packs, increased wind exposure and potential energy used for converting snow to water, may explain the decreased productivity in P1 in the BGcon treatment compared to the DL. Table 4.4 provides an estimate of energetic requirements associated with various activities in the current study.

Table 4.4 Summary of energetic requirements for intensive (DL) and extensive (BGcon) overwintering systems during P1 based on the Beef Cattle Nutrient Requirements Model 2016 and estimates from literature

Source of energy loss	DL	BGcon
	Mcal cow^{-1} d^{-1}	
NEma[a]	14.4 to 20.7	13.0 to 19.0
Energy Requirements		
NEm[a]	13.5 to 14.5	13.5 to 14.5
NEpreg[a]	0.97 to 1.42	0.97 to 1.42
NEcs[a]	0	0.12 to 1.57
Walking[b]	na	0 to 0.24
Snow consumption[b]	na	0 to 4.0
Difference NEma – Requirements	-1.52 to 6.23	-8.73 to 4.41

[a] Estimated using the Beef Cow Nutrients Requirements Model 2016 (NASEM 2016)
[b] Estimated from literature

Table 4.4 demonstrates that the BGcon treatment had the greatest potential to lack dietary energy required to cover energetic expenditures. As the estimated energetic cost of walking does not consider the depth of snow pack, we estimate the lower end of the range of the difference in NEma minus requirements to be more plausible and a possible explanation for the negative ADG observed in P1. The mud depth factor in the Beef Cattle Nutrient Requirements Model 2016 was explored for its potential to describe the energy expenditure associated with depth of snow pack. However, the mud depth factor primarily affects animal DMI and as DMI between the DL and BGcon treatments were similar in the current study, mud depth was not explored further as a potential additional factor to describe differences in energetic requirements between the systems.

Ratio of protein and energy in ruminant rations has also been noted to be an important factor for optimal rumen microbial function (Illius and Jessop 1996). A ratio of greater than 48.3

g of CP per Mcal ME has been noted as optimal for feed efficiency (Gabler and Heinrichs 2003). Restriction of protein relative to energy can lead to a reduction in microbial growth and rate of forage digestion (Leng 1990). This would potentially increase CH_4 emission and lead to less efficient use of ingested nutrients. Illius and Jessop (1996) also noted, however, that although lack of dietary protein relative to energy can lead to inefficient rumen function, endogenous recycling of microbial protein and NH_3 can be used by the ruminant to an extent to compromise for protein deficient diets, and enable animals to maintain productivity on low quality diets. This recycling of nitrogen in the rumen may compensate for short-term nutrition deficiencies and therefore measurable productivity changes in body weight may not be immediately apparent. Serum urea nitrogen can be used as a tool to indicate potential N and energy deficiencies in the short-term.

Ratios of CP (g d^{-1}) to ME (Mcal $d^{-1;}$ NAESM 2016) were determined to be 39.9 for the DL and BGcon diets in P1, 42.5 for the DL and BGcon diets in P2 (addition of barley), and 57.5 for BGdg diets across both period (averaging DDGS supplementation over 3-d). Therefore despite the fact that diets met protein requirements, the DL and BGcon treatments were considered to have low protein:energy ratios, increasing CH_4 emissions per unit energy consumed and suggesting more protein was required in the diet. This is supported by the low SUN status measured across both DL and BGcon treatments in P1. The addition of barley to DL and BGcon diets in P2 successfully increased SUN status of cows in P2. However, the addition of barley increased the ratio of protein:energy only slightly, despite the fact that barley used in the study had a higher protein concentration (16.2%) than what is considered typical for barley (12.78 ± 2.83%; NASEM 2016). Despite the higher protein concentration, the ratio of barley compared to forage in the diet was comparatively small and therefore did not make a significant difference in overall dietary protein intake.

Despite the low protein:energy ratio in the DL in P1, the cows in the DL may not have been under as much energetic stress as cows in the BGcon treatments, in terms of energy needed for walking and foraging and increased wind exposure. The forage-only diet in BGcon may not have been adequate to provide sufficient nutrients for the added energy expenditure associated with lower temperatures and increased walking and wind exposure. Energy and protein requirements have been developed for cattle housed in confinement in winter and may require further refinement for cattle foraging in extensively overwintered environments. The combination of increased dietary protein and energy associated with barley supplementation combined with warmer temperatures and decreased wind speeds in P2 resulted in positive ADGs. The addition of barley did not decrease CH_4 emissions (L d^{-1}) for either DL or BGcon treatment in P2 compared to P1, again suggesting that protein continued to be the limiting factor in the diets.

Other differences between the two systems that may have impacted CH_4 emissions included forage processing, as hay in the intensive system was chopped while in the extensive system it was not. Ground and pelleted orchardgrass hay (14% CP, 61.6 to 63.6 % NDF) increased rate of passagecompared to chopped forage (3 to 10 cm; Bernard et al. 2000), however, no differences in rumen OM or NDF digestibility were found. In the current study, chopped hay length ranged from 15 to 20 cm in length, compared to non-chopped hay which had hay lengths of 20 to 40 cm in length. As intakes were found to be similar between the DL and BGcon treatments in P1, and the chop length was relatively large for both treatments compared to chop length reported in the literature, it seems unlikely that chop length of the magnitude reported here impacted the results of the study.

4.5.3 Every Third-Day Feeding of DDGS

Supplementing low-quality forages with a protein and energy source such as DDGS has been found to improve the efficiency of rumen fermentation and reduce emission of CH_4 when expressed as a % GEI (McGinn et al. 2009; Bernier et al. 2012). The results of the current study demonstrate the improvement in fermentation efficiency from cows overwintered extensively with DDGS supplementation when compared to cows overwintered extensively on low-quality forages alone. However, few differences were seen between the BGdg treatment and the intensive DL treatment in terms of cow productivity, with the exception of improved SUN concentrations. Despite the fact that dietary protein and SUN concentrations were much greater for the BGdg treatment than the DL, no significant differences in CH_4 emissions between BGdg and DL treatments occurred in P1 suggesting that CH_4 emissions in the BGdg treatment was also being impacted by other factors.

It is important to note that some cows in the BGdg treatment also had negative or no gain in P1. This was surprising considering the BGdg treatment received additional protein and energy in their diet via DDGS. These negative and low weight gains may be attributed to decreased DMI on days with extreme wind, when animals may have spent more time behind wind fences than foraging. Again, the energy requirements for foraging and walking in deep snow packs are unknown. Weather in P2 was more favourable than P1, which may have contributed to the differences between periods within the treatments.

Asynchrony of CP and ME has also been noted to cause inefficient microbial growth and fermentation of substrates in the rumen (Beever 1993). Delivering the DDGS every three days meant that the rumen had recommended protein to energy ratios on the day of feeding, but as DDGS moved through the system, the protein and energy ratio would change as particulate and fluid passed through the rumen. Bernier et al. (2014) found that particulate rumen retention time was 84.3 h and fluid rumen retention time was 11.4 h for cows fed a low-quality forage diet supplemented with 20% DDGS. The difference in CH_4 emissions and SUN concentrations measured on d 2 compared to d 3 support this theory that protein to energy ratios were changing daily. The lack of difference in GHG emissions between the DL and BGdg diets in P1 could be related to the asynchrony of supply of available protein and energy via every third-day feeding of DDGS, in combination with the differences in weather conditions noted between intensive and extensive treatments.

Supplementation in the BGdg treatment did not appear to improve animal productivity compared to cows intensively overwintered in terms of ADG, BCS and post-trial animal productivity, but supplementation prevented animals from losing weight as occurred in the BGcon treatment. The added costs associated with increased supplementation to an extensive overwintering system, compared to intensive overwintering must be demonstrated. From an environmental perspective, the lack of improvement in enteric CH_4 emissions in P1 reduces the appeal of bale grazing with every third-day DDGS supplementation. However, supplementation was necessary to maintain animal productivity in the extensive treatment. Improved economic sustainability is often the primary factor influencing producers to switch from intensive to extensive overwintering practices. Kelln et al. (2012) found only a \$0.09 cow^{-1} d^{-1} economic benefit from bale grazing compared to a traditional drylot system In the current study, the cost of

DDGS supplementation and labour would have increased the cost associated with the BGdg system by \$0.49 cow^{-1} d^{-1} at current market prices for wheat DDGS (Saskatchewan Forage Council 2018).

4.6 Conclusions

This is the first trial to measure individual DMI in an extensive overwintering environment. The alkane technique demonstrated potential to be an effective method for determining intakes from hay only diets in winter grazing scenarios, with measured intakes similar to GrowSafe intakes measured in the DL. A 2^{o}C decrease in near animal temperatures measured in the extensive treatments suggested that differences in microclimates were occurring between intensive and extensive overwintering environments, potentially influencing animal maintenance energy requirements. Methane emissions were greater in extensive overwintering environments (BGcon) compared to intensive (DL) during P1, and DDGS supplementation did not significantly decrease methane emissions compared to the DL in P1. Methane emissions from the extensive overwintering treatment were believed to be related to a combination of low protein to energy ratios in the diet and increased exposure to cold temperatures and energy requirements of cows in these extensive overwintering environments that were not being met with the low-quality forage diet. It is important to remember other environmental and economic implications associated with feeding DDGS when recommending this management strategy to producers. Average daily gain and SUN measurements in P1 indicated that the NRC 2016 recommended nutrient requirements were not adequate for animals in extensive overwintering environments and more research is needed to quantify energy and protein requirements of animals in extensive overwintering environment experiencing increased cold stress and activity levels.

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5.0 MANUSCRIPT 2

SHORT-TERM IMPACTS OF WINTER BALE GRAZING BEEF COWS ON FORAGE PRODUCTION AND SOIL NUTRIENT STATUS IN A FORAGE FIELD IN THE EASTERN CANADIAN PRAIRIES

5.1 Abstract

This study was conducted to determine the impact of winter bale grazing (BG) on forage productivity and nutrient cycling in the eastern region of the Canadian Prairies. An intensive grid sampling methodology for soil and forage measurements was utilized to capture the highly variable distribution of nutrients and forage yield within BG areas on a perennial grass-legume forage field. Results showed a 68% decrease in forage dry matter (DM) yield the year following BG and no difference in DM yield in year two following BG, relative to a control. Decreased yield was attributed to the large mass of waste feed and feces (21% of feed delivered) that remained at the centre of the area in which the bale was placed. Concentrations of crude protein, total digestible nutrients, phosphorus (P) and potassium in harvested forage increased in the first growing season following winter bale grazing compared to the control, particularly at the centre of the bale placement areas, where forage yield was depressed. Percent of weed species increased from 7 to 13% of plant biomass while the percent of legume species decreased from 23 to 14% of plant biomass for the bale graze treatment relative to the control. In addition, concentrations of residual nitrate-nitrogen and Olsen P in soil were 15 and 2.5 times greater, respectively, at the centre of the bale placement areas compared to an untreated control. We recommend dispersing waste feed packs when bale grazing in sub-humid climates on clay soils to minimize smothering

and encourage rapid decomposition of waste feed and feces. Long-term studies are needed to determine the potential benefits of bale grazing to forage productivity and soil nutrient status in the eastern Canadian Prairies.

5.2 Introduction

Winter grazing management practices have become increasingly popular for cow-calf producers on the Canadian Prairies (Sheppard et al. 2015) due to the economic benefits compared to more traditional, drylot overwintering practices (Kelln et al. 2012b). Bale grazing is one strategy of winter grazing where bales of hay are imported and placed on a forage (Donohoe 2018; Jungnitsch et al. 2011) or annual crop (Kelln et al. 2012a) field. During the winter, cows have systematic access to bales, resulting in manure and waste feed distribution directly on the soil surface. This practice reduces the need for manure spreading and decreases labour inputs required for daily feeding (Kelln et al. 2012b).

A winter bale grazing study on a forage field in the central Canadian Prairies found increased forage productivity, forage quality and soil nutrient status in the first two years following bale grazing, with forage yield that was three-fold greater than an ungrazed control (Jungnitsch et al. 2011). These benefits were attributed to the imported nutrients in the forage bales and the subsequent deposition of manure and waste feed onto the soil surface over winter. Kelln et al. (2012a) also found a pattern of increased biomass yield and increased soil nutrients which appeared to be concentrated around bale placement areas when winter grazing on annual cropland in the central Canadian Prairies, creating a pattern of “hot-spots” of increased soil nutrient status throughout the field. Substantial benefits of winter bale grazing were observed in these studies, which were conducted at locations characterized as having a semi-arid climate with precipitation of 392 mm annually, and soils with low productivity in the untreated state.

The overall purpose of our study was to characterize the impact of winter bale grazing on forage productivity and soil nutrient cycling for an inherently highly productive soil type in a sub-humid climate in the south-eastern region of the Canadian Prairies that receives an average of 521 mm precipitation annually. The specific objectives of this study were to: i) characterize a forage field in the Red River Valley in the first and second growing seasons following bale grazing in terms of forage dry matter (DM) yield and forage quality for beef cows, ii) determine the locations and intensities of “hot-spots” of soil nutrients using an intensive grid-based sampling methodology, and iii) determine if, where, and when differences occur between a control hay field, with no impact of winter bale grazing, and a hay field used for winter bale grazing, within the first two growing seasons following bale grazing, in terms of forage DM yield, forage quality for beef cows, soil nutrient status, and forage species composition. We hypothesized that bale grazing, specifically the impact of manure and waste feed deposition on the soil surface, would increase average forage yield and quality and soil nutrients at each bale placement location, compared to an ungrazed control forage field.

5.3 Materials and Methods

5.3.1 Site Description

The study was located on a 5.6 ha forage field at the University of Manitoba’s National Centre for Livestock and the Environment’s Glenlea Research Station (lat. 49.65N, long. 97.13W). Dominant plant species included *Phleum pretense* (Timothy grass), *Poa pratensis*

(Kentucky blue grass), *Bromus inermis* (Smooth bromegrass), and *Lotus corniculatus* (Bird's-foot Trefoil) and management history included mechanical harvest of forage once annually, with no fertilizer or manure application for at least the previous 10 years. The soil was imperfectly drained heavy clay with level to nearly level topography, part of the Scanterbury soil association (Michalyna, 1975), described as a Gleysolic Humic Vertisol in the Canadian soil classification system and a Typic Humicryert in the U.S. system. Prior to bale grazing, the surface soil (0-15 cm) had a bulk density of 1.1 Mg m^{-3}, pH of 6.7, 10 mg kg^{-1} extractable Olsen phosphorus (P), 501 mg kg^{-1} potassium (K) and 710 g kg^{-1} organic matter, with 14.6 kg ha^{-1} nitrate nitrogen (NO_3-N) at the 0 to 60 cm depth.

Management of cattle during the winter trial is described in Donohoe (2018). In brief, the hay field was divided into eight smaller paddocks with high-tensile electric fencing, with four bale grazed (BG) paddocks and four unamended and ungrazed control (CON) paddocks. On 23 Dec 2010, 24 round bales of grass hay consisting of 9% crude protein (CP), 4.25 Mcal kg^{-1} gross energy (GE), and 0.11% P, weighing 511 ± 51 kg, were placed in each BG paddock on 12 m spacings, resulting in 1774 cow d ha^{-1} stocking density or 69 bales ha^{-1}. This bale density resulted in 706 kg N ha^{-1} and 53 kg P ha^{-1} imported to the field. Ten pregnant, non-lactating mature cows per BG treatment paddock grazed the hay bales from 4 Jan 2011 to 2 Mar 2011, and received a diet of hay with or without dried distillers grains with solubles (DDGS; 30% CP and 0.99% P) at a rate of 8.3 kg cow^{-1} fed every third day, as described in Donohoe (2018). Cows were given access to new bales using a measuring and moving system that resulted in 21% waste feed on average. The measuring system ensured that cattle moved, based on residual feed remaining, with sufficient residual feed to ensure ad libitum intake, avoid excessive feed waste and provide a small amount of waste feed as bedding (Donohoe 2018). Cows were not provided with additional bedding, but each paddock had two 10-m portable windbreaks that were moved each time a new row of bales was allocated. Cattle had access to heated waterers at the north end of each paddock. One BG paddock in which cows received the DDGS supplemented diet and its adjacent control paddock was selected to characterize the effects of extensive overwintering on forage productivity and soil nutrient cycling. Characterization was limited to these two paddocks as the other paddocks were flooded by the nearby Red River in the spring of 2011.

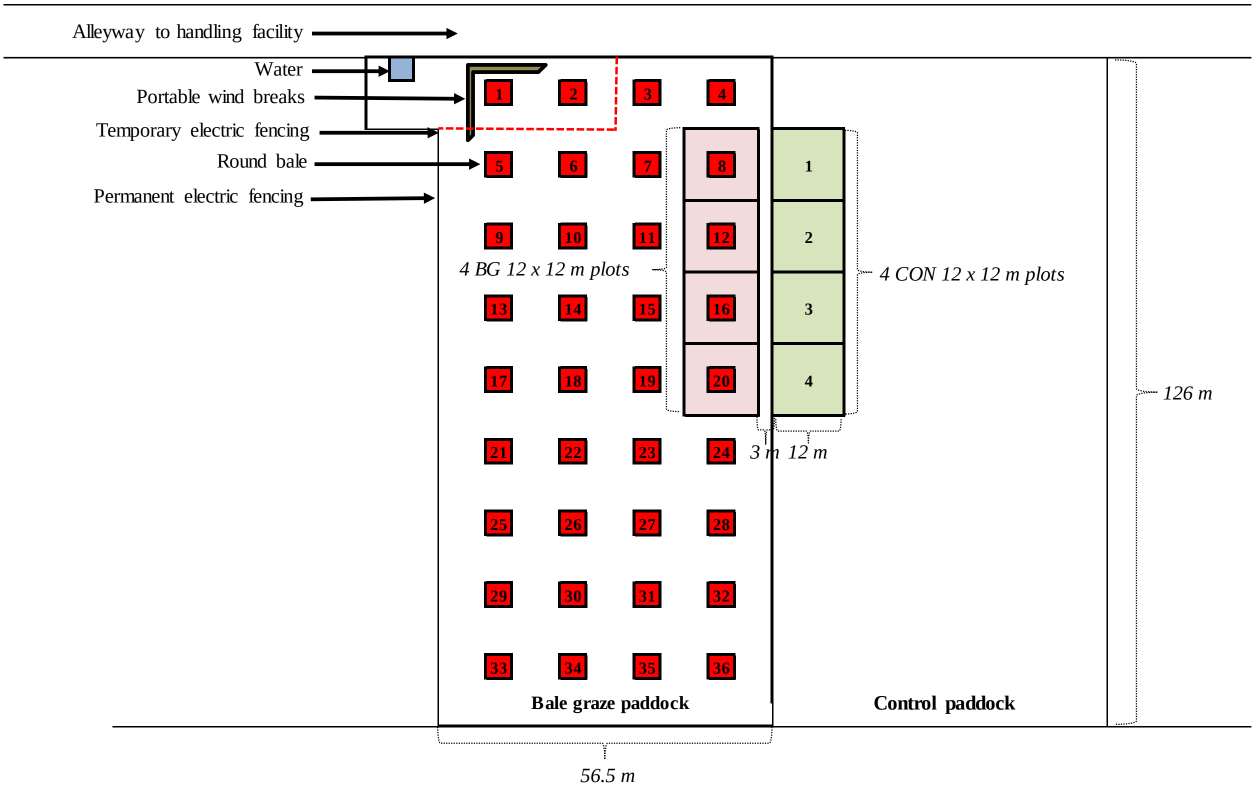

Figure 5.1 Diagram of paddock layout and location of soil and forage sampling plots for bale graze (BG) and control (CON) treatments

Four individual bale feeding areas directly adjacent to the CON paddock were selected to compare CON and BG soil and forage samples (Figure 5.1). For each bale feeding area, a 12 x

12 m plot was marked and divided into a 5 cell x 5 cell sampling grid resulting in 25, 2.4 x 2.4 m cells, with the original bale location in the centre of the plot (Figure 5.2). An equivalent four plot and 25-cell grid system was used for soil and forage sampling in the CON treatment paddock to create a non-randomized complete block design. The distance between the outer edges of the BG plots and their equivalent CON plots was 3 m, in order to ensure soil and forage characteristics were as similar as possible between paired CON and BG plots.

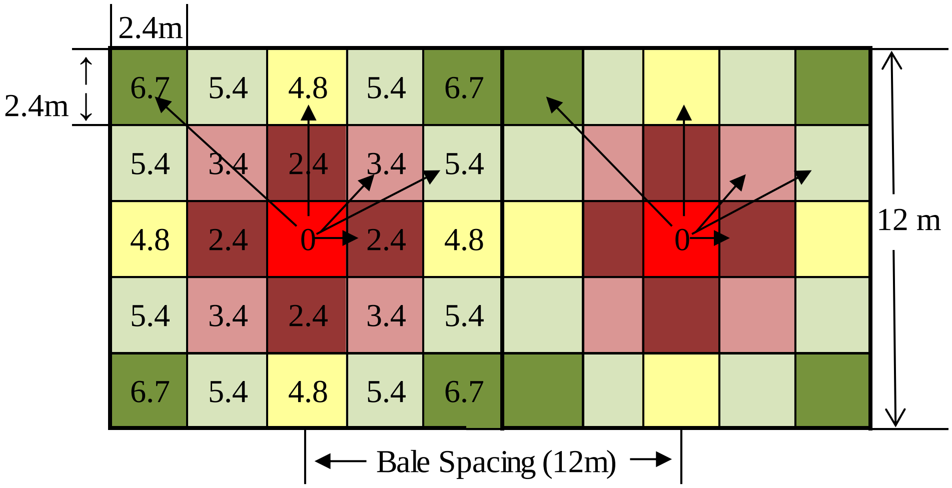

Figure 5.2 Layout of the soil and forage sampling grid for a bale grazed plot depicting the division of the 12 m x 12 m area for each bale into a 5 cell x 5 cell grid. Numbers within each cell depict the distance (m) from bale centre (0 m) to the centre of each cell within the sampling grid for each plot

5.3.2 Forage Sampling and Analyses

Forage samples were taken during the 2011 and 2012 growing seasons, with one harvest in the first growing season (GS1) following bale grazing (summer 2011) and two harvests in the second growing season (GS2) following bale grazing (summer 2012). In GS1, an extremely wet spring delayed first cut forage sampling until early July and lack of precipitation during the latter part of that summer resulted in minimal late season growth of the forage. Forage in GS1 was harvested from a 0.25 m^2 square quadrat to a height of 5 cm, with four quadrats per cell harvested from two BG plots and the equivalent CON plots, and one quadrat harvested per cell from the remaining two BG plots and the equivalent CON plots. During GS1, an average DM yield was determined for each individual cell. In GS2, standing forage biomass and species composition were used to determine the number of quadrats harvested per cell. If standing forage biomass and species composition in a cell appeared to be spatially consistent throughout the cell, one quadrat was used to determine forage DM yield from a cell. If standing forage biomass and/or species within the cell were highly variable, the percentage area of the cell covered by each patch of differing biomass or species was determined and one quadrat was harvested per patch, with DM yield determined using the percentage area covered and forage DM yield per quadrat.

In both growing seasons, forage samples were weighed and air dried immediately after harvest and stored for further processing and analyses. Immediately prior to grinding, forage samples were dried in a forced-air oven at 60°C for at least 48 h. Samples were then ground through a 1-mm screen (Cyclotec Tecator 1093 Sample Mill, Foss Analytical, Denmark). Forage samples collected in GS1 from plots with four quadrats harvested per cell were composited on equivalent weight basis from each of the four quadrats per cell. Forage samples from GS1 with one quadrat harvested per cell and from all samples collected in GS2 had subsamples from each quadrat collected and analyzed individually. All subsamples were analyzed by a commercial lab, Central Testing Laboratory Ltd. (Winnipeg, MB) for moisture, crude protein (CP), total digestible nutrients (TDN), and minerals P, potassium (K), calcium (Ca) and magnesium (Mg) using near infrared reflectance spectroscopy.

The grass tetany ratio of forage samples was calculated using units of mEq kg^{-1} for forage sample analyses in the equation [K] / ([Ca] + [Mg]) with the following conversion factors used to convert % mineral analyses to mEq kg^{-1}: K = 255.74, Ca = 499.00, Mg = 822.64 (Oetzel 1993).

5.3.3 Species Composition

Relative species composition of biomass was visually estimated in 0.25 m^2 quadrats in GS2. Percent species composition, with all vegetation adding up to 100% of the quadrat, was estimated in each cell of the BG plots and CON plots. Sum of forage grass species, legume species, weed species and "other" species were calculated for each cell.

5.3.4 Soil Sampling and Analyses

Soil samples to determine residual soil nutrient status after bale grazing were collected in the first fall (Fall1) and second fall (Fall2) after winter bale grazing. The soil was sampled 24-28 October 2011 and 5-9 November 2012, at depths of 0-15 and 15-60 cm using a Giddings soil coring machine. In both falls, four soil cores per cell were collected from every cell in BG and CON plots. Samples were air dried and ground to pass through a 2-mm mesh sieve prior to analysis. For two BG plots and the equivalent CON plots, the four cores per cell collected at each depth were analyzed individually and the mean of these four analyses was calculated arithmetically for each cell. For the remaining two BG plots and the equivalent CON plots, the four soil cores per cell were composited by depth prior to analysis. The number of subsamples associated with each distance were 24 for 0 m, 64 for 2.4, 3.4, 4.8 and 6.7 m distances and 128 for the 5.4 m distance.

Soil inorganic ammonium-nitrogen (NH_4) and nitrate NO_3-N were extracted with 2 M potassium chloride (KCl; 5:1 extractant:soil) and measured by automated phenate colorimetry and automated cadmium reduction colorimetry, respectively (Maynard et al. 2008), using a Technicon Autoanalyzer II system (Pulse Instruments, Mequon, WI). Olsen-P was measured by shaking 1.0 g soil with 20 mL of 0.5 M sodium bicarbonate ($NaHCO_3$; buffered at a pH of 8.5) in the presence of 0.25 g of P-free charcoal for 30 min (Olsen et al. 1954; Olsen and Sommers 1982), filtering the extract through Whatman No. 40 filter paper and measuring P in the extract by ascorbic-acid molybdate colorimetry. Exchangeable K was extracted with 1 M ammonium acetate (NH_4OAC; pH 7, 5:1extractant:soil) and measured by inductively coupled plasma membrane atomic emission spectroscopy (ICP-AES; Thermo Electron ICAP 6500, Cambridge, UK).

5.3.5 Waste Feed

After winter bale grazing, waste hay and feces were collected immediately following spring thaw of GS1 from two bale feeding areas in the paddock, using the same 5 x 5 cell grid system that was used for forage and soil sampling. Waste hay and feces from each 2.4 x 2.4 m cell were air dried, separated and weighed. Dry matter content was determined using the method described above for forage samples and DM mass of waste hay and feces was determined for each cell from both bale feeding locations.

In Fall2, after soil sampling was completed, depth of waste feed remaining was determined for the remaining two BG treatment plots by measuring depth of waste of feed to soil surface at four locations per cell and depths were averaged for each cell. Percentage area covered by waste feed and feces for these two BG plots was then estimated and mapped for each cell of the sampling grid.

5.3.6 Statistical Analysis

Statistical Analysis Software (SAS) version 9.4 (SAS Institute Inc. 2000) was used for all statistical analyses. A three-way analysis of variance using Proc GLIMMIX was performed on all soil and forage data, including fall residual soil NO_3-N, Olsen P, exchangeable K, Mg and Ca, and forage DM yield and concentrations of CP, P, K, Mg, and Ca. The model was a non-randomized, complete block design with block, treatment, time and distance from bale center used as the model fixed factors. As only one of four treated paddocks was unaffected by inundation during a flooding event in spring 2011, randomization was not possible. Interactions of treatment by distance, treatment by time, time by distance, and treatment by distance by time were included. Blocks included paired sampling grids of adjacent BG and CON plots in order to minimize variability attributed to factors other than treatment. Tukey's test for multiple comparisons of means was used to determine significant differences at $P < 0.05$. Due to the lack of normal distribution of the raw data, natural log-transformed means were used for all forage and soil data comparisons and results were back- transformed and presented as geometric means.

Percent species composition as well as grass tetany ratio in forage was analyzed using SAS GLIMMIX to compare means of forage grass species, legume species, and weed species in BG and CON treatments. Fixed effects included block, treatment and distance, and treatment by distance interactions were considered.

Spearman correlation analysis was used to determine relationships between forage DM yield, soil nutrient status, and depth of waste feed in 2012, within sampling times and across all sampling times, with significant relationships determined using a P value of < 0.05.

5.4 Results

5.4.1 Forage Yield and Quality

Forage DM yield was highly variable within both the BG and CON treatments. Forage DM yield in GS1 varied from 0 to 9090 kg ha^{-1} per cell for the BG treatment, with yields of 0 kg ha^{-1} recorded at the bale centre (0 m) locations. The CON treatment had a range of 1861 to 7374 kg ha^{-1} per cell (Appendix Table 9.1). In GS2, forage DM yield varied from 725 to 6553 kg ha^{-1} in the BG treatment, while the CON treatment ranged from 727 to 4641 kg ha^{-1}. Variability in concentrations of forage CP, TDN and minerals was consistently greater for the BG treatment compared to the control treatment, but was not nearly as extreme as the variability in forage DM yield.

Analysis of variance for forage DM yield indicated a three-way treatment by time by distance interaction (Tables 5.1 and 5.2), due to the substantially lower yields in the centre of the sampling grid for the BG treatment compared to the CON in GS1 (Figure 5.3a). Furthermore, within the BG treatment in GS1, the DM yields at the centre of the sampling grid were significantly lower than for distances that were 2.4 m or further away. In GS2, there were no significant differences between treatments or between distances within the BG treatment, partly due to the recovery of DM yield at the bale centre and partly due to the inherently large spatial variability in forage DM yield itself, in both treatments.

A treatment by time interaction indicated that forage CP concentration was greater in BG compared to CON treatments only in GS1, with no difference between treatments in GS2 (Tables 5.1 and 5.2). Crude protein concentration increased in the CON treatment between GS1 and GS2. A treatment by distance interaction indicated that in the BG treatment, CP concentration was greatest at bale centre to the 2.4 m distance from bale centre, while no effect of distance occurred in the CON treatment.

Table 5.1 Geometric means of forage dry matter (DM) yield and concentration of crude protein (CP), total digestible nutrients (TDN) and phosphorus (P) in forage harvested at increasing distances (Dist) away from the centre of the sampling grid from bale graze (BG) and control (CON) treatments (Trt) during the first (GS1) and second (GS2) growing seasons following bale grazing

Factor	**Trt**	**Time**	**Dist**	**DM yield**	**CP**[a]	**TDN**	**P**
			m	**kg ha^{-1}**		**g kg^{-1}**	
Trt	**BG**			1576	88.8	601	1.64
	CON			2910	78.5	593	1.48
Time		**GS1**		2094	71.8	581	1.47
		GS2		2189	97.0	613	1.65
Dist			**0**	1031	103	602	2.08
			2.4	2143	90.6	600	1.67
			3.4	2393	81.5	694	1.54
			4.8	2657	77.3	597	1.46
			5.4	2686	76.5	596	1.36
			6.7	2552	75.2	595	1.36
Trt x Time	**BG**	**GS1**		1183	79.9b	591	1.62a
		GS2		2098	98.6a	613	1.66a
	CON	**GS1**		3707	64.6c	573	1.34b
		GS2		2284	95.5a	614	1.64a
Trt x Dist	**BG**		**0**	337	125a	614	2.69a
			2.4	1677	102ab	606	1.84b
			3.4	2055	83.6c	594	1.62bc
			4.8	2384	77.4c	599	1.45cd
			5.4	2514	77.6c	599	1.30d
			6.7	2201	76.2c	598	1.30d
	CON		**0**	3163	85.5bc	590	1.61bcd
			2.4	2740	80.2c	594	1.51cd
			3.4	2786	79.4c	594	1.46cd
			4.8	2960	77.1c	594	1.48cd
			5.4	2870	75.4c	594	1.43cd
			6.7	2959	74.2c	593	1.43cd
Time x Dist		**GS1**	**0**	444	96.4	596	2.12
			2.4	1850	79.6	586	1.57
			3.4	2481	69.2	580	1.46
			4.8	3370	65.0	578	1.37
			5.4	3679	63.7	577	1.24
			6.7	3346	62.4	576	1.24
		GS2	**0**	2399	111	608	2.04
			2.4	2484	103	615	1.77
			3.4	2308	95.8	609	1.61
			4.8	2094	91.2	616	1.56
			5.4	1961	91.8	616	1.50
			6.7	1947	90.5	616	1.50

Means within the same column and factor group followed by the same lower case letter are not significantly different ($P \geq 0.05$) by Tukey's test for multiple comparisons of means

Table 5.2 Analysis of variance for forage dry matter (DM) yield and concentration of crude protein (CP), total digestible nutrients (TDN) and phosphorus (P) in forage harvested at increasing distances (Dist) away from the centre of the sampling grid from bale graze (BG) and control (CON) treatments (Trt) during the first (GS1) and second (GS2) growing seasons following bale grazing

ANOVA (*Pr > F)*	**DM yield**	**CP[a]**	**TDN**	**P**
Trt	<.0001	<.0001	<.0001	<.0001
Time	0.6258	<.0001	<.0001	<.0001
Dist	<.0001	<.0001	0.0366	<.0001
Trt x Time	<.0001	<.0001	<.0001	<.0001
Trt x Dist	<.0001	<.0001	0.0133	<.0001
Time x Dist	<.0001	0.0569	0.0001	0.2245
Trt x Time x Dist	<.0001	0.5358	0.0256	0.6287
CV (%)	50.0	5.75	0.59	61.6

For TDN, a three-way interaction between treatment, time and distance indicated a trend that was opposite to that for DM yield (Figure 5.3b). In GS1, the BG treatment at the centre of the sampling grid (0 m) had greater concentrations of TDN in forage harvested compared to the CON, and forage TDN concentration at the BG treatment at 0 m distance was greater than all other increasing distances from bale centre. In GS2, no differences in distance or treatment could be determined for forage TDN concentrations.

Forage P concentrations were influenced by two, two-way interactions, similar to those for CP (Tables 5.1 and 5.2). A treatment by time interaction indicated that in GS1, forage P concentrations in the BG treatment were significantly greater than those for the CON treatment, but forage P concentrations were similar for the two treatments in GS2. A treatment by distance interaction demonstrated that only in the BG treatment, forage P concentration was greatest at the bale centre (0 m) and decreased away from bale centre, and that at the centre of the sampling grid, BG had greater forage P concentrations compared to the CON.

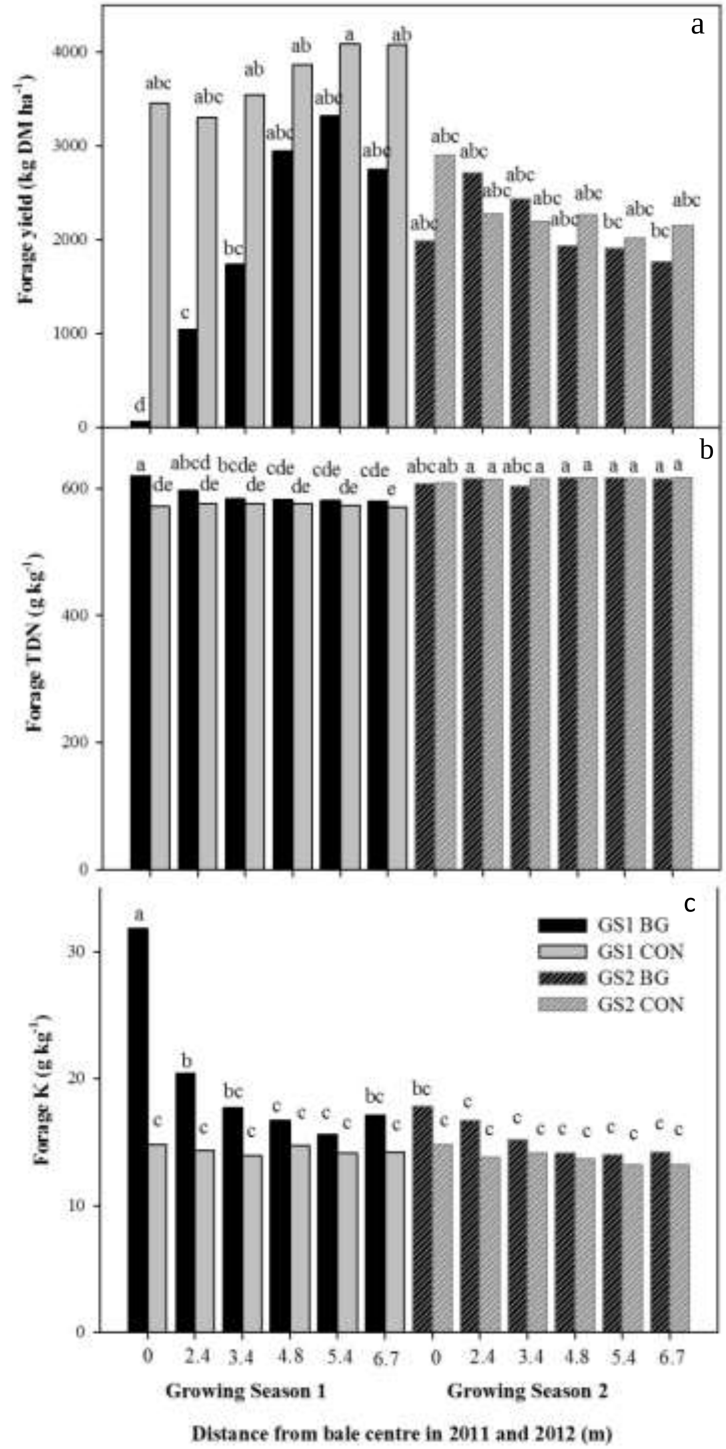

Figure 5.3 Means comparisons for the three-way interactions for (a) forage dry matter (DM) yield, and concentrations of forage (b) total digestible nutrients (TDN) and (c) potassium (K) at increasing distances away from the centre of the sampling grid for the bale graze (BG) and control (CON) treatments during the first (GS1) and second (GS2) growing seasons following bale grazing. Vertical bars denoted by the same lower case letter are not significantly different (*P* ≥ 0.05) by Tukey's test for multiple comparisons of means

The trend for forage K concentrations was similar to that for TDN (Tables 5.3 and 5.4). A three-way interaction between treatment, time and distance resulted in a greater forage K concentration in the BG treatment in GS1 at the centre of the sampling grid (0 m) when compared to all other BG and CON treatment distances in both GS1 and GS2 (Figure 5.3c). In GS2, there were no differences in forage K concentration between treatments or distances within treatments.

Concentrations of forage Ca were unaffected by distance from bale centre in the BG treatment, unlike that observed for the other forage quality measurements (Tables 5.3 and 5.4). However, a treatment by time interaction was evident as forage Ca concentration was greater in BG compared to the CON in GS1; whereas, both treatments had similar forage Ca concentrations in GS2.

Forage Mg concentrations were influenced by two, two-way interactions, similar to forage CP and P (Tables 5.3 and 5.4). Although the BG treatment had greater forage Mg concentrations compared to the CON in both GS1 and GS2, a treatment by time interaction was observed because the differences between treatments were larger in GS2 than in GS1. A treatment by distance interaction occurred because the BG treatment resulted in increased Mg concentration at the bale centre compared to all other BG distances and compared to all CON distances; conversely, there was no effect of distance in the CON treatment.

5.4.2 Grass Tetany Ratio

Overall, the grass tetany ratio was significantly greater in GS1 (1.4) than GS2 (0.8), with no differences between treatments and no treatment by time or treatment by distance interactions (Tables 5.3 and 5.4). Despite the large variability seen in forage DM yield and quality, forage grass tetany ratios were normally distributed without extreme outliers. However, the variability in the tetany ratios for individual forage samples appeared to be greater within the BG treatment than in the CON treatment. As a result, in GS1, a few individual forage samples from the BG treatment exceeded the maximum recommended threshold of 2.2 for risk of grass tetany, with ratios as large as 2.33 (Appendix Table 9.2), while the largest ratio for the BG treatment in GS2 was 1.92. None of the grass tetany ratios for individual samples of forage from the CON treatment exceeded the 2.2 threshold in either growing season.

5.4.3 Species Composition

Percent species composition analysis revealed a significant difference in the percent weed composition for the BG and CON treatments, with a higher percentage of weeds present in the BG plots compared to the CON plots (Table 5.5). As well, the analysis demonstrated a lower percentage of legumes in the BG plots compared to the CON plots. No significant differences were found in percent species composition as distance increased from centre of the sampling grid, making it questionable as to whether treatment affected weed and species composition, or whether it was an effect of the large spatial variability in both treatments, with some cells ranging from 0% legumes and weeds to as great as 80 and 54%, respectively (Appendix Table 9.3)

Table 5.3 Mean grass tetany ratios and concentrations of potassium (K), calcium (Ca) and magnesium (Mg) in forage harvested at increasing distances (Dist) from the centre of the sampling grid from bale graze (BG) and control (CON) plots during the first (GS1) and second (GS2) growing seasons following bale grazing

Factor	**Trt**	**Time**	**Dist**	**Grass Tetany Ratio**	**K**	**Ca**	**Mg**
			m		**g kg^{-1}**		
Trt	**BG**			1.12	17.2	4.36	2.37
	CON			1.12	14.1	3.48	1.98
Time		**GS1**		1.44a	16.6	3.10	1.77
		GS2		0.81b	14.5	5.36	2.65
Dist			**0**	1.15	18.8	4.83	2.52
			2.4	1.16	16.1	4.12	2.23
			3.4	1.12	15.2	3.91	2.10
			4.8	1.10	14.7	3.93	2.11
			5.4	1.11	14.2	3.78	2.01
			6.7	1.10	14.6	3.95	2.04
Trt x Time	**BG**	**GS1**		1.43	19.3	3.62b	2.04c
		GS2		0.83	15.3	5.26a	2.76a
	CON	**GS1**		1.44	14.3	2.65c	1.54d
		GS2		0.79	13.8	5.46a	2.54b
Trt x Dist	**BG**		**0**	1.20	23.8	5.59	3.14a
			2.4	1.20	18.5	4.42	2.51ab
			3.4	1.14	16.4	4.09	2.21bc
			4.8	1.10	15.4	4.02	2.21bc
			5.4	1.08	14.7	3.90	2.09bcd
			6.7	1.05	15.6	4.36	2.20bc
	CON		**0**	1.10	14.8	4.18	2.03bcd
			2.4	1.13	14.0	3.84	1.99cd
			3.4	1.10	14.0	3.74	1.99cd
			4.8	1.10	14.2	3.84	2.02cd
			5.4	1.13	13.7	3.66	1.93d
			6.7	1.14	13.7	3.58	1.90d
Year x Dist		**GS1**	**0**	1.47	21.7	3.92	2.23
			2.4	1.45	17.1	3.12	1.81
			3.4	1.41	15.7	2.98	1.70
			4.8	1.44	15.7	2.89	1.67
			5.4	1.42	14.8	2.80	1.60
			6.7	1.43	15.6	2.99	1.66
		GS2	**0**	0.82	16.3	5.96	2.86
			2.4	0.88	15.2	5.44	2.75
			3.4	0.83	14.7	5.14	2.60
			4.8	0.76	13.9	5.33	2.66
			5.4	0.80	13.6	5.10	2.51
			6.7	0.77	13.7	5.22	2.51

Means within the same column and factor group followed by the same lower case letter are not significantly different ($P \geq 0.05$) by Tukey’s test for multiple comparisons of means

Table 5.4 Analysis of variance for grass tetany ratios and concentrations of potassium (K), calcium (Ca) and magnesium (Mg) in forage harvested at increasing distances (Dist) from the centre of the sampling grid from bale graze (BG) and control (CON) plots during the first (GS1) and second (GS2) growing seasons following bale grazing

ANOVA (*Pr > F*)	**Grass Tetany Ratio**	**K**	**Ca**	**Mg**
Trt	0.6494	<.0001	<.0001	<.0001
Time	<.0001	<.0001	<.0001	<.0001
Dist	0.6695	<.0001	0.0473	<.0001
Trt x Time	0.5624	<.0001	<.0001	<.0001
Trt x Dist	0.4564	<.0001	0.4210	0.0019
Time x Dist	0.8529	0.1570	0.8731	0.4837
Trt x Time x Dist	0.9911	0.0403	0.6415	0.7310
CV (%)	41.6	6.72	30.5	40.2

5.4.4 Soil Nutrient Status

In the first fall after bale grazing (Fall1), the amount of residual soil NO_3-N in individual subsamples was extremely variable, ranging from 1.4 to 240 kg N ha^{-1} for the BG treatment and from 1.1 to 69.5 kg N ha^{-1} for the CON treatment (Appendix Table 9.4). In the second fall after bale grazing (Fall2), residual soil NO_3-N varied from 0.2 to 106 kg N ha^{-1} for the BG treatment and 1.5 to 18.3 kg N ha^{-1} for the CON treatment. A treatment by time interaction occurred because soil NO_3-N was greater for BG compared to the CON in Fall1, but similar for BG and CON treatments in Fall2 (Tables 5.6 and 5.7). A treatment by distance interaction occurred because soil residual NO_3-N was increased at the 0 and 2.4 m distances for the BG treatment relative to the CON treatment, while at the other distances, residual NO_3-N in the BG treatment was not significantly different from the CON treatment. A time by distance interaction occurred because in Fall1 residual soil NO_3-N was greater at the 0 and 2.4 m distances compared to all other distances, while in Fall2 no differences were measured at the various distances from the centre of the sampling grid.

Table 5.5 Mean percent species composition at increasing distances (Dist) from the centre of the sampling grid measured in the second growing season following bale grazing on the bale graze (BG) and control (CON) plots

Factor	**Trt**	**Dist**	**Legume species**	**Grass species**	**Weed species**	**Other species**
		m		%		
Trt	**BG**		14b	72	13a	0
	CON		23a	69	7b	0
Dist		**0**	26	60	11	0
		2.4	18	71	10	0.01
		3.4	15	75	9	0
		4.8	22	70	9	0
		5.4	16	73	10	0.01
		6.7	15	75	9	0
Trt x Dist	**BG**	**0**	30	54	16	0
		2.4	14	72	14	0
		3.4	11	77	12	0
		4.8	12	76	12	0
		5.4	11	77	11	0.02
		6.7	9	80	11	0
	CON	**0**	23	66	6	0
		2.4	23	71	6	0
		3.4	19	73	7	0.01
		4.8	31	63	5	0
		5.4	22	69	9	0
		6.7	21	71	8	0
ANOVA				*Pr > F*		
Trt			0.0066	0.3115	<.0001	0.6865
Distance			0.4244	0.3687	0.9465	0.5221
Trt x Distance			0.5139	0.5857	0.3146	0.5937
CV (%)			117	28	78	650

Means within the same column followed by the same lower case letter are not significantly different ($P \geq 0.05$) by Tukey's test for multiple comparisons of means

Variability in soil Olsen P among subsamples in Fall1 was similar between treatments, with samples ranging from 2.15 to 33.7 kg P ha^{-1} for the BG treatment and 4.17 to 29.3 kg P ha^{-1} for the CON treatment (Appendix Table 9.4). However, in Fall2, soil Olsen P variability was greater, with a range of 2.51 to 55.2 kg P ha^{-1} for the BG treatment, compared to a range of 2.51 to 20.7 kg P ha^{-1} for the CON treatment. A treatment by time interaction resulted from greater amounts of Olsen P for the BG treatment than for the control in Fall2 (Tables 5.6 and 5.7). This interaction appeared to occur due to a decrease in Olsen P for the CON treatment in Fall2, compared to Fall1; whereas, the Olsen P in the BG treatment remained similar in both years. A treatment by distance interaction demonstrated that the BG treatment had greater Olsen P at 0 and 2.4 m away from the centre of the sampling grid, compared to further distances away; this pattern was not present for the CON treatment.

Variability in soil exchangeable K was consistently greater for the BG treatment compared to the CON, but was very similar between years for both treatments (Appendix Table 9.4). The ANOVA indicated a treatment by distance interaction, because the amount of exchangeable K at the centre of the BG treatment was greater than further away and was also greater than for any distance from the centre of the sampling grid in the CON treatment.

The amounts of exchangeable Ca and Mg in soil were significantly greater for the CON treatment compared to the BG treatment (Tables 5.6 and 5.7). Although the ANOVA identified a significant overall effect of sample distance from the centre of sampling grid for exchangeable Ca in soil, significant differences between the mean values were not observed.

Table 5.6 Geometric means for soil residual NO_3-N (0-60 cm), Olsen P, and exchangeable (exch.) K, Ca, and Mg (0-15 cm) at increasing distances (Dist) away from the centre of the sampling grid for the bale graze (BG) and control (CON) treatments (Trt) during the first fall (Fall1) and second fall (Fall2) after bale grazing

Factor	**Trt**	**Time**	**Dist**	**NO_3-N**	**Olsen P**	**Exch. K**	**Exch. Ca**	**Exch. Mg**
			M	**kg ha^{-1}**				
Trt	**BG**			8.05	10.5	979	9501b	3537b
	CON			4.19	8.64	1004	10060a	3941a
Time		**Fall1**		7.04	9.81	1009	9782	3756
		Fall2		4.79	9.22	974	9771	3710
Dist			**0**	13.7	15.2	1127	9502a	3689
			2.4	8.00	11.6	1014	9704a	3748
			3.4	4.57	8.86	962	9700a	3735
			4.8	3.87	8.56	952	9848a	3748
			5.4	4.33	7.58	950	9959a	3733
			6.7	4.58	7.34	955	9955a	3746
Trt x Time	**BG**	**Fall1**		12.0a	10.1a	990	9575	3563
		Fall2		5.42b	10.8a	968	9429	3510
	CON	**Fall1**		4.15b	9.48a	1028	9994	3960
		Fall2		4.22b	7.87b	981	10125	3922
Trt x Dist	**BG**		**0**	53.7a	24.2a	1254a	9157	3460
			2.4	15.1b	16.3a	1046b	9476	3574
			3.4	5.35c	10.4b	940cd	9433	3506
			4.8	3.38c	7.61bc	897d	9517	3591
			5.4	3.96c	6.51c	886d	9633	3525
			6.7	4.69c	6.44c	898d	9806	3562
	CON		**0**	3.47c	9.50bc	1013bcd	9861	3932
			2.4	4.24c	8.17bc	983bcd	9938	3930
			3.4	3.91c	7.53bc	984bcd	9974	3980
			4.8	4.42c	9.63b	1012bcd	10189	3912
			5.4	4.74c	8.83bc	1018bc	10296	3952
			6.7	4.47c	8.37bc	1016bc	10105	3939
Time x Dist		**Fall1**	**0**	23.0a	15.5	1170	9552	3725
			2.4	11.9a	11.9	1040	9791	3795
			3.4	5.68b	9.51	977	9697	3747
			4.8	3.93b	8.75	970	9776	3782
			5.4	4.76b	7.94	957	9953	3729
			6.7	4.19b	7.29	956	9929	3759
		Fall2	**0**	8.11ab	14.8	1086	9452	3653
			2.4	5.37b	11.2	988	9618	3702
			3.4	3.68b	8.25	947	9703	3725
			4.8	3.81b	8.37	935	9919	3714
			5.4	3.95b	7.24	943	9964	3736
			6.7	5.00b	7.40	954	9982	3733

Means within the same column and factor group followed by the same lower case letter are not significantly different ($P \geq 0.05$) by Tukey's test for multiple comparisons of means

Table 5.7 Analysis of variance for soil residual NO_3-N (0-60 cm), Olsen P, and exchangeable (exch.) K, Ca, and Mg (0-15 cm) at increasing distances (Dist) away from the centre of the sampling grid for the bale graze (BG) and control (CON) treatments (Trt) during the first fall (Fall1) and second fall (Fall2) after bale grazing

ANOVA *(Pr > F)*	**NO_3-N**	**Olsen P**	**Exch. K**	**Exch. Ca**	**Exch. Mg**
Trt	<.0001	<.0001	0.0681	<.0001	<.0001
Time	<.0001	0.2047	0.0116	0.9036	0.3738
Dist	<.0001	0.0103	<.0001	0.0362	0.9969
Trt x Time	<.0001	<.0001	0.3922	0.1304	0.8385
Trt x Dist	<.0001	<.0001	<.0001	0.6675	0.9038
Time x Dist	0.0003	0.9194	0.7499	0.9044	0.9793
Trt x Time x Distance	0.9701	0.1411	0.7649	0.9752	0.9788
CV (%)	56.1	22.8	2.02	0.98	4.19

5.4.5 Waste Hay and Feces Distribution

Immediately following bale grazing, a substantial amount of waste hay was located primarily at bale centre, ranging from 35 to 3 t DM ha^{-1} as distance increased from 0 m to 4.8 m (Appendix Figure 9.1). Mass of waste hay decreased as distance increased from bale centre to the 2.4, 3.4 and 4.8 m distances, with negligible amounts deposited at the 5.4 and 6.7 m distances. Feces distribution did not follow the same pattern as that observed for waste hay. The largest masses of feces were consistently located at the centre of the BG plots (e.g., 32 t DM ha^{-1} at 0 m); however, substantial amounts of feces were also measured in all cells, ranging from 3 to 32 t DM ha^{-1}.

In Fall2, waste feed and feces still covered 100% of surface area of cells in the centre (0 m) of the BG plots as well as the majority of the surface area of cells 2.4 m away from centre, and approximately 50% of cells 3.4 m away (Figure 5.4 and Appendix Figure 9.2). Depths of waste feed and feces ranged from 0.040 m at 3.4 m distances to 0.064 m at bale centre (Figure 5.4).

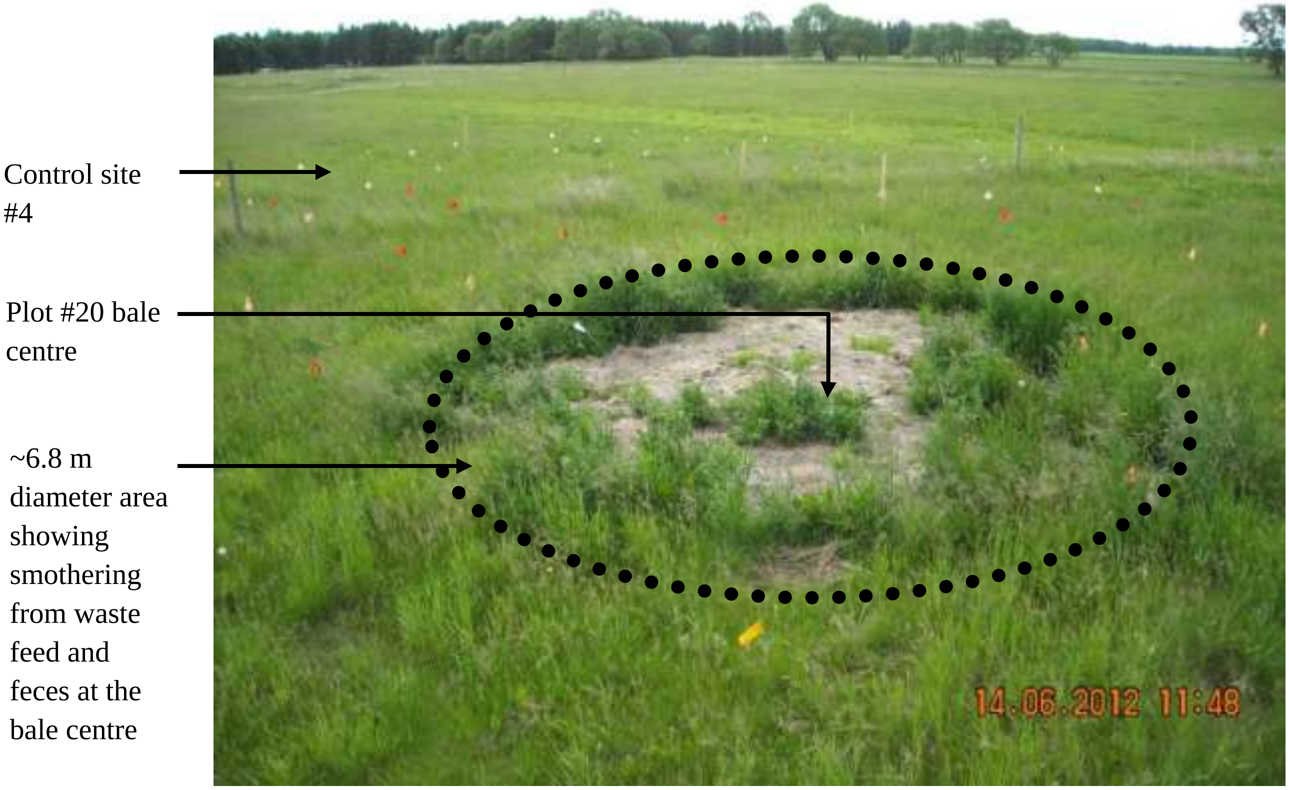

Figure 5.4 Forage growth and waste feed in the bale graze treatment (during GS2, the second growing season after bale grazing) and ungrazed control treatment located at the Glenlea Research Station. Photo taken 14 June 2012

5.4.6 Spearman Correlation Analysis

5.4.6.1 Correlations for the BG Treatment

As indicated in Table 5.8, Spearman correlation analysis revealed positive relationships in the BG treatment between GS1 forage DM yield and measurements of exchangeable K, Ca and Mg in soil in the subsequent fall (Fall1). Residual soil NO_3-N in Fall1 was also positively related to Fall1 soil Olsen P and exchangeable K, Ca and Mg. Soil Olsen P in Fall1 was positively related to Fall1 exchangeable K; exchangeable K was positively related to exchangeable Ca and Mg and exchangeable Ca and Mg were positively related to each other.

Forage DM yield in GS2 was positively related to Fall2 residual soil NO_3-N and negatively related to Fall2 exchangeable Ca. Residual soil NO_3-N in Fall2 was negatively related to Fall2 soil Olsen P and positively related to exchangeable K and Mg. Soil Olsen P in Fall2 was negatively related to Fall2 exchangeable soil K. Exchangeable soil K, Mg, and Ca in Fall2 were all positively related to each other. Depth of waste feed measured in Fall2 was positively related to Fall2 exchangeable soil K.

Forage DM yield in GS2 was positively related to Fall1 residual soil NO_3-N, Olsen P, and exchangeable K. Residual soil NO_3-N and exchangeable K in Fall2 were positively related to all Fall1 residual nutrient measurements. Soil Olsen P in Fall2 was negatively related to Fall1 forage DM yield as well as Fall1 residual soil NO_3-N. Exchangeable soil Ca and Mg in Fall2 were positively related to GS1 DM yield and Fall1 residual soil exchangeable K, Ca and Mg. Depth of waste feed measured in Fall2 was negatively related to GS1 forage DM yield and positively related to Fall1 residual soil NO_3-N and Olsen P.

5.4.6.2 Correlations for the Control Treatment

Spearman correlation analysis revealed positive relationships in the CON treatment between GS1 forage DM yield and residual soil NO_3-N measured in the subsequent fall (Fall1; Table 5.9). In Fall1, positive correlations also occurred between exchangeable K and exchangeable Ca and Mg, and between exchangeable Ca and Mg.

Negative relationships were found between GS2 forage DM yield and the subsequent fall (Fall2) exchangeable Ca and Mg, and between Fall2 Olsen P and exchangeable Mg. Positive relationships were found between Fall2 residual soil NO_3-N and Olsen P, exchangeable K and Ca; between Olsen P and exchangeable K; between exchangeable K and exchangeable Ca and Mg; and between exchangeable Ca and Mg.

Table 5.8 Spearman correlation analysis of forage dry matter (DM) yield, fall residual soil nutrient status and depth of waste feed measured on the bale graze (BG) plots. Significant relationships ($P < 0.05$) indicated by * (n = 100 for all parameters except waste feed where n=50)

BG Spearman Correlation		GS1 Forage	Fall1 Residaul Soil Nutrients					GS2 Forage	Fall2 Residaul Soil Nutrients					Fall2 Waste Feed
		DM Yield	NO_3-N	Olsen P	Exch. K	Exch. Ca	Exch. Mg	DM Yield	NO_3-N	Olsen P	Exch. K	Exch. Ca	Exch. Mg	Depth
GS1 Forage	DM Yield	1												
Fall1 Residaul Soil Nutrients	NO_3-N	-0.15	1											
	Olsen P	-0.11	**0.36***	1										
	Exch. K	**0.30***	**0.44***	**0.45***	1									
	Exch. Ca	**0.48***	**0.21***	-0.03	**0.68***	1								
	Exch. Mg	**0.56***	**0.20***	-0.03	**0.72***	**0.78***	1							
GS2 Forage	DM Yield	0.04	**0.21***	**0.24***	**0.21***	0.1	0.14	1						
Fall2 Residaul Soil Nutrients	NO_3-N	0.17	**0.48***	**0.29***	**0.61***	**0.39***	**0.48***	**0.21***	1					
	Olsen P	**-0.23***	**-0.22***	-0.14	-0.19	-0.16	-0.13	-0.02	**-0.38***	1				
	Exch. K	0.1	**0.34***	**0.44***	**0.52***	**0.24***	**0.29***	0.06	**0.60***	**-0.20***	1			
	Exch. Ca	**0.39***	-0.02	-0.13	**0.31***	**0.60***	**0.47***	**-0.21***	0.22	-0.15	**0.29***	1		
	Exch. Mg	**0.62***	0.12	0.13	**0.56***	**0.63***	**0.82***	0.04	**0.43***	-0.14	**0.35***	**0.55***	1	
Fall2 Waste Feed	Depth	**-0.38***	0.47*	**0.63***	0.24	-0.12	-0.06	0.26	0.27	-0.25	**0.48***	-0.2	-0.03	1

Table 5.9 Spearman correlation analysis of forage dry matter (DM) yield and fall residual soil nutrient status for the unamended control plots (CON). Significant relationships ($P < 0.05$) indicated by * ($n = 100$ for all parameters)

Control Spearman Correlation		**GS1 Forage**	**Fall1 Residaul Soil Nutrients**					**GS2 Forage**	**Fall2 Residaul Soil Nutrients**				
		DM Yield	**NO_3-N**	**Olsen P**	**Exch. K**	**Exch. Ca**	**Exch. Mg**	**DM Yield**	**NO_3-N**	**Olsen P**	**Exch. K**	**Exch. Ca**	**Exch. Mg**
GS1 Forage	**DM Yield**	1											
Fall1 Residaul Soil Nutrients	**NO_3-N**	**0.28***	1										
	Olsen P	-0.06	-0.02	1									
	Exch. K	0.01	-0.05	-0.06	1								
	Exch. Ca	0.05	0.02	0.17	**0.23***	1							
	Exch. Mg	-0.06	0	0.06	**0.22***	**0.30***	1						
GS2 Forage	**DM Yield**	**-0.22***	**-0.31***	-0.08	0.01	**-0.32***	0.07	1					
Fall2 Residaul Soil Nutrients	**NO_3-N**	**0.52***	**0.20***	**-0.22***	0.17	0.19	0.12	0.01	1				
	Olsen P	**0.29***	-0.13	-0.12	**0.37***	0.04	-0.08	0.27	**0.28***	1			
	Exch. K	0.16	**0.34***	-0.08	**0.22***	**0.26***	**0.25***	-0.12	**0.31***	0.27*	1		
	Exch. Ca	0.1	**0.28***	0.06	0.06	**0.52***	0.07	**-0.20***	**0.22***	0.01	**0.36***	1	
	Exch. Mg	-0.03	**0.41***	0.01	-0.1	**0.21***	**0.5***	**-0.23***	-0.01	**-0.48***	**0.32***	**0.34***	1

Forage DM yield in GS2 was negatively related to GS1 DM yield, as well as the previous fall (Fall1) measurements of residual soil NO_3-N and soil exchangeable Ca. Residual soil NO_3-N in Fall2 was positively related to GS1 DM yield and Fall1 residual soil NO_3-N, and negatively related to fall1 Olsen P. Olsen P in Fall2 was positively related to Fall1 forage DM yield and Fall1 exchangeable K. Exchangeable soil K in Fall2 was positively related to Fall1 residual soil NO_3-N, exchangeable soil K, Ca and Mg. Exchangeable soil Ca in Fall2 was positively related to Fall1 residual soil NO_3-N and exchangeable Ca. Exchangeable soil Mg in Fall2 was positively related to Fall1 residual soil residual NO_3-N and exchangeable Ca and Mg.

5.5 Discussion

5.5.1 Forage Production, Composition and Quality

The lack of increased forage growth after bale grazing, particularly the depression of DM yield near the bale centre in GS1, was unexpected and caused us to reject our hypothesis statement. This lack of increased forage growth in the BG compared to the CON treatment occurred despite increased residual soil NO_3-N measured in Fall1 and soil Olsen-P in Fall2. These findings are contrary to those reported by Jungnitsch et al. (2011) where bale grazing in SK resulted in a 3.3 to 4.7 fold increase in forage DM yield compared to a control. The lack of a positive forage yield response in our study may be attributed to the waste feed and feces measured at bale centre, which did not decompose quickly and appeared to smother the forage. The significant ($P < 0.05$) negative relationship between forage DM yield in GS1 and depth of waste feed as measured in Fall2 supports this theory. Smothering of forage by waste feed may be partially responsible for the increased residual soil nutrient status at bale centre as well, supported by the significant ($P < 0.05$) positive relationship between depth of waste feed and Fall1 residual soil NO_3-N and Olsen P. As these areas had little forage growth, plants were not taking up the additional available N and P supplied over the growing season at bale centre, leaving excess N and P remaining at the soil surface measured as residual soil NO_3-N and Olsen P in the fall.

It does not appear that the difference in feed waste between our study and the study by Jungnitsch et al. (2011) contributed to the difference in forage yield. Jungnitsch (2008) reported depth of waste hay as 5 cm thick, with areas of waste straw as thick as 20 cm. In the first year following bale grazing, Jungnitsch also reported areas of no forage growth in the bale grazed field in patches around bale locations. Hay and straw imported to their site was reported as 32.3 t DM ha^{-1} to the 1 ha site (10 x 12 m bale spacing) with average cow forage intake (n=16) of 12.3 kg d^{-1} over 130 d, resulting in an estimated waste feed of 21%; a value similar to that observed in our study. Jungnitsch (2008) also reported the mass of waste feed as 16 t ha^{-1} on average following bale grazing. Total N in the surface residue for Jungnitsch's BG site was reported as 180 kg ha^{-1} on average, ranging from 1.8 to 1196 kg ha^{-1}, suggesting a large amount of imported N was left as waste feed.

Interestingly, a large portion of the feces were located at bale centre in our study. We had assumed that feces would primarily be distributed around the outer portions of each BG plot, as cows eat with their heads to the middle of the plot and excrete feces from the hind end. However, the cows appeared to have spent some time congregating at the bale centre, either foraging for feed or bedding down in waste feed, once the bale was partially consumed.

Another factor that may have influenced forage smothering by waste feed was precipitation and soil moisture. Precipitation at the Glenlea Research Station was 463 mm in the first year following bale grazing, with a significant amount of the rainfall in the fall and spring preceeding GS1. In contrast, rainfall near Lanigan, SK, Canada, where the Jungnitsch et al (2011) trial was conducted, was only 260 mm in the first year following bale grazing. This difference in precipitation between the study by Jungnitsch et al. (2011) and our study resulted in relatively greater yields of forage for the CON treatment in our study. The DM yield for the CON treatment in our study was three times greater than the control treatment yield in the study by Jungnitsch et al. (2011), despite the fact that those authors reported 0-15 cm soil NO_3-N + NH_4-N concentrations in the control plots that were almost five times greater than in our study. Interestingly, for the CON treatment, Fall1 residual NO_3-N was negatively correlated with GS2 forage growth, suggesting that forage growth in CON was not limited by soil NO_3-N status, but possibly by other factors. Since increased organic matter on the soil surface can increase moisture holding capacity of the soil and decrease evaporation, the presence of waste feed and feces at the SK site may have conserved moisture, contributing to increased forage DM yields following bale grazing in that dry region of the Prairies. Conversely, the relatively large amount of precipitation at our study site may have resulted in compaction of the waste feed and feces, limiting light and air penetration, leading to poor growth of forage. If excessive accumulation of waste feed was the cause of decreased forage yields, we hypothesize that mechanical dispersal of the waste feed packs (i.e., harrowing) in the spring may have improved short-term forage yields in our study by breaking up and redistributing the waste feed and manure pack to reduce smothering of forage and spread imported nutrients more uniformly. Providing a separate, centralized area for cattle to bed down in and forcing cattle to ingest more feed at the bale locations, may have improved forage growth in this study, as well, although this practice may have compromised ad libitum forage intake for cows. Both of these management strategies, however, would increase the cost of overwintering the cows.

Decreased forage DM yield at the bale centre also affected forage quality. Following a spatial pattern that was opposite to that for DM yield, forage quality in the BG treatments increased at bale centre in GS1. However, since forage DM yield at bale centre was decreased by 90% in GS1, the modest increase in forage quality for the BG treatment at bale centre was not sufficient to compensate for the large loss in yield.

Increased concentrations of K in forage can raise concerns regarding grass tetany. Grass tetany can be a serious health risk to cattle and is caused by an imbalance of Ca, Mg, and K in cattle diets. Gagnon et al. (2003) found that variability in soil exchangeable K was one of the key risk factors for forage mineral imbalances that cause grass tetany. As cattle manure often contains high concentrations of K, and bale grazing can concentrate nutrients in specific “hot spot” locations in the field, we examined grass tetany ratio in both treatments. Although grass tetany ratio was increased in GS1 compared to GS2, grass tetany ratios were similar between treatments and mean grass tetany ratios for both treatments were below the 2.2 mEq kg^{-1} threshold for cattle (Kemp and t’Hart 1957).

Species composition analysis revealed a negative impact of BG on forage species composition in GS2, with increased weed species and decreased legume species. The study site in Jungnitsch et al. (2011) was dominated by Russian wildrye grass and did not have a significant portion of legumes in the stand, which may have enabled a positive effect of waste feed on forage productivity at that study site. In our study, legume species and some grass species, particularly grass species with bunch-type root systems, may not have been as resilient as some weedy species and rhyzomitus grass species to the change in surface residue cover

(Klein and Peardon 2008). Therefore, the change in species composition at our site may have been due to smothering of portions of the site by waste feed. As well, hay bales may have imported seeds from some weed species, increasing the percentage of weed species at the site over time. Interestingly, the change in species composition did not seem to decrease forage quality.

5.5.2 Residual Nutrients in Soil

Although there were some relatively large differences in soil residual nutrients between the BG and CON treatments, the absolute values of overall plot means for soil residual NO_3-N and soil Olsen P remained relatively low for both treatments. For example, the overall mean soil residual NO_3-N in the BG treatment was three times greater than in the CON treatment in Fall1. However, the overall mean NO_3-N concentration in the BG treatment that year was considered very low (12 kg ha^{-1} in the top 60 cm), in terms of that needed for agronomic production and also very low compared to provincial NO_3-N regulations to protect water quality, where the upper limit on this class of soil is 157 kg ha^{-1} residual NO_3-N (0-60 cm). In fact, only two soil subsamples exceed Manitoba provincial regulation thresholds for Class 1 soils. Therefore, the differences in overall plot mean soil N and P status between the treatments were considered agronomically and environmentally small despite the statistically significant differences.

Nevertheless, bale grazing resulted in localized accumulations of soil nutrients where soil residual NO_3-N, Olsen P and soil exchangeable K increased at distances within 2.4 m from the bale centre, resulting in “hot-spots” that were approximately 4.8 m in diameter (Figure 5.4). The BG treatment at bale centre (0 m) had 15.5 times more NO_3-N than in the same location in the CON treatment, and 2.5 times more Olsen P. In a Saskatchewan study, Jungnitsch et al. (2011)

found similar “hot-spots” of soil nutrients in BG fields with concentrations as high as 600 kg NO_3-N + NH_4-N ha^{-1} and 240 kg P ha^{-1} (0-15 cm; Modified Kelowna) at bale placement locations measured in the spring. In another Saskatchewan study, Kelln et al. (2012a) measured concentrations of soil NO_3-N in spring that varied from 35.3 to 71.8 kg ha^{-1} in the top 15 cm, averaging 56 kg ha^{-1}. Soil test P (0-15 cm; Kelowna method) varied from 151 to 215 kg ha^{-1}, with an average of 187 kg ha^{-1}. In our study, the highest nitrate-nitrogen value was 240 kg NO_3-N ha^{-1}, which is intermediate, to the maximum values measured in the Saskatchewan studies. After accounting for the relatively small difference in analytical methods for soil test P, our maximum soil test P values were much smaller than those measured in the Saskatchewan studies. These differences suggest that bale grazing did not have as great an impact on the nutrient status of clay soils in the sub-humid climate as on loam soils in the semi-arid climate. Additional studies are needed to determine the relationships between soil type, soil moisture, precipitation and impact of winter grazing on forage fields.

The soil sampling strategy used for these highly variable soil status fields is another consideration when comparing results across studies. The studies by Jungnitsch et al. (2011) and Kelln et al. (2012a) used a 36-point sampling grid with samples taken at 25-m intervals over the entire field site on loam soils in a semi-arid climate. These soil sampling strategies were much coarser than the 100-point sampling grid over 12 x 12 m area in our study. The current study found that the “hot-spot” areas were a small percentage of the paddock, estimated to be within 2.4 m from bale centre or no more than 20% of the bale grazed area. We did not see an impact from BG on soil nutrient status for nearly 80% of the field site when compared to the Control. Therefore it is important that the sampling strategy used does not overestimate field mean because of selective sampling near the hot spots.

An interesting observation of the study was the large variability in the soil nutrient status and forage yield within the CON treatment plots. This observation was similar to that of Daniels et al. (2001), who found that pastures with low soil-P status required more soil subsamples to determine field average nutrient status compared to pastures with high soil P concentrations. This background variability made it difficult to determine statistically if the BG treatment significantly altered the overall soil nutrient status and yield of the forage plots. Similarly, the large variability in nutrients within the CON plots made it difficult to detect a clear spatial pattern for forage yield or forage quality within BG plots. In addition, soil and forage data in the CON treatment were not normally distributed. This large background variability, particularly for soil NO_3-N, suggests that soil sampling using a traditional zig-zag pattern sampling protocol with 15 to 20 subsamples, may not accurately measure the true soil nutrient status of a field and may lead to recommendation of inappropriate nutrient management practices.

The mean soil nutrient status for the BG treatment was also relatively low given the mass of nutrient imported to the paddock as feed. According to Donohoe et al. (2018a), each of the 28 bales weighed 511 kg, had 85% DM and 8.8% CP; therefore, 171 kg of N was imported to each paddock as hay at the start of the trial. This large mass of nutrient import to the BG treatment in feed hay and DDGS resulted in little to no overall mean increases in forage yield, forage quality or soil residual NO_3-N or Olsen P. A small portion of this additional available N and P may have been lost to the environment via gaseous losses of N and runoff losses of N and P in snowmelt. Recent studies have found 3 to 10% of total N and 4 to 10% of total P imported to a bale graze field (with no additional supplement fed) were lost in runoff water in a field with significant slope (Chen et al. 2017). The majority of nutrients imported to our overwintering site were likely in stable forms that were not readily converted into plant available forms or measured in conventional soil fertility analyses. Therefore, longer term studies may be needed to evaluate the benefits of bale grazing as it is possible that the large mass of nutrients imported will generate benefits over the long-term. The correlation analysis demonstrated that GS2 DM yield from the BG treatment was positively related to Fall1 residual soil NO_3-N, Olsen P and extractable K, which may suggest that long-term benefits (past the initial year following bale grazing) may occur. Other studies have shown the long-term benefits of manure application to forage land (Smoliak et al. 1965, Smika et al. 1960; Lardner 2003). Smoliak et al. (1965) also observed reduced yields in the first year following straw application to forage, but increased yields in years 4 to 8 years following application.

5.6 Conclusions

The results of this bale grazing study were substantially different from recent studies in Saskatchewan, suggesting that benefits of bale grazing may vary depending on location, climate and soil type. The large mass of waste feed and feces remaining after the second growing season, with depths up to 0.06 m, following bale grazing limited the potential benefits of increased soil nutrient profile created following bale grazing, by preventing light penetration. Although these "hot-spots" of increased soil NO_3-N and Olsen P increased forage quality parameters at the bale centre locations, the modest benefits in quality did not compensate for the large depression of forage growth. Locations on the Canadian Prairies with inherently high soil productivity and a sub-humid climate may require strategies such as harrowing waste feed and feces packs reduce the risk of smothering the forage. Whereas Jungnitsch et al. (2011) measured substantial and immediate benefits of bale grazing from increased nutrient import and, potentially, soil moisture conservation, the generation of benefits from bale grazing at our site may require more than the two-year time period for our study. Determining nutrient imports, exports and balances for bale grazing systems would be an asset for defining the long term benefits of bale grazing. Developing a system for sampling soil fertility at bale grazed sites is also an important issue for producers and future studies, given the large natural variability in plant and soil parameters of forage fields, with and without a history of bale-grazing.

5.7 References

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6. MANUSCRIPT 3

A SOIL SAMPLING STRATEGY FOR DETERMINING SOIL RESIDUAL NITRATE AND OLSEN PHOSPHORUS IN A FORAGE FIELD AFTER WINTER BALE GRAZING

6.1 Abstract

Feeding beef cattle during the winter months by grazing bales placed on forage fields creates “hot-spots” or areas of high concentrations of soil phosphorus (P) and nitrogen (N). This variability creates a substantial challenge for accurately measuring soil nutrient concentrations following bale grazing in these forage fields; measurements which are important from both an agronomic and environmental perspective. The objective of this study was to determine a practical soil sampling protocol to accurately assess residual soil Olsen P and nitrate-nitrogen (NO_3-N) in the first two years following bale grazing on a forage field. The results demonstrated that random sampling a bale-grazed forage field at the end of the first growing season after bale grazing could lead to large errors in estimating field residual soil NO_3-N, even when 100 subsamples of soil were collected and composited where mean soil NO_3-N varied from 8 to 25 kg N ha^{-1} in the first year following bale grazing. Separating subsamples collected from areas affected and unaffected by waste feed residue decreased variability and accurately identified hot-spots, but did not provide an overall field mean or substantially decrease the number of subsamples required. The most efficient and effective method for assessing soil residual N and P in the bale-grazed field was to use area-weighted mean N and P values from the subsamples collected from areas affected and unaffected by waste feed. Using a 4:1 ratio for the number of soil subsamples collected from the waste feed affected areas compared to the unaffected areas

reduced the number of recommended subsamples to a total of 40, with 32 from waste feed affected and 8 from unaffected areas of the bale-grazed field, and reduced field mean variability to a range between 15 and 24 kg N ha^{-1} and 7 and 13 kg P ha^{-1}.

6.2 Introduction

Bale grazing is a popular strategy for feeding beef cows overwinter on the Canadian Prairies (Sheppard et al. 2015) and can be described as a practice where large round bales of hay are imported onto a field and electric fencing is used to manage access to bales systematically during the winter months. When compared to traditional drylot overwintering and subsequent mechanical spreading of manure onto fields, bale grazing reduces labour and overwintering costs for beef cow producers and can increase soil fertility, with increased concentrations of soil nitrate-nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), and phosphorus (P) (Jungnitsch et al. 2011; Kelln et al. 2012a; Kelln et al. 2012b). Jungnitsch et al. (2011) found mean soil NO_3-N + NH_4-N in the 0 to 15 cm depth to be more than three times greater on a forage field in the spring following grazing than in an adjacent treatment spread with drylot manure.

Donohoe (2018b) found increased concentrations of nutrients in soil following bale grazing, concentrated in circular areas approximately 5 m in diameter and centred at bale placement locations. These same areas could be visually identified as having significant waste feed remaining on the soil surface in years one and two following bale grazing. These “hot-spots” accounted for a relatively small area of the field, approximately 20%; however, in the first year following bale grazing, these areas had 2.5 times greater soil Olsen P and 15 times greater residual soil NO_3-N, compared to an unamended control area (Donohoe 2018b). As well, the area unaffected by waste feed in the bale-grazed field (approximately 80% of the bale-grazed field site) had no effect from bale grazing on soil nutrient status when compared to an unamended control (Donohoe 2018b). These conclusions were determined by collecting 100 soil subsamples from a 12 x 12 m grid centred on each of four bale placement locations and their adjacent control sites, for a total of 400 soil subsamples per treatment.

Nutrient status of bale-grazed fields is important from an agronomic perspective for producers, but also from an environmental perspective. In the province of MB, legislation designed to protect surface water quality sets a field mean limit of 157 kg ha^{-1} residual soil NO_3-N on fields with Water Quality Management Zone 1 soils (i.e., highly productive soil types), with much lower limits for NO_3-N in poorer quality soils. As well, manure application rates are governed by soil Olsen P status, with no manure application permitted on fields with soil Olsen P status greater than 180 ppm. Accurate determination of nutrient status in fields following bale grazing is therefore important. However, due to the large variability in soil nutrient status following bale grazing, traditional random sampling procedures may not be appropriate (Donohoe 2018b). Alternatively, collection of 400 soil subsamples, as used in our research protocol, is impractical for a producer or an agronomist.

The objective of this study was to determine a practical soil sampling protocol to accurately assess forage residual soil NO_3-N and Olsen P in the first two years following bale grazing. Ideally, the protocol should provide accurate measurements of the overall mean concentrations of soil test N and P for the field, as well as accurate measurements of the "hot-spots" where nutrients are highly concentrated, but minimize the overall number of subsamples required.

6.3 Materials and Methods

Study location, bale grazing trial design and methodology, and soil sampling methodology are described in Donohoe (2018a and 2018b). In brief, beef cows grazed round bales of hay over winter on a tame forage field located at the University of Manitoba's National Centre for Livestock and the Environment located at the Glenlea Research Station. Following bale grazing, two individual bale-grazed (BG) plots, directly adjacent to a control (CON) paddock, were selected for detailed soil fertility sampling. Each 12 x 12 m bale feeding plot was divided into a 5 cell x 5 cell sampling grid with the bale located in the centre of the plot, and with each of the 25 cells measuring 2.4 x 2.4 m. An equivalent two-plot, 25-cell grid system was established in the CON paddock to create a non-randomized complete block design. The distance between the outer edges of the BG plots and their equivalent CON plots was 3 m.

Soil samples were collected from both plots in each BG and CON paddock at the end of the first (Fall1; 24-28 October 2011) and second growing season (Fall2; 5-9 November 2012) to determine residual soil nutrient status after winter bale grazing. Samples were collected at depths of 0-15 and 15-60 cm using a Giddings soil coring machine. In both fall collection periods, four soil cores per cell were collected from every cell in both BG and CON plots, resulting in 100 soil subsamples per plot at each depth. Samples were air dried and ground to pass through a 2-mm mesh sieve prior to analysis. Each of the four cores per cell collected at each depth was analyzed individually, for a total of 200 subsample analyses for each treatment at each depth.

Olsen P was measured in the 0-15 cm subsamples by shaking 1.0 g soil with 20 mL of 0.5 M sodium bicarbonate ($NaHCO_3$; buffered at a pH of 8.5) in the presence of 0.25 g of P-free charcoal for 30-min, filtering the extract through Whatman No. 40 filter paper and measuring P in the extract by ascorbic acid molybdate colorimetry (Olsen et al. 1954; Olsen and Sommers 1982). Soil NO_3-N was determined in the 0-15 cm and 15-60 cm subsamples by extraction with 2 M potassium chloride (KCl; 5:1 extractant: soil) and NO_3-N measured by automated cadmium reduction colorimetry (Maynard et al. 2008), using a Technicon Autoanalyzer II system (Pulse Instruments, Mequon, WI). Analyses were converted to kg ha^{-1} using field mean bulk density.

6.3.1 Calculations and Statistical Analysis

Three different sampling methods were evaluated for their ability to estimate field mean soil nutrient status for Olsen P and NO_3-N in bale-grazed areas using the fewest number of soil subsamples to achieve a CV of less than 5% or 10%: 1) randomly sampling the plots, 2) dividing the BG plots into two visually distinct areas affected or unaffected by waste feed and randomly sampling and reporting on the two areas separately, and 3), using area-weighted mean N and P values from different numbers of subsamples collected from areas of the BG plots that were affected and unaffected by waste feed. Although a 5% CV is the common statistically acceptable level of variation in sample analysis, the highly variable nature of soil nutrients in field analyses led us to increase our level of acceptable precision to 10%.

The first two methods were also evaluated using a statistical approach, the Z-test, to determine the minimum number of subsamples required to match the precision generated from collecting the maximum number of soil subsamples that could be practically collected from a field site (i.e., 100 subsamples) or a particular area of a bale-grazed field (i.e., 35 for waste feed affected, 100 for waste feed unaffected). The Z-test was used to compliment the 5 and 10% CV results, by indicating if increasing number of subsamples collected results in decreased variability of the mean.

6.3.1.1 Sampling Strategy 1: Random Composite Subsamples for the Whole Plot Area

The minimum number of random subsamples required to accurately determine residual soil N and P on the BG and CON plots was determined using a method similar to that described by Daniels et al. (2011). In brief, the Random Select procedure in SAS (SAS Institute Inc. 2000) was used to select values from original data sets (n = 200 subsamples per treatment) for residual soil NO_3-N and Olsen P from BG and CON plots in a given year. This procedure simulated collection of composite soil subsamples from a treatment, with composites made up of n = 20, 30, 40, 50, 60, 70, 80, 90 and 100 subsamples. The maximum number of subsamples that could be practically collected and composited from a treatment was considered to be 100. For each n (i.e., number of soil subsamples), data pools were randomly sampled 100 times to generate 100 estimates for the treatment mean for a given n. The Random Select procedure ensures no replacement in data pools during each composite sampling scenario (i.e., no subsample value is selected twice when developing each of the 100 composite sample scenarios). Mean soil nutrient status for a given n was then determined by averaging all 100 estimates for the mean, and standard error (SE) was considered to be the standard deviation (SD) of the 100 estimates. The minimum number of subsamples required to generate CVs less than 5% and 10% were identified. It should be noted that this method of repeatedly selecting different groups of subsample analyses from a dataset may not introduce as much variability as would result from repeatedly collecting different groups of physical subsamples from a field site. Therefore, using the Random Sampling technique may be slightly conservative in terms of estimating actual treatment variability.

6.3.1.2. Sampling Strategy 2: Separate Subsamples and Mean Estimates for Bale-Grazed Areas Affected and Unaffected by Waste Feed

Since “hot-spots” with high concentrations of soil nutrients were observed in areas of waste feed packs (Donohoe 2018b), subsamples from the two BG field plots were reassigned into two categories: soil subsamples from areas affected by waste feed (approximately 20% of the field site) and soil subsamples from areas that were unaffected by waste feed (approximately 80% of the field site), using measurements of depth of waste feed in Fall2 for the two BG plots (Donohoe 2018b). This approach was practical, in that a BG field could be soil sampled based on areas that could be visually observed as having waste feed vs. areas with no waste feed. The dataset consisted of 200 soil subsamples at each depth from the two BG plots, which resulted in a maximum of 35 subsamples to represent waste feed affected areas and 165 subsamples to represent the areas unaffected by waste feed. Similar to the first sampling strategy, the Random Select procedure in SAS (SAS Institute Inc. 2000) was used to simulate composite subsample scenarios for the BG plots by selecting values from the original data sets of residual soil NO_3-N and Olsen P. Due to the relatively small number of subsamples available for waste feed affected areas, composite subsamples were simulated using n = 4, 8, 10, 16, 20, 25, 30, and 32 for waste feed affected areas, while 4, 8, 10, 16, 20, 25, 30, 32, 35, 40, 50, 60, 70, 80, 90 and 100 subsamples were used to simulate waste feed unaffected areas. Data pools were sampled 100 times, generating 100 estimates for the mean for each n. Mean nutrient concentration for a given n was determined by averaging all 100 estimates and SD was considered as the SE of the 100 estimates. The minimum number of subsamples (n) required to achieve CVs less than 5% and 10% was identified for waste feed affected and unaffected areas of the BG field.

6.3.1.3. Sampling Strategy 3: Area-Weighted Mean Estimates for Bale-Grazed Areas Based on Differing Ratios of Subsamples from Areas Affected and Unaffected by Waste Feed

This strategy estimated soil nutrient concentrations in the BG plot on an area-weighted basis using the two sets of composite samples determined in Sampling Strategy 2: those affected by waste feed and those unaffected by waste feed. The numbers of subsamples used to estimate the plot mean from waste feed affected and unaffected areas were examined in two ways. First, subsamples from waste feed affected and unaffected areas were combined in three different ratios. The three ratios of subsamples used from the areas affected by waste feed relative to those areas unaffected were 1:4 (i.e., using a ratio of subsamples that was the same as the ratio of two physical areas within the plots, representing a similar level of sampling intensity for both areas), 1:1 (representing a 4- fold increase in sampling intensity for the relatively small waste feed affected area, compared to the unaffected area), and 4:1 (representing a 16-fold increase in sampling intensity within the waste feed affected area, compared to the unaffected area). Second, within each of the three ratios of subsamples selected from the two areas, variable numbers of soil subsamples were also tested. For example, for the 1:4 ratio, the number of subsamples from the waste feed affected area varied from 4 to 20 and were paired with 16 to 80 subsamples from the unaffected area.The 100 estimated means generated for each area were paired randomly with each combination of ratio and number of total subsamples and then averaged based on the percentage of the area the samples represented (i.e., area weighted basis), in order to create 100 estimates for the overall plot mean. The overall mean and standard error were then determined for each combination of ratio and total number of subsamples.

6.3.1.4. Z-Test for Homogeneity of Coefficients of Variation

A test for homogeneity of coefficients of variation (Zar 1999; Zvomuya et al. 2008) was also performed on the data generated in Sampling Strategy 1 and 2, to determine the minimum number of soil samples that best describes field mean soil Olsen P and residual soil NO_3-N. The Z-test was used to compare the pooled variability for a given number of subsamples, n, to the pooled variability associated with collecting the maximum number of subsamples (Zar 1999). It was assumed that $n = 100$ was the maximum number of subsamples that could be physically collected and composited from the BG and CON treatments in Sampling Strategy 1 and from the areas unaffected by waste feed in Sampling Strategy 2, and $n = 35$ was the maximum number of soil subsamples that could be practically collected from the waste feed affected areas of the BG plots in Sampling Strategy 2. A P value of greater than 0.05 was used to identify the populations with various numbers of soil subsamples that had a pooled variance similar to the variance for the maximum number of soil subsamples collected (Zar 1999). Therefore, the Z-test was used to determine the value of additional subsamples to achieve a more reliable measurement of soil test N and P.

6.4 Results

6.4.1. Sampling Strategy 1: Random Composite Samples for the Whole Area

Mean soil Olsen P from the BG plots could be estimated using 50 and 60 randomly collected soil subsamples to achieve a CV of less than 10% in Fall1 and Fall2, respectively (Table 6.1). However, 100 subsamples were not sufficient to estimate a mean with a CV of less than 5%. For the CON treatment in Fall1 and Fall2, mean soil Olsen P could be estimated with 20 subsamples or less to achieve a CV of less than 10%. To estimate mean soil Olsen P in the

CON plots with a CV of less than 5%, 40 subsamples were required in Fall1, while 50 subsamples were required in Fall2.

Residual soil NO_3-N (Table 6.2) was more variable than Olsen P for both treatments. The lowest CV for estimating mean residual soil NO_3-N in the BG plots via random sampling was 21.3% in Fall1 and 31.5% in Fall2, both for 100 subsamples. For the CON treatment, estimating mean residual soil NO_3-N in Fall1 required 90 subsamples to achieve a CV less than 10%, while 100 soil subsamples was not sufficient to achieve a CV of less than 5%. In Fall2, 50 subsamples were required to estimate mean soil residual NO_3-N in the CON with a CV of less than 10%, and 100 subsamples were required to reach a CV less than 5%.

For the BG treatment in Fall1, the *Z*-test determined that at least 80 randomly collected subsamples were required to generate estimates for mean soil Olsen P that were statistically similar to collecting 100 random subsamples (Appendix Table 9.5). In Fall2, the variability in soil Olsen P increased and 90 subsamples were not sufficient to generate estimates for the mean that were statistically similar to collecting 100 subsamples. For the CON treatment, the *Z*-test revealed that the minimum number of random subsamples required for estimating mean soil Olsen P was between 60 and 70 in Fall1 and between 80 and 90 in Fall2, in order to be statistically similar to collecting 100 random subsamples.

Further, the *Z*-test revealed that the minimum number of random subsamples required for determining mean residual soil NO_3-N in the BG plots was greater than 90 in Fall1 and between 80 and 90 in Fall2, in order to be statistically similar to collecting 100 subsamples (Appendix Table 9.6). The minimum number of random subsamples required for residual soil NO_3-N analyses from the CON treatment was between 80 and 90 soil subsamples in both Fall1 and Fall2, in order to be statistically similar to collecting 100 subsamples.

Table 6.1 Variability in estimates for mean Olsen extractable soil phosphorus (P) determined using Sampling Strategy 1, with an increasing number of randomly collected soil subsamples (0 to 15 cm) from a bale grazed (BG) and ungrazed (control) forage field at the end of the growing season in the first fall (Fall1) and second fall (Fall2) after winter bale grazing

Sampling Time	**Trt**	**Number of subsamples**[a]	**Range in estimated means**[a]	**Standard Error**[b]	**CV**[b]
		n_c	*kg P ha*$^{-1}$		*%*
Fall1	BG	20	6.71 to 15.1	1.56	16.5
		30	7.29 to 13.4	1.23	12.9
		40	7.44 to 14.9	1.31	13.5
		50	7.46 to 11.8	0.87	9.10
		60	7.84 to 11.8	0.80	8.26
		70	8.31 to 11.8	0.73	7.53
		80	8.36 to 11.3	0.63	6.50
		90	8.54 to 10.4	0.59	5.96
		100	7.97 to 10.1	0.59	6.09
	Control	20	8.35 to 11.3	0.55	5.69
		30	7.89 to 11.3	0.52	5.38
		40	8.75 to 10.7	0.43	4.37
		50	8.99 to 10.8	0.33	3.37
		60	8.96 to 10.4	0.30	3.11
		70	9.17 to 10.6	0.26	2.69
		80	9.18 to 10.6	0.24	2.47
		90	9.25 to 10.2	0.21	2.11
		100	9.13 to 10.3	0.21	2.14
Fall2	BG	20	6.60 to 15.1	1.79	18.8
		30	6.41 to 15.4	1.53	16.1
		40	7.03 to 16.2	1.40	14.5
		50	7.31 to 11.7	0.93	10.4
		60	7.45 to 12.1	1.00	9.83
		70	7.61 to 12.1	0.90	9.46
		80	7.89 to 11.5	0.82	8.56
		90	7.46 to 12.1	0.76	7.89
		100	8.33 to 11.2	0.58	6.03
	Control	20	7.16 to 10.6	0.83	9.46
		30	7.62 to 10.5	0.56	6.40
		40	7.49 to 10.1	0.54	6.17
		50	8.78 to 9.69	0.44	4.96
		60	7.81 to 9.59	0.36	4.05
		70	8.20 to 9.60	0.33	3.68
		80	8.05 to 9.60	0.34	3.92
		90	8.14 to 9.41	0.28	3.23
		100	8.17 to 9.27	0.26	2.94

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[a] Each range is for 100 means randomly generated from 20 to 100 subsamples (n_c) in the original dataset (n = 200)
[b] Standard error and CV describe absolute and percent deviation, respectively, for 100 means randomly generated within each subsample number category

6.4.2 Sampling Strategy 2: Separate Subsamples and Mean Estimates for Bale-Grazed Areas Affected and Unaffected by Waste Feed

In both years, at least 25 subsamples were required from the waste feed affected areas of the BG plots to determine estimated mean values for soil Olsen P with a CV of 10% or less (Table 6.3). In both years, 32 subsamples were not sufficient to reach a CV less than 5%. In Fall1, at least 16 subsamples from areas of the BG plot that were unaffected by waste feed were required to determine mean soil Olsen P concentrations with a CV of less than 10%, and 80 subsamples were required to reach a CV less than 5%. For areas of the BG treatment in Fall2 that were unaffected by waste feed, at least 30 subsamples were necessary to determine mean soil Olsen P concentrations with a CV less than 10%, and at least 80 subsamples were necessary to reach a CV of less than 5%.

Table 6.2 Variability in estimates for mean residual soil nitrate nitrogen (NO_3-N) determined using Sampling Strategy 1, with an increasing number of randomly collected soil subsamples (0 to 60 cm) from a bale grazed (BG) and ungrazed (control) forage field at the end of the growing season in the first fall (Fall1) and second fall (Fall2) after winter bale grazing

Sampling Time	Trt	Number of subsamples[a]	Range in estimated means[a]	Standard Error[b]	CV[b]
		n_c	*kg N ha^{-1}*		*%*
Fall1	BG	20	3.2 to 63.9	11.3	70.9
		30	3.7 to 43.9	9.33	55.0
		40	4.0 to 38.0	6.82	41.5
		50	4.5 to 35.6	6.36	42.0
		60	5.2 to 28.6	5.62	35.1
		70	4.9 to 34.9	5.69	35.1
		80	7.4 to 28.9	4.78	29.0
		90	8.2 to 28.1	4.36	26.0
		100	8.0 to 25.2	3.66	21.3
	Control	20	1.3 to 4.7	0.64	25.0
		30	1.7 to 3.4	0.44	17.9
		40	1.7 to 3.2	0.33	13.6
		50	1.8 to 3.5	0.34	13.7
		60	1.9 to 3.3	0.30	11.8
		70	1.9 to 3.2	0.27	11.0
		80	2.0 to 3.0	0.24	10.1
		90	2.1 to 3.0	0.20	8.23
		100	2.0 to 2.9	0.18	7.47
Fall2	BG	20	0.44 to 7.6	1.68	105
		30	0.54 to 6.6	1.55	77.3
		40	0.55 to 4.6	1.09	63.0
		50	0.59 to 4.7	1.16	55.1
		60	0.62 to 4.2	0.95	52.1
		70	0.65 to 3.4	0.72	42.1
		80	0.73 to 3.4	0.76	43.0
		90	0.75 to 3.1	0.63	35.5
		100	0.68 to 2.9	0.57	31.5
	Control	20	0.78 to 1.6	0.17	16.8
		30	0.81 to 1.5	0.12	11.6
		40	0.85 to 1.3	0.11	10.5
		50	0.86 to 1.3	0.09	8.9
		60	0.93 to 1.3	0.08	7.5
		70	0.90 to 1.2	0.07	6.3
		80	0.92 to 1.2	0.06	5.8
		90	0.93 to 1.2	0.06	5.3
		100	0.95 to 1.2	0.05	4.9

[a] Each range is for 100 means, randomly generated from 20 to 100 soil subsamples (n_c) in the original dataset ($n = 200$)

[b] Standard error and CV describe absolute and percent deviation, respectively, for 100 means randomly generated within each subsample number category

In Fall1, at least 30 subsamples from the waste feed affected areas and 80 subsamples from the unaffected areas were required to generate estimates for mean residual soil NO_3-N with a CV less than 10% (Table 6.4). In Fall2, none of the subsampling scenarios for the waste feed affected areas generated estimates for mean soil NO_3-N with a CV of less than 10%. For unaffected areas, at least 80 subsamples were required to generate estimated means for residual soil NO_3-N with a CV of less than 10%. Mean soil NO_3-N values with a CV less than 5% could not be achieved for either area of the BG plots in either year.

Table 6.3 Variability in estimates for mean Olsen extractable soil phosphorus (P) determined using Sampling Strategy 2, with an increasing number of randomly collected soil subsamples (0 to15 cm) for waste feed affected and unaffected areas of a bale grazed (BG) forage field at the end of the growing season in the first fall (Fall1) and second fall (Fall2) after winter bale grazing

Sampling Time	Area of BG field	Number of subsamples[a]	Range in estimated means[a]	Standard Error[b]	CV[b]
		n_c	*kg P ha^{-1}*		%
Fall1	Waste feed affected	4	7.5 to 38.7	7.16	40.7
		8	8.6 to 30.3	4.92	28.2
		10	8.6 to 29.5	4.34	24.5
		16	10.9 to 23.4	2.62	15.4
		20	13.0 to 21.9	2.00	11.4
		25	13.0 to 20.8	1.71	10.0
		30	13.5 to 19.6	1.27	7.21
		32	13.7 to 19.1	1.12	6.52
	Waste feed unaffected	4	4.9 to 12.9	1.70	21.7
		8	5.3 to 12.0	1.15	14.6
		10	6.2 to 10.5	0.89	11.4
		16	6.5 to 10.3	0.70	8.9
		20	6.5 to 9.9	0.72	9.0
		30	6.6 to 9.1	0.51	6.4
		32	6.8 to 9.7	0.58	7.3
		40	6.9 to 8.9	0.45	5.8
		80	7.3 to 8.5	0.27	3.4
		100	7.4 to 8.3	0.19	2.4
Fall2	Waste feed affected	4	8.7 to 45.2	7.1	34.0
		8	8.8 to 32.5	4.6	23.2
		10	11.3 to 29.4	4.4	22.8
		16	12.3 to 25.9	2.8	14.1
		20	14.8 to 25.1	2.2	11.3
		25	16.7 to 23.0	1.1	5.6
		30	17.4 to 22.5	1.2	6.0
		32	16.0 to 21.9	1.1	5.5
	Waste feed unaffected	4	4.1 to 15.9	2.3	29.9
		8	4.52 to 11.3	1.3	18.9
		10	4.52 to 9.74	1.1	14.7
		16	4.89 to 9.90	0.87	12.3
		20	5.34 to 9.10	0.84	11.8
		30	5.43 to 9.11	0.67	9.2
		32	9.08 to 6.02	0.57	7.9
		40	6.05 to 8.26	0.60	8.4
		80	6.57 to 7.77	0.27	3.7
		100	6.73 to 7.66	0.26	3.7

[a] Each range is for 100 estimated means randomly generated from 4 to 32 soil subsamples (n_c) in the original dataset of waste feed affected areas of the field (n = 35) and 4 to 100 subsamples (n_c) in the original dataset of waste feed unaffected areas of the field sites (n = 165)

[b] Standard error and CV describe absolute and percent deviation, respectively, for 100 means randomly generated within each subsample number category

At least 32 and 25 random subsamples in Fall1 and Fall2, respectively, were required to generate estimates for mean soil Olsen P for the waste feed affected areas of the BG treatment that were statistically equivalent to collecting 35 soil subsamples (Appendix Table 9.7). For unaffected areas of the BG treatment in Fall1, more than 90 subsamples were required, and in Fall2, at least 80 soil subsamples were required to determine soil Olsen P values that were statistically equivalent to those for 100 subsamples.

For soil residual NO_3-N in waste feed affected areas, at least 32 and 30 soil subsamples were required in Fall1 and Fall2, respectively, to generate estimates that were statistically similar to those for 35 soil subsamples (Appendix Table 9.8). For areas that were not affected by waste feed, at least 80 subsamples were required in both years to generate estimates for mean soil residual NO_3-N that were statistically equivalent to those for 100 subsamples.

Table 6.4 Variability in estimates for mean residual nitrate nitrogen (NO_3-N) determined using Sampling Strategy 2, with an increasing number of randomly collected soil samples (0 to 60 cm) for waste feed affected and unaffected areas of a bale grazed (BG) forage field at the end of the growing season in the first fall (Fall1) and second fall (Fall2) after winter bale grazing

Sampling time	**Area of BG field**	**Number of subsamples**[a]	**Range in estimated means**[a]	**Standard error**[b]	**CV**[b]
		n_c	*kg N ha^{-1}*		%
Fall1	Waste feed affected	4	4.9 to 214	55.09	75.1
		8	9.8 to 169	31.24	43.2
		10	18.2 to 139	26.51	35.5
		16	23.3 to 125	19.57	25.5
		20	35.7 to 110	14.87	20.5
		25	44.5 to 98.8	11.47	15.4
		30	55.2 to 84.9	6.86	9.10
		32	58.5 to 79.6	5.24	7.04
	Waste feed unaffected	4	1.9 to 18.8	2.81	58.4
		8	2.1 to 12.0	1.95	40.9
		10	2.6 to 12.1	1.66	34.8
		16	2.8 to 8.5	1.27	27.1
		20	2.7 to 8.5	1.29	26.6
		25	3.2 to 8.1	1.15	23.7
		30	3.4 to 7.0	0.98	20.4
		32	3.1 to 6.8	0.77	16.8
		40	3.4 to 6.8	0.68	14.7
		80	4.0 to 5.5	0.35	7.40
		100	3.8 to 5.4	0.34	7.44
Fall2	Waste feed affected	4	0.14 to 40.0	8.23	130
		8	0.36 to 21.3	5.81	80.5
		10	0.47 to 18.9	5.39	74.2
		16	1.95 to 13.3	3.42	46.8
		20	2.14 to 11.9	2.81	38.6
		25	2.14 to 10.2	2.16	31.3
		30	2.67 to 8.81	1.61	22.7
		32	3.96 to 8.38	1.32	18.8
	Waste feed unaffected	4	0.01 to 1.89	0.36	61.1
		8	0.21 to 1.25	0.22	34.2
		10	0.26 to 1.17	0.21	32.4
		16	028 to 1.11	0.16	25.2
		20	0.36 to 0.99	0.13	20.6
		25	0.37 to 0.97	0.13	21.3
		30	0.31 to 1.01	0.13	19.7
		32	0.42 to 0.85	0.10	15.8
		40	0.41 to 0.88	0.10	15.5
		80	0.52 to 0.73	0.04	7.1
		100	0.53 to 0.75	0.04	6.4

[a] Each range is for 100 estimated means randomly generated from 4 to 32 soil subsamples (n_c) in the original dataset of waste feed affected areas of the field (n = 35) and 4 to 100 subsamples (n_c) in the original dataset of waste feed unaffected areas of the field sites (n = 165)
[b] Standard error and CV describe absolute and percent deviation, respectively, for 100 means randomly generated within each subsample number category

6.4.3 Sampling Strategy 3: Area Weighted Mean Estimates for Bale-Grazed Areas Based on Differing Ratios of Number of Subsamples from Areas Affected and Unaffected by Waste Feed

Using Sampling Strategy 3 for the BG plots, 40 subsamples were required in both the 1:1 and 4:1 ratios (ratio of the number of samples in the affected vs. unaffected by waste feed) to generate estimates for mean soil Olsen P with a CV less than 10% in Fall1 (Table 6.5). Using the 1:4 ratio, a total of 50 subsamples from the waste feed affected and unaffected areas of the BG treatment also resulted in a CV of less than 10%. For soil Olsen P in Fall1, the ratio of 1:1 soil subsamples, 60 subsamples collected from waste feed affected and unaffected areas reduced the CV to less than 5%. For soil Olsen P in Fall2, none of the scenarios resulted in estimated means with a CV of less than 10%. The lowest CV was 16% for 100 subsamples collected using a 1:4 ratio with 20 waste feed affected and 80 unaffected subsamples, 17% for 60 subsamples collected using a 1:1 ratio, and 17% for 40 subsamples collected using a 4:1 ratio.

In Fall1, 40 soil subsamples collected from waste feed affected and unaffected areas at a ratio of 4:1 were required to generate estimates of mean residual soil NO_3-N with a CV of less than 10% (Table 6.6). When equal numbers of subsamples from each area were used to generate the estimated means, (i.e., a 1:1 ratio), 60 subsamples were required to achieve a CV less than 10%. When the ratio of subsamples from waste feed affected and unaffected areas was 1:4, there was no scenario where the CV for estimated mean NO_3-N was less than 10%, even if 100 subsamples were collected. There were no subsampling scenarios that achieved a CV of less than 10% when estimating mean residual soil NO_3-N in Fall2. The lowest CVs were 21.4%, for 60 subsamples in a 1:1 ratio 22.1% for 40 subsamples in a 4:1 ratio.

Table 6.5. Variability in estimates for mean Olsen extractable soil phosphorus (P) determined using Sampling Strategy 3, with different ratios and increasing numbers of randomly collected soil subsamples (0 to 15 cm) for waste feed affected and unaffected areas of a bale grazed (BG) forage field at the end of the growing season in the first fall (Fall1) and second fall (Fall2) after winter bale grazing.

Sampling time	**Waste feed affected: waste feed unaffected**		**Total number of subsamples**	**Range of area weighted means**[a]	**Standard error**[b]	**CV**[b]
	Ratio of subsamples	*Number of subsamples in each area*	n_c	*kg P ha^{-1}*		*%*
Fall1	1:4	4:16	20	7.3 to 14.0	1.45	14.9
	1:4	8:32	40	7.4 to 12.0	1.06	10.9
	1:4	10:40	50	7.9 to 12.3	0.89	9.24
	1:4	20:80	100	8.5 to 10.7	0.43	4.38
	4:1	16:4	20	7.0 to 14.0	1.50	15.6
	4:1	32:8	40	7.4 to 13.1	0.94	9.77
	1:1	10:10	20	7.1 to 13.2	1.13	11.7
	1:1	20:20	40	8.4 to 11.4	0.68	6.98
	1:1	30:30	60	8.8 to 10.9	0.47	4.80
Fall2	1:4	4:16	20	5.6 to 14.0	2.1	21.6
	1:4	8:32	40	6.5 to 11.9	1.6	17.2
	1:4	10:40	50	7.0 to 10.8	1.6	17.9
	1:4	20:80	100	8.1 to 10.9	1.6	16.0
	4:1	16:4	20	5.7 to 17.7	2.5	25.1
	4:1	32:8	40	6.7 to 11.8	1.6	16.7
	1:1	10:10	20	5.8 to 10.3	1.7	19.3
	1:1	20:20	40	7.1 to 10.7	1.7	18.4
	1:1	30:30	60	7.7 to 10.3	1.6	16.6

[a] Each range is for 100 randomly generated composites of 4 to 100 subsamples (n_c) from the original dataset of waste feed unaffected areas of the field (n = 165) and 4 to 32 subsamples (n_c) from the original dataset of waste feed affected field sites (n = 35)

[b] Standard error and CV describe absolute and percent deviation, respectively, for 100 means randomly generated within each subsample number category

Table 6.6. Variability in estimates for mean residual soil nitrate-nitrogen (NO_3-N) determined using Sampling Strategy 3, with different ratios and increasing numbers of randomly collected soil subsamples (0 to 60 cm) for waste feed affected and unaffected areas of a bale grazed (BG) forage field at the end of the growing season in the first fall (Fall1) and second fall (Fall2) after winter bale grazing.

Sampling time	**Waste feed affected: waste feed unaffected**		**Total number of subsamples**	**Range of area weighted means**[a]	**Standard error**[b]	**CV**[b]
	Ratio of subsamples	*Number of subsamples in each area of the field*	n_c	*kg N ha^{-1}*		*%*
Fall1	1:4	4:16	20	4.5 to 43.9	10.4	59.1
	1:4	8:32	40	6.0 to 36.0	5.9	33.7
	1:4	10:40	50	6.9 to 29.0	4.9	27.6
	1:4	20:80	100	10.5 to 24.8	2.8	16.0
	4:1	16:4	20	6.6 to 32.5	4.5	24.5
	4:1	32:8	40	14.5 to 24.2	1.8	9.8
	1:1	10:10	20	6.8 to 29.7	5.0	28.6
	1:1	20:20	40	11.2 to 23.8	2.7	15.6
	1:1	30:30	60	13.4 to 20.7	1.5	8.5
Fall2	1:4	4:16	20	0.26 to 7.4	1.7	97.4
	1:4	8:32	40	0.41 to 4.7	1.9	62.3
	1:4	10:40	50	0.47 to 4.3	1.1	57.3
	1:4	20:80	100	0.73 to 3.0	0.6	32.0
	4:1	16:4	20	0.38 to 4.0	0.92	49.1
	4:1	32:8	40	0.91 to 2.6	0.41	22.1
	1:1	10:10	20	0.30 to 4.5	1.1	61.7
	1:1	20:20	40	0.70 to 2.8	0.56	32.8
	1:1	30:30	60	0.74 to 2.4	0.39	21.4

[a] Each range is for 100 randomly generated composites of 4 to 100 subsamples (n_c) from the original dataset of waste feed unaffected areas of the field (n = 165) and 4 to 32 subsamples (n_c) from the original dataset of waste feed affected field sites (n = 35)

[b] Standard error and CV describe absolute and percent deviation, respectively, for 100 means randomly generated within each subsample number category

6.5 Discussion

The results of this study provide a guide for producers, agronomists and regulators regarding soil sample numbers required to determine mean soil Olsen P and residual NO_3-N in bale-grazed forage fields. These results also demonstrate the natural variability that can occur in a forage field unaffected by bale grazing.

Soil residual NO_3-N was generally more variable than Olsen P. Using Sampling Strategy 1 in the untreated (CON) forage plots, at least 50 to 90 randomly collected subsamples were needed to achieve a CV of less than 10% for estimates in mean soil residual NO_3-N, depending on the year. However, for the same plot, only 20 subsamples or less were required to estimate mean Olsen P with a CV of less than 10%, depending on the year. The differences in CV values for NO_3-N sampling in Fall1 and Fall2 in the CON treatment suggest that environmental factors, such as soil moisture over the growing season, played a significant role in residual soil nutrient status and likely influenced, to some extent, the variability in residual NO_3-N in the BG treatment, as well.

The results of the *Z*-test for the Control treatment in Sampling Strategy 1 demonstrate that the 10% CV target for precision may not be sufficient, as a larger number of soil subsamples were typically required to achieve maximum precision for both treatments for soil residual NO_3-N and Olsen P compared to the number of samples required to achieve a 10% CV. However, when using the *Z*-test for the BG treatment, the number of subsamples required was typically less than the number required to achieve the 5% CV target, suggesting the 5% CV guideline was too restrictive. In fact, a CV less than 5% for estimated means was nearly impossible to achieve, even in Sampling Strategy 2 and 3, whereas the *Z*-test suggested that a reduced number of soil samples would be sufficient in most scenarios. The *Z*-test and % CV method express variability of estimated means and the precision of sampling strategies. However, it is also important to consider the accuracy of the estimated means when selecting a recommended sampling protocol, which includes examining the difference in absolute values.

It is not uncommon for agronomists and producers to use 20 randomly collected subsamples or less to determine mean soil NO_3-N and Olsen P in a forage field. In this study, if 20 randomly collected soil subsamples were used to estimate soil residual NO_3-N in the CON treatment, the CV would range from 25% in Fall1 to 17% in Fall2. From an agronomic perspective, however, the range of absolute values for estimated means of residual soil NO_3-N from 20 subsamples for the CON treatment was small, varying from 1.3 to 4.7 kg N ha^{-1} in Fall1 and 0.78 to 1.6 kg N ha^{-1} in Fall2 (Table 6.2). The range of absolute values for estimated means from 20 subsamples was also small for soil Olsen P, ranging from 8.35 to 11.3 kg P ha^{-1} in Fall1 and from 7.16 to 10.6 kg P ha^{-1} in Fall2 (Table 6.1). Therefore, collecting 20 random samples from an untreated forage field would be agronomically sufficient to determine mean soil residual NO_3-N and Olsen P status. Furthermore, this small number of random samples is unlikely to cause substantial errors in management decisions on a forage field that was not bale-grazed, despite the high CV obtained for residual soil NO_3-N.

If a random composite sampling technique was used for a bale-grazed forage field, (i.e. Sampling Strategy 1), more than 100 soil subsamples would be necessary to accurately determine field mean residual soil NO_3-N with a CV less than 10%. The absolute values of residual soil NO_3-N in Fall1 were much larger for the BG treatment compared to the CON treatment, with a range in estimated means of 3.2 to 63.9 kg N ha^{-1} for 20 soil subsamples. Therefore, collection of only 20 randomly subsamples to determine soil residual NO_3-N from a bale-grazed field could result in significant errors in estimating mean field nutrient status. Collection of as many as 100 random field subsamples from a BG field in Fall1 would result in a significant range of estimated means (8 to 25.2 kg N ha^{-1}), with a range in means of 17 kg ha^{-1}. In Fall2, however, ranges in estimated means for soil residual NO_3-N in the BG treatment were smaller with as few as 20 randomly collected soil subsamples resulting in a range of estimated means of 0.44 to 7.6 kg N ha^{-1}. Therefore, in Fall2, despite the large variation (CV), a smaller number of soil subsamples to determine mean soil residual NO_3-N would be unlikely to result in poor management decisions or recommendations.

The range in absolute values for estimates of soil Olsen P measured from randomly collected soil subsamples in the BG treatment were smaller than for soil residual NO_3-N and similar between years. The ranges in estimated means for Sampling Strategy 1 in the BG treatment in Fall1 were 6.7 to 15.1 kg P ha^{-1} for 20 soil subsamples and 8 to 10.1 kg P ha^{-1} for 100 soil subsamples, and in Fall2 the ranges were 6.6 to 15.1 kg P ha^{-1} for 20 soil subsamples and 8.3 to 11.2 kg P ha^{-1} for 100 subsamples. It appears to be less likely that poor management decisions for soil P fertility would be made if only 20 random soil subsamples were taken. However, if testing for residual NO_3-N in year one following bale grazing, random sampling the field site (Sampling Strategy 1) is not recommended.

Daniels et al. (2001) examined the number of soil samples required to accurately determine P threshold status of pasture forage land in order to assess risk of P loss to the environment. To determine field mean soil P status within a 95% confidence interval for soils with less than 150 mg P kg^{-1}, 28 to 48 soil subsamples in a zig-zag pattern were required, while only 9 to 18 subsamples were required for soils with a field mean of greater than 150 mg P kg^{-1}. The sample range for soils with less than 150 mg kg^{-1} P reported by Daniels et al. (2001) was within the same range of randomly collected soil subsamples determined for the current study from the BG treatments to achieve a mean field Olsen P status with a CV of less than10%.

In order to accurately determine mean residual soil NO_3-N in a bale-grazed field with a CV of less than 10%, it appears that a systematic sampling strategy is necessary. Using Sampling

Strategy 2, with separate samples and estimates for areas affected and unaffected by waste feed, at least 30 soil subsamples were required to generate estimates for mean residual soil NO_3-N with a CV less than 10% for the waste feed affected areas in Fall1. This strategy resulted in a range of estimated means of 55 to 85 kg N ha^{-1}. From an agronomic perspective, this range is quite large despite achieving a CV of less than 10%. Increasing the sampling density for waste feed affected areas is recommended to achieve an accurate estimate of residual soil NO_3-N in the first fall following winter bale grazing. Unfortunately, we were limited in this study to a maximum of 35 soil subsamples from the waste feed affected areas. In Fall2, Sampling Strategy 2 revealed that more than 32 soil samples were required to achieve an estimated soil residual NO_3-N mean with a CV less than 10% for waste feed affected areas. However, by Fall2 the range in estimated means was quite small at 3.96 to 8.38 kg N ha^{-1}, suggesting that 30 subsamples were adequate from an agronomic perspective.

For areas unaffected by waste feed, although 80 soil subsamples were required in both Fall1 and Fall2 to achieve a CV less than 10% for soil residual NO_3-N, the range in estimated means was very small compared to the waste feed affected areas. With 20 soil subsamples collected in Fall1 from unaffected areas, the range was 2.7 to 8.5 kg N ha^{-1}, and in Fall2 was 0.36 to 0.99 kg N ha^{-1}. Therefore, collecting 20 random samples from areas unaffected by waste feed should be adequate from an agronomic perspective, despite not achieving a CV of less than 10%.

The small range in absolute values for field residual NO_3-N in areas unaffected by waste feed suggest it may be possible to reduce the sampling intensity in these areas when estimating the mean soil test N status for a bale-grazed field. Therefore, dividing the field subsamples between waste feed affected and unaffected areas could reduce the overall number of samples collected to determine residual soil NO_3-N status and reduce absolute variability.

Using Sampling Strategy 2 for soil Olsen P, the range in estimated means in Fall1 for waste feed affected areas was 7.5 to 38.7 kg P ha^{-1} for 4 soil subsamples and 13.7 to 19.1 kg P ha^{-1} for 32 soil subsamples. In Fall2, ranges in estimated means were even smaller. Although at least 30 and 25 soil subsamples in Fall1 and Fall2, respectively, were required to generate estimated means with a CV less than 10%, the small range in estimated means suggests that 20 soil subsamples would be adequate to obtain reasonably accurately Olsen P measurements in the waste feed affected areas. The range in estimated means for soil Olsen P in areas unaffected by waste feed was again very small from an agronomic perspective and collecting only 4 soil subsamples, although above the less than 10% CV threshold, resulted in estimated means ranging from 4.9 to 12.9 kg P ha^{-1} in Fall1 and 4.1 to 15.9 kg P ha^{-1} in Fall2. For soil Olsen P, splitting the field into waste feed affected and unaffected areas did not make a significant difference in the number of subsamples required for measuring soil Olsen P, compared to random sampling, when using less than 10% CV as the target for precision. However, splitting the areas for subsampling helped to accurately describe the difference between areas affected and unaffected by waste feed.

For Strategy 3, we attempted to improve the efficiency and accuracy of measuring the N and P status of the BG forage fields. Based on Sampling Strategy 2, we observed that increasing the sampling density in “hot-spots,” particularly for residual soil NO_3-N was necessary to reduce the CV and the absolute variability in measured values. The results of Sampling Strategy 3 revealed that using the 4:1 ratio of waste feed affected vs. unaffected subsamples resulted in estimates of field mean residual soil NO_3-N in Fall1 with a CV less than 10%, using only 40 subsamples (32 waste feed affected plus 8 unaffected). In this scenario, the difference in range of area-weighted means was 14.5 to 24.2 kg N ha^{-1}. In Fall1, either a 1:1 or 4:1 sampling ratio with at least 40 soil subsamples was appropriate to determine field mean residual soil Olsen P with a CV of less than 10%. Both these ratio scenarios for Olsen P resulted in a difference in ranges of area-weighted means of less than 6 kg P ha^{-1}.

In Fall2, however, none of the ratio techniques were successfully able to measure field mean residual soil Olsen P or NO_3-N with a CV less than 10%. For both soil residual NO_3-N and Olsen P in Fall2, the 4:1 ratio of subsamples from waste feed affected: unaffected areas had the lowest CV of any scenarios, with 40 subsamples. However, for both Olsen P and residual soil NO_3-N, the range in absolute values and the absolute values of the standard errors for nearly all of the sampling ratios were quite low in Fall2, suggesting that they could be used with little risk of error based on the soil analyses despite having high CVs. This data suggests year one following bale grazing poses the greatest risk of error when estimating field mean residual soil NO_3-N and Olsen P, from both an agronomic and environmental perspective, due to the large absolute differences in estimated means, even though variability as measured in % CV was highest in Fall2.

Accurate and precise measurements of soil nutrient status following bale grazing will enable producers to better estimate appropriate rates and location to apply livestock manure or synthetic fertilizer for optimum crop yield. It will also help producers understand the impact of bale grazing on soil nutrient status and determine the frequency with which a field should be reused for bale grazing. An effective and efficient soil sampling strategy is also required to address concerns regarding the potential impact of soil P and N on surface water and groundwater, respectively. Towards these goals, Sampling Strategy 3 provided a reliable estimate of field mean Olsen P and residual NO_3-N, as well as information about N and P “hot-spots” on the bale-grazed field using a reasonable number of subsamples. Based on the bale spacing, bale size, climate and soil type in the current study, we recommend a minimum of 32 soil subsamples collected from waste feed affected areas and 8 soil subsamples from unaffected areas of the bale-grazed field in the first two falls following winter bale grazing, but encourage increased numbers of subsamples from the waste feed affected areas, if possible.

When applying these guidelines to other bale grazing situations, it is important to note that the number of subsamples recommended for a BG field may be affected by the size of bales and bale spacing as well, which may alter the ratio of unaffected vs. affected areas of the field. Decreased bale spacing and smaller bales may result in smaller and fewer differences between waste feed affected and unaffected areas, and vice-versa. As well, arid climates, less fertile soil types, or management strategies such as harrowing to spread out waste feed and manure, that affect the rate of decomposition of waste feed packs following bale grazing, may alter the impact of “hot-spots” on BG field soil nutrient status and therefore may require different sampling strategies.

6.6 Conclusions

Residual soil NO_3-N and Olsen P were highly variable in BG plots, and variability, measured in % CV, increased in the second year following bale grazing. Residual soil NO_3-N was more variable than Olsen P, and therefore required more subsamples to achieve a target of 10% CV, while a CV of 5% was not achievable for NO_3-N in BG plots using any of the strategies tested in Fall2. However, the absolute means and ranges for NO_3-N decreased in the second year following bale grazing. Therefore, although it was more difficult to obtain a statistically stable estimate of the field mean in Fall2 compared to Fall1, the agronomic or environmental risk from an error in determining nutrient status was decreased. Random sampling throughout the bale-grazed field to determine both residual soil NO_3-N and Olsen P required at least 100 subsamples. Collecting separate composite samples from two distinct areas in a bale-grazed field, waste feed affected and unaffected, reduced the total number of subsamples required and overall CV. Analyses from waste feed affected and unaffected areas were combined on an area weighted basis to provide a reasonably accurate measurement of N and P fertility in the field, with fewer subsamples required than for random sampling throughout the whole field. However, we recommend a higher intensity of subsampling from waste feed affected than unaffected areas. Based on data collected from clay soils with little to no variation in topography and based on the bale size and spacing in our study, at least 32 subsamples should be collected from waste feed affected areas of a BG field and at least 8 subsamples from areas unaffected by waste feed when determining residual soil NO_3-N and Olsen P in years one and two following bale grazing.

6.7 References

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7.0 MANUSCRIPT 4

CHARACTERIZATION OF NITROGEN AND PHOSPHORUS BUDGETS FOR TWO BEEF COW WINTER FEEDING SYSTEMS ON THE CANADIAN PRAIRIES

7.1 Abstract

With increasing public concern regarding the environmental impacts of beef production, it is important for beef producers to adopt management practices that are environmentally friendly. A system-scale nutrient budget model was developed to assess nitrogen (N) and phosphorus (P) inputs, outputs, balance, recovery and efficiency for bale graze with distillers grain supplementation (BGdg) and drylot (DL) winter feeding systems for pregnant beef cows on the Canadian Prairies. Variables examined for efficiency included the cows during the overwintering period, plus forage harvested and soil residual N over the two subsequent growing seasons. Inputs were 361 and 281 g N cow^{-1} d^{-1}, and 45.1 and 20.6 g P cow^{-1} d^{-1} for the BGdg and DL systems, respectively. Nitrogen surplus was 448 and 285 kg N ha^{-1} and P was 52 and 25.7 kg P ha^{-1}, for the BGdg and DL systems, respectively. Recovery of inputs in cows plus forage harvested was 1.41 and -0.13 kg N ha^{-1} and 0.64 and 0.28 kg P ha^{-1}, for the BGdg and DL systems, respectively. Cows were the most efficient at recovering N and P inputs from both winter feeding systems, recovering 2.9 and 1.5% of N inputs and 9.9 and 10% of P inputs, from the BGdg and DL systems, respectively, while harvested forage recovered -0.5 and -1.8% of N inputs and -1.2 and 2.1% of P inputs, from the BG and DL systems, respectively, within the two-year period of this study. Total N efficiency was determined to be 2.4 and -0.3% and total P efficiency 8.7 and 12.1% for the BGdg and DL winter feeding systems, respectively. The

nutrient budget model allowed us to gain insight into possible strategies to improve nutrient use efficiency in both overwintering systems. Increasing yields of forage harvested was determined to have the greatest potential to improve N and P efficiency from both the DL and BGdg overwintering systems.

7.2 Introduction

Economically and environmentally sound management practices are essential for the long-term sustainability of the beef industry, given increasing public concern regarding the environmental impacts of beef production (Eshel et al. 2014). Measuring system sustainability is necessary to address these concerns; however, identifying a common methodology and approach remains a challenge for producers and policy makers worldwide (Hayati et al. 2011).

In western Canada, many producers have adopted extensive winter feeding systems to offset the high costs of overwintering cattle in a more “traditional” drylot system (Sheppard et al. 2015). Extensive winter feeding systems, such as bale grazing, are characterized by cattle “grazing” throughout the winter months, on standing, swathed or imported forages, thereby reducing labour and input costs. Similar to summer grazing scenarios, extensive winter feeding systems result in nutrient deposition directly by cattle, in the form of feces, urine and waste feed, onto annual or perennial crops. However, in the Northern Great Plains, these fields are frozen and/or snow covered at the time of winter grazing, which may result in different nutrient dynamics in soil and forage compared to traditional summer grazing (Donohoe 2018a; Donohoe 2018b; Jungnitsch et al. 2011; Kelln et al. 2012a). Furthermore, importing large quantities of nutrients in the form of harvested forages and supplements to a field site, as practiced for bale grazing winter feeding systems, will further alter field nutrient dynamics.

Pioneering studies on nutrient dynamics in soil and forage following bale grazing have reported both environmental benefits and concerns. This includes benefits of bale graze winter feeding systems in terms of increased yield, as well as increased nitrogen (N) and phosphorus (P) recovery, in subsequent forage crops grown following winter bale grazing (Jungnitsch et al. 2011). However, increased nutrient runoff from bale graze sites compared to a control up to two years following winter feeding has also been reported (Chen et al. 2017).

Nutrient balance models are an effective strategy to measure and characterize nutrient dynamics of a specific farm management system and are used around the world to help producers understand and adjust management practices to reduce environmental impact and increase economic benefits (Janzen et al. 2003; Oborn et al. 2003; Oenema et al. 2003; Schroder et al. 2003). Nutrient balance models rely on “the law of conservation of mass” (Oborn et al. 2003), where inputs and outputs of a particular nutrient or element are summed and the resulting surplus or deficit determined. Nutrient budgets are a simplified form of a nutrient balance model compared to detailed mechanistic computer models (e.g., the Integrated Farm System Model; Rotz et al. 2015). Nutrient budgets do not require knowledge of the internal cycling of nutrients within each component of a system. Instead, only measurements of the gross inputs and outputs of a nutrient are required, which are often simpler to obtain from commercial farms. These nutrient budget tools can be applied at various scales, including a farm-gate perspective (broad scale; including a farm’s overall inputs and outputs, only), field or soil-surface perspective (medium scale) and a system-scale perspective (detailed scale; including transfers within the farm), as described by Oborn et al. (2003).

A system-scale nutrient budget is ideal for mapping the transfer of nutrients throughout the many production practices of livestock or mixed farming systems, from feed delivered through to manure deposited and forage harvested (Oborn et al. 2003). Further, system-scale nutrient budgets can be used to complement farm-gate nutrient budgets, by providing a more detailed assessment of the movement of nutrients within a farm and their impact on overall farm nutrient dynamics. Quality assurance and quality control of measurements used to populate a nutrient budget are essential to maintain confidence in results (Oenema et al. 2003). In order to compare results to other production systems, a similar or standard methodology must be used along with an interpretation that includes a solid understanding of the processes regulating nutrient dynamics, and the spatial and temporal variability that may result in differences between the systems (Oborn et al. 2003). An example of a simple nutrient budget tool used by producers for bale grazing is the Nutrient Loading Calculator for In-Field or Extensive Winter Feeding Systems (Agriculture and Agri-Food Canada 2013). This calculator examines potential nutrient loading to a field site from extensive winter management practices during the winter feeding period. However, it does not include the forage or soil components of the system. Alternatively, Jungnitsch et al. (2011) used a nutrient budget approach to map nutrients following the winter feeding period associated with animal, forage and soil components of the system over two growing seasons.

The results obtained from nutrient budgets can also be used to derive indicators including nutrient balance and net utilization efficiency (NUE; the ratio of nutrient outputs to inputs) to evaluate the environmental sustainability of a system (Schroder et al. 2003). Large nutrient surpluses can be directly and indirectly related back to potential nutrient losses to the environment, suggesting an economically and environmentally unfavorable practice (Nevens et al. 2006). Net utilization efficiency can be used to evaluate the flow of nutrients between various compartments within the farm, thereby assessing productivity as well as environmental

(Schroder et al. 2003) and economic performance. These indicators may be used to compare systems and management practices, provided they are derived from the same methodology (Oborn et al. 2003).

The primary objectives of this study were to: 1) develop a system-scale nutrient budget to characterize N and P inputs and outputs in two beef cow winter feeding systems, tracking N and P from feed delivered during the winter feeding period through two subsequent growing seasons, using data from a winter feeding case study examining drylot (DL; intensive) and bale graze with distillers grain supplementation (BGdg; extensive) winter feeding practices; and 2) use these measurements to determine sustainability indicators, including nutrient balance, recovery and efficiency of N and P from the economically viable outputs from the systems, including the cows themselves and forage harvested, as well as residual soil nitrate nitrogen (NO_3-N). These results will be used to identify areas of improvement for winter feeding systems and to direct future research regarding the sustainability of beef cow winter management systems on the Canadian Prairies.

7.3 Characterization Approach

7.3.1 Nutrient Budget Spreadsheet

Following the guidelines suggested by Oborn et al. (2003), a schematic of known pools, inputs, outputs, transfers, gains and losses of N and P within two winter feeding systems used for pregnant beef cows was developed (Figures 7.1 and 7.2). Literature sources were used to identify important nutrient pools and movement of N and P within a cattle winter feeding system (Hass et al. 2002; Oborn et al. 2005; Bassanino et al. 2007; Jungnitsch et al. 2011). Numerical values for the defined inputs and outputs of N and P were then obtained from a beef cow winter feeding case study (Donohoe 2018a and 2018b) to form the basis of the winter feeding system nutrient budget in a simple spreadsheet model. Table 7.1 describes the measurements and estimates used to characterize inputs, transfers and recovery of N and P for each component of the winter feeding system nutrient budget spreadsheet. Inputs to the winter feeding systems included hay, bedding, and supplemental feeds. The mass of stockpiled manure generated and transferred to the DL field site was calculated in order to determine total area required for spreading of DL manure for the DL winter feeding system. Outputs from the winter feeding systems included N and P in cow weight gain and N and P in forage harvested from the land where residual feed and manure were deposited by the cows (BG system) or mechanically applied (DL system).

Values that could not be obtained from the case study were estimated from published literature where possible. If no suitable measurements or literature values were found, a description of "unaccounted for" was used to acknowledge the unknown values, in order to identify the uncertainties in the nutrient budget model (Oenema et al. 2003; Figure 7.1 and 7.2). Gains of N and P that were unaccounted for included biological N fixation and atmospheric deposition of N and P. Atmospheric deposition was considered small and equivalent for the two systems. Biological N fixation was considered minimal as the forage land in the case study was dominated by grass species (Donohoe 2018b). Bale grazing was noted to cause a small decrease in legume species in year two following bale grazing (Donohoe 2018b). The value of N fixed by the legume species present in that study, birdsfoot trefoil (*Lotus corniculatus),* was estimated to be in the range of 56 to 112 kg ha^{-1} y^{-1} for a pure stand (Havlin et al. 2014). However, at only 14 to 23% of the total percent species composition for the BGdg and CON treatments, respectively, the difference in N input between the two treatments was not predicted to be large enough to affect the results of the nutrient budget calculator in the current study.

Losses of N and P from the land base that were considered “unaccounted for” included runoff losses of N and P and gaseous losses of N. Nitrogen and P storage and transformations were not measured or estimated for soil or vegetative matter affected by each winter feeding system. Although these internal flows might have been estimated from literature, they are very sensitive to site specific conditions and values that were relevant to these two systems were not available in the published literature.

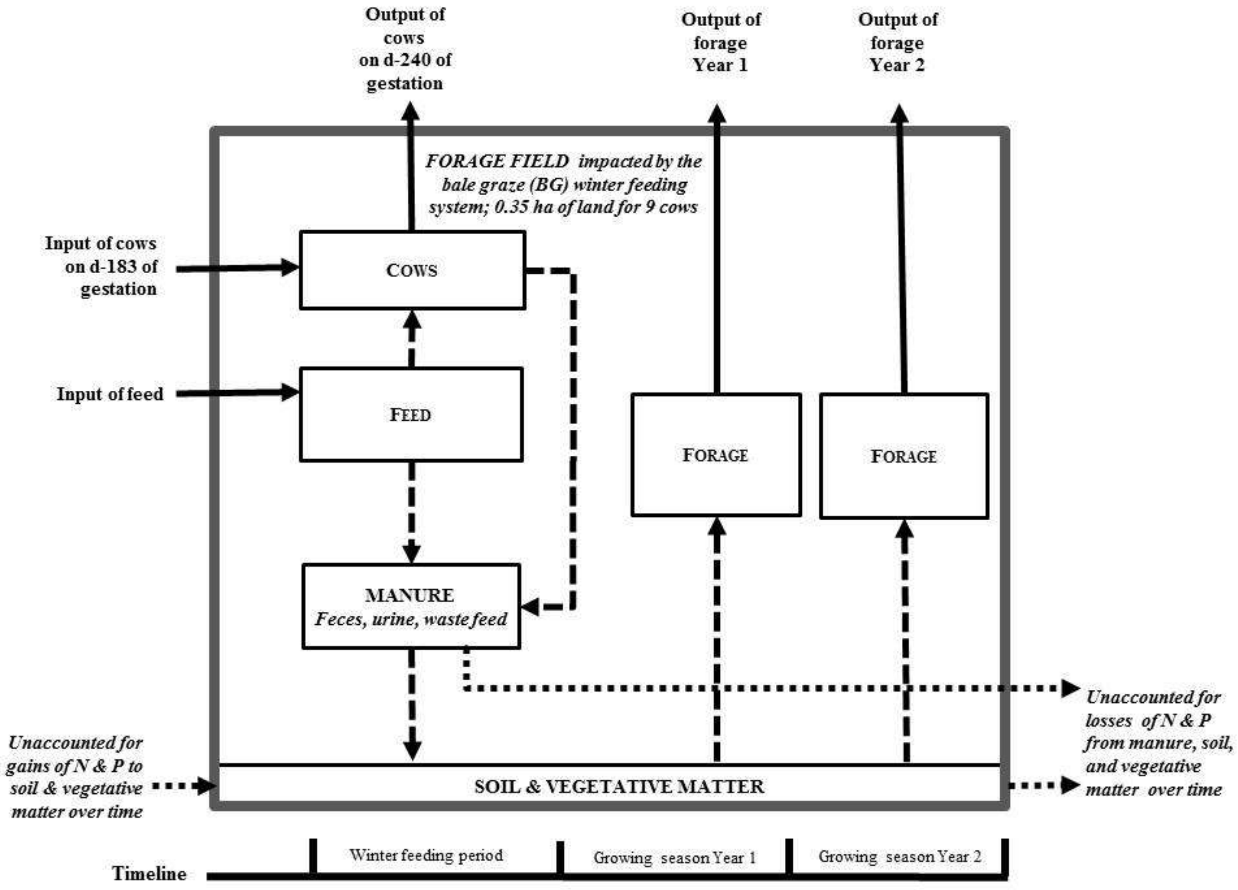

Figure 7.1 Schematic of the mass flows of nitrogen (N) and phosphorus (P) for the bale graze (BGdg) winter feeding case study, where the boundary of the system is the forage field impacted by the winter feeding system (0.35 ha). Inputs and outputs to the system are denoted by solid lines and internal transfers to pools of N and P within the winter feeding system are denoted by long dashed lines. Short-dashed lines indicate unaccounted for gains and losses of N and P to and from the system. Timeline indicates input of cows and output of cows to/from the bale graze field including manure deposition (winter feeding period), forage harvested in the first growing season following bale grazing (growing season Year 1) and forage harvested during the second growing season after winter bale grazing (growing season Year 2)

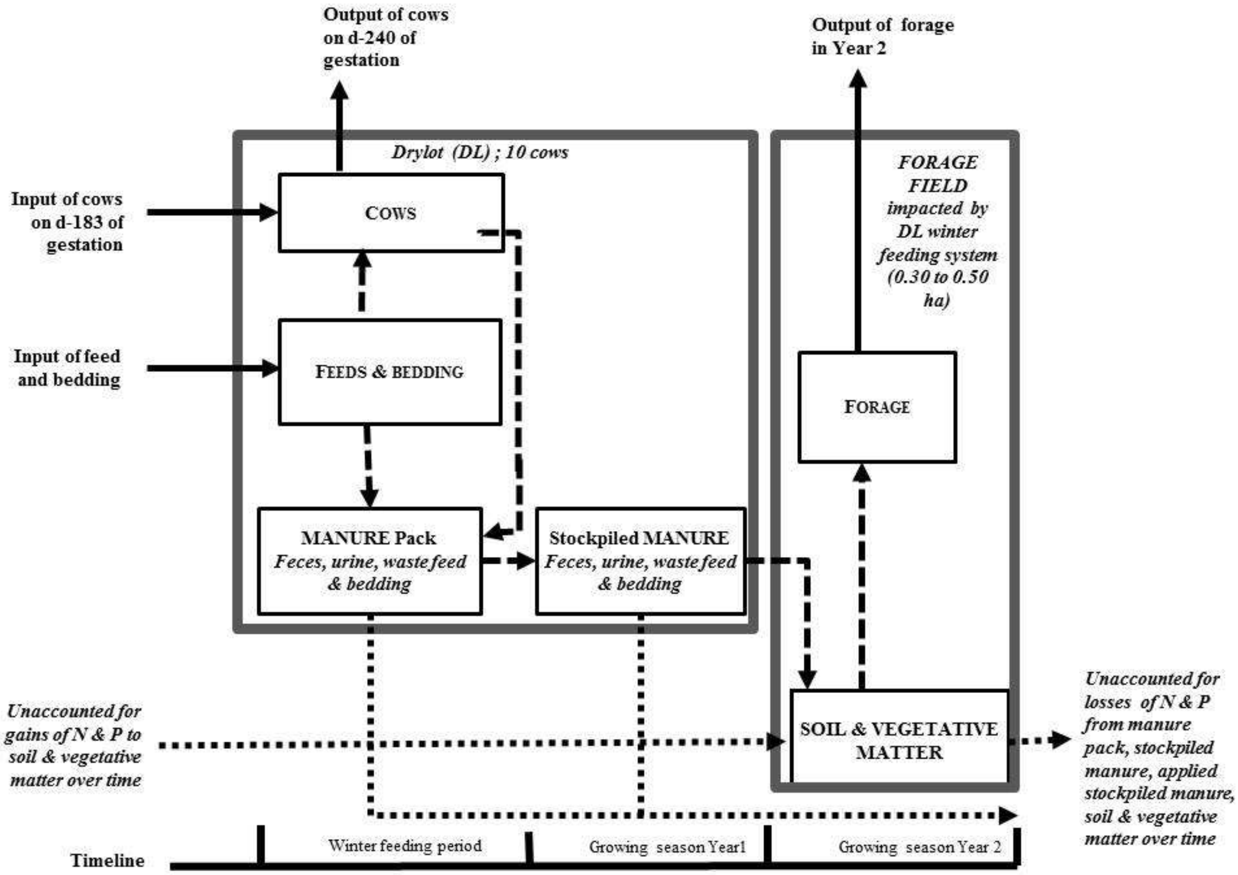

Figure 7.2 Schematic of the mass flows of nitrogen (N) and phosphorus (P) for the drylot (DL) winter feeding case study, where the boundary of the system is the DL and the forage field impacted by the winter feeding system (0.30 to 0.50 ha). Inputs and outputs to the system are denoted by solid lines and internal transfers to pools of N and P within the winter feeding system are denoted by long dashed lines. Short-dashed lines indicate unaccounted for gains and losses of N and P to and from the system. Timeline indicates input of cows and output of cows to/from the DL including manure deposition (winter feeding period) and stockpiling of manure (growing season Year 1), application of stockpiled manure to the forage field site (end of growing season Year 1) and forage harvested in the second year following bale grazing (growing season Year 2)

Table 7.1 Summary of measurements used to characterize inputs, transfers and recovery of N and P in cow, forage and soil components of bale graze with distillers grains (BGdg) and drylot (DL) winter feeding systems for pregnant beef cows

System Component	BGdg	DL
Inputs of N & P to cow winter feeding systems		
Feeds & bedding delivered		
Mass of N & P in hay	Measured (Donohoe 2018a)	
Mass of N & P supplements	Measured (Donohoe 2018a)	
Mass of N & P in bedding	Measured (Donohoe 2018a)	
Transfer of manure within the drylot system		
Stockpiled manure applied to the land base[a]		
Mass of N & P transferred from drylot to the land base	Not applicable	Estimated from Donohoe (2018a), Bernier et al. (2012) and Larney et al. (2006)[b]
Recovery of N & P in cow weight gain & subsequent forage production system		
Recovery in cow weight gain		
Mass of N & P in cow body weight gain[b]	Estimated from Donohoe (2018a) and Berg & Butterfield (1976)	
Mass of N & P in gravid uterus growth[c]	Estimated from Donohoe (2018a), Ferrell et al. (1976; N) and Ferrell et al. (1985; P)	
Recovery in forage harvested[d]		
Mass of N & P in treatment forage harvested minus mass of N & P in control forage harvested	Measured (Donohoe 2018b)	
Change in residual soil nutrients[e]		
Concentration of residual nitrate-N & Olsen P in treatment soil minus concentration of residual nitrate-N & Olsen P in background soil	Measured (Donohoe 2018b)	

[a] Mass of N and P in DL manure was determined from total N and P inputs to the DL. Total quantity of manure dry matter (DM) produced was estimated from measured values of total mass of bedding and waste feed inputs to the DL (Donohoe 2018a), plus DM excretion rates by cows estimated from Bernier et al. (2012). Manure DM loss during stockpiling was then estimated from Larney et al. (2006). Area required for drylot manure application for the drylot winter feeding system was calculated using the measured manure application rate of 67.3 t ha^{-1}, and the estimated total mass of drylot manure after stockpiling

[b] Concentration of N and P in cow body weight gain (cow weight gain minus gravid uterus growth) was estimated as 3% N and 0.84% P of live weight as described in Berg and Butterfield (1976). Balance and recovery of N and P in cow weight gain was then determined as final minus initial mass of N and P of cows over the 57-d overwintering period

[c] Mass of N in gravid uterus was estimated using values ranging from 0.17 % on d 179 of gestation to 0.32% on d 238 as described in Ferrell et al. (1976). Concentration of P in gravid uterus growth was estimated as 0.88 to 2.13 g P d^{-1} as described in Ferrell et al. (1985). Balance and recovery N and P in gravid uterus growth was then determined as final minus initial mass of N and P in the gravid uterus over the 57-d winter feeding period

[d] Bale graze forage harvested included two subsequent growing seasons. As DL manure was stockpiled during growing season Year 1 and spread on the forage field in the fall of Year 1, forage harvested measurements from the control site were used to estimate forage harvested from the DL plots in Year 1. Forage balance of N and P was determined as total N and P in forage harvested minus inputs of N and P. Forage recovery was calculated as treatment forage N and P harvested minus control forage N & P harvested

[e] Change in soil residual nutrients was calculated as the change from initial (background) residual soil nutrient concentration. Soil residual nutrients were sampled before the trial (initial), in the fall of Year 1 and Year 2 on the BG field site, and in the fall of Year 2 on the DL manure field site

Nutrient balance was defined as the gross difference between N and P inputs and outputs for each winter feeding system, with a positive balance indicating accumulation of N and P over time and a negative balance indicating N and P depletion. Measurements from adjacent, unamended (control) forage plots were used to further refine nutrient balance of forage N and P into nutrient recovery, defined as the change in forage yield N and P directly attributed to the winter feeding management practice. A control field site was established on the same forage field as the BGdg and DL field sites, directly adjacent to and the same size as the BGdg site. The control received no winter feeding inputs, fertilizer, manure or amendments. Nutrient recovery in forage harvested was calculated as harvested N and P from treatment forage plots minus harvested N and P in the control plot. Change in residual soil nitrate-N and Olsen P over the whole study was calculated as residual soil test NO_3-N and Olsen P above the background residual soil test N and P measured at the beginning of the study, while annual change in residual soil NO_3-N and Olsen P was calculated as residual soil test NO_3-N and Olsen P above the residual soil test N and P measured for the previous year. Nutrient balance and nutrient recovery of N and P in cow weight gain (cow body weight gain plus gravid uterus growth) were considered to be synonymous in this study; both were calculated on the basis of weight gain in the cow, including gravid uterus, during the winter feeding period. Nutrient use efficiency was then calculated as nutrient recovery divided by total nutrient inputs.

7.3.2 Characterization of Inputs: Case Study

The timeline of monitoring the winter feeding systems included a 57-d winter feeding period (4 Jan 2011 to 2 Mar 2011) and the subsequent two years of forage production as affected by manure and residual feed deposition (from the BGdg system) or application of stockpiled manure (from the DL system). The boundary of the system was defined as the area required for manure deposition or application for a given winter feeding system which fed nine cows (BGdg) or ten cows (DL) for 57 days. The forage land to which the manure was applied was located on the University of Manitoba's Glenlea Research Station (lat. 49.65N, long. 97.13W), on imperfectly drained heavy clay soil with level to nearly level topography, mapped as Scanterbury soil association (Michalyna 1975), which is described as a Gleysolic Humic Vertisol in the Canadian soil classification system and a Typic Humicryert in the U.S. system. This area is part of the Lake Manitoba Plain ecoregion, one of the most humid regions in the Canadian Prairies, with a mean annual temperature of 3^{o}C and annual precipitation ranging between 450 to 700 mm.

As described above, inputs, including pregnant beef cows, feed (hay and supplements) and bedding, were measured over the winter feeding period of the trial as described by Donohoe (2018a). In brief, 40 non-lactating, pregnant beef cows at the end of their second trimester were divided into four groups of similar total body weight. Two groups of animals were assigned to a

BGdg winter feeding system located on a 0.35 ha forage field and two were assigned to a DL winter feeding system. Cows had mean body weights (body weight plus mass of gravid uterus), entering the BGdg and DL systems of 616 ± 39 and 606 ± 32 kg cow^{-1}, respectively. The mass of gravid uterus at the start of the trial was estimated to be 20.4 kg cow^{-1} (Ferrell et al. 1976). The winter feeding period for the trial included a 14-d period to adapt to a new diet in the DL starting on d 22 of the trial. On d 57, cows were removed from the BGdg field site and DL pens. One paddock within the BGdg field site was selected to be sampled intensively for forage yield and residual soil NO_3-N and Olsen P, (Donohoe 2018b); this paddock had one cow removed near the beginning of the trial, leaving nine cows for the remainder of the trial period (Donohoe 2018a).

The diets in both management systems consisted of low-quality hay (8.8% crude protein, 37.6% acid detergent fibre, 62.3% neutral detergent fibre, 0.11% P), fed *ad libitum*, from whole round bales on a 12 m x 12 m spacing in the BGdg treatment and chopped hay (25 to 30 cm in length) delivered in bunks in the DL system. Hay and supplement imported provided adequate nutrition to maintain animal productivity, as was indicated by measurement of dry matter (DM) intake (Donohoe 2018a). Cows were given access to hay in the BGdg treatment as described in Donohoe (2018a). Cows in the BGdg system also received supplemental dried distillers grains with solubles (DDGS) every-third day, delivered in portable feed bunks at the rate of 8.3 kg DM per cow. As DDGS is a low-bloat risk supplement, it can be fed intermittently to reduce labour associated with daily feeding of supplementation in extensive management systems. Cows in the DL treatment received barley supplementation daily at a rate of 0.78 kg DM d^{-1}, starting on d 22 of the trial, as energy requirements increased with increasing days of gestation. Cows in the DL also received straw bedding as needed, while no bedding was provided to cows in the BGdg paddocks as they bedded in waste hay. Table 7.2 provides DM, N and P supplied values for both BGdg and DL management systems.

Table 7.2 Dry matter, N and P inputs delivered in feeds and bedding for bale graze with distillers grains (BGdg) and drylot (DL) winter feeding systems

	BGdg	**DL**[a]
Hay		
DM (kg cow^{-1} d^{-1})	17.3	15.0
N (g cow^{-1} d^{-1})	233	202
P (g cow^{-1} d^{-1})	17.7	15.3
Straw		
DM (kg cow^{-1} d^{-1})	na	9.9
N (g cow^{-1} d^{-1})	na	66.2
P (g cow^{-1} d^{-1})	na	11.5
Dried distillers grains with solubles		
DM (kg cow^{-1} d^{-1})	2.8	na
N (g cow^{-1} d^{-1})	127	na
P (g cow^{-1} d^{-1})	27.4	na
Barley		
DM (kg cow^{-1} d^{-1})	na	0.8
N (g cow^{-1} d^{-1})	na	13.1
P (g cow^{-1} d^{-1})	na	3.4
Total feed & bedding input supplied		
DM (kg cow^{-1} d^{-1})	20.1	25.6
N (g cow^{-1} d^{-1})	361	281
P (g cow^{-1} d^{-1})	45.1	30.2

[a] Expressed on a per animal basis (BGdg n = 9 cows; DL n = 10 cows) for the 57-d winter feeding period

7.3.2.1 Transfer of Manure from the Drylot to the Field Site

Drylot manure was stockpiled on a concrete pad during the first growing season following the winter feeding period. In October, a portion of the DL manure was mechanically applied to the forage field directly adjacent to the BGdg field site, at a rate of 67.3 t ha^{-1} (wet or "as is" basis) on four, 5 m x 15 m treatment plots. The DL field had not received manure or fertilizer application in the past 10 years and consisted of the same species and was under the same managmenet as the BG field. The rate of manure application was similar to the rate used in other cattle winter management studies (67.2 t ha^{-1}; Jungnitsch et al. 2011) and represents typical industry practice.

Nutrient analysis of N and P in DL manure was not used in the nutrient budget spreadsheet. When the manure analysis values were scaled up in the model, N and P generation during the stockpiling process occurred instead of the expected loss. Nitrogen and P concentrations in manure can be highly variable, as manure is a very non-uniform mixture of feces, urine, bedding, and waste feed subject to unmeasured losses during the winter feeding period itself and losses during the stockpiling and application process (Haas et al. 2002; Larney et al. 2006). The most recent update of Beef Cattle Nutrient Requirements (National Academies of Science, Engineering and Medicine 2016), suggests that the highly variable nature of beef cattle manure can lead to errors when manure analyses are used to determine cattle nutrient budgets, particularly for N. Alternatively, total input of N and P in feed, supplements and bedding delivered to the DL was used to determine N and P inputs in the DL system. This approach, using input N and P values instead of manure analysis, allowed direct comparison of the DL and BGdg systems, as inputs of N and P to the BGdg system were also used to create the model, not excretion-based values.

Total mass of DL manure generated over the study from 10 cows (i.e., one pen) was not measured, but rather it was estimated using literature values and used to determine the total land base required for spreading all manure produced during the winter feeding period and subsequently applied at the same rate as in the DL forage treatment plots. To estimate the mass of feces and urine generated during feeding, the mass of hay and supplement imported to the DL (Table 7.2) was reduced by a factor of 49% to account for animal DM retention (Bernier et al.

2014). Then the mass of bedding was added to the estimated mass of feces and urine generated during feeding after animal retention, in order to estimate the total quantity of manure before stockpiling. It should be noted that the amount of straw used for bedding can vary, depending on producer preferences and climate. Dry matter decomposition during stockpiling was then estimated at 26% as described by Larney et al. (2006) for stockpiled manure from a site in Brandon, MB, as measured over a period of 100 to 150 days during the summer and fall months of stockpiling. It should be noted, however, that our case study location generally receives more precipitation on average than Brandon (474 mm). Due to uncertainty and the variability in DM mass balance ratios described by Larney et al. (2006), in addition to the individual value used for the Brandon site, a range of DM decomposition rates were also used to reflect this uncertainty, based on the data collected from all research sites on the Canadian Prairies described by Larney et al. (2006). The average value and the range in decomposition values were then used to estimate the average and also the range in area needed to spread the entire amount of DL manure at the pre-determined rate. The average estimated mass of manure remaining after stockpiling was 7913 kg, as is basis, with a range from 5412 to 8883 kg. The average estimated area needed to spread stockpiled DL manure was 0.45 ha, with a range of from 0.30 to 0.50 ha. These average and range values were used to calculate inputs, balance, recovery and efficiency for the DL system.

The total measured mass of N and P in inputs of feed, supplements, and bedding delivered, along with the area required for bale grazing or spreading DL manure, were used to obtain input values of 536 kg N ha^{-1} and 67 kg P ha^{-1} for the BG system, and 343 kg N ha^{-1} and 39 kg P ha^{-1} (ranging from 321 to 526 kg N ha^{-1} and 34 and 56 kg P ha^{-1}) for the DL system. As is demonstrated in Table 7.2, DDGS appears to be a significant source of N and P input for the

BGdg management system, much larger than the barley supplementation used in the DL management system. Similarly, straw is also an important input of N and P to the DL management system. Nevertheless, despite similar values of total DM input, the BGdg system had a much larger total input of N and P compared to the DL, due to the DDGS supplementation.

7.4 Nitrogen and Phosphorus Balance and Recovery

7.4.1 Recovery of N and P in Cows

Average daily gains were 0.38 and 0.57 kg cow^{-1} d^{-1} for cows, including gravid uterus, in the DL and BGdg systems, respectively, which were both acceptable rates of gain for cows in their 2nd and 3rd trimesters of pregnancy (National Research Council 2000). Mass of gravid uterus was estimated to increase from 20.4 kg to 36.6 kg per cow (as is basis) over the trial, based on days of gestation (Ferrell et al. 1976). Concentration of N in the gravid uterus was assumed to increase from 1.50 to 1.96 % during the 57 days of gestation (Ferrell et al. 1976) and P accumulation in the gravid uterus was estimated to increase from 0.88 to 2.13 g P d^{-1} as described by Ferrell et al. (1982). It should be noted that the cows used in both Ferrell et al. (1976) and Ferrell et al. (1982) were British breeds, with cow body weights that were smaller than in our study, which means that our estimates of mass of N and P retention in the gravid uterus might be low due to underestimation of mass of gravid uterus.

Body mass N (3% live weight) and P (0.84% live weight) concentrations from Berg and Butterfield (1976) were used to estimate gains in the mass of N and P above those of gravid uterus. These values were generated from grazing beef steers, which may have different ratios of fat to muscle compared to mature beef cows, resulting in different concentrations of body mass N and P. However, estimates for mature cows were not found in the published literature.

Based on the calculations listed above, N acquisition in cow weight gain, including gravid uterus growth was estimated to be 10.40 and 4.09 g N cow^{-1} d^{-1} in the BG and DL systems, respectively, and P acquisition was estimated to be 4.46 and 2.75 g P cow^{-1} d^{-1} in the BGdg and DL systems, respectively. When expressed on a kg ha^{-1} basis, 15 and 5 kg N ha^{-1} and 7 and 4 kg P ha^{-1} were recovered in cows from the BGdg and DL systems, respectively (Table 7.3).

7.4.2 Nutrient Balance Before Forage Removal

The balance of N and P before forage removal refers to the amount of N and P provided to the field sites through feed, supplements and bedding, minus the N and P that accumulated as cow weight gain (including gravid uterus growth), but does not include N and P removed in harvested forage, and can also be regarded as N and P loading for the overall system. It should be noted that these values of nutrient balance before forage removal do not account for potential losses of N and P that occurred during the winter feeding period (Figure 7.1a and b).

Table 7.3 Gross input, output and balance of N and P for bale graze with distillers grains (BGdg) and drylot (DL) winter feeding systems

	BGdg		DL	
	kg cow^{-1} ha^{-1} [a]	kg ha^{-1}	kg cow^{-1} ha^{-1} [a]	kg ha^{-1}
Nitrogen				
N inputs in feeds & bedding	59.6	536	36.0	360
N output in cow weight gain[b]	1.7	15.4	0.5	5.2
N balance before forage removal[c]	57.9	521	35.5	355
N output in forage harvested[d]	8.2	73	7.7	70
N balance after forage removal[e]	49.7	448	27.8	285
Phosphorus				
P inputs in feeds & bedding	7.4	67	3.9	39
P output in cow weight gain[b]	0.7	6.6	0.4	3.5
P balance before forage removal[c]	6.7	60	3.5	35.5
P output in forage harvested[d]	0.9	8.3	1.1	9.8
P balance after forage removal[e]	5.8	52	2.4	25.7

[a] Expressed on a per animal basis (BGdg n = 9 cows; DL n = 10 cows), per ha of forage land impacted by each system from manure deposition (BGdg = 0.35 ha) or manure application (DL = 0.45 ha)

[b] Includes N and P in cow body weight gain and in gravid uterus growth

[c] Balance was calculated as inputs in feeds & bedding minus output in cow weight gain

[d] Gross forage yield, harvested over two growing seasons. As DL manure was stockpiled during growing season of Year 1 and spread on the forage field in the fall of Year 1, forage measurements from the an untreated control were used to estimate forage harvested from the DL plots in Year 1

[e] Balance was calculated as inputs in feeds & bedding minus output in cow weight gain plus forage harvested

Nutrient balance before forage removal at the end of the winter feeding period was 521 kg N ha^{-1} and 355 kg N ha^{-1} for the BGdg and DL systems, respectively, with a range of 315 to 521 kg N ha^{-1} for the DL system depending on stockpiled manure DM decomposition rates. Balance of P before forage removal was 60 kg P ha^{-1} for the BG system and 35 kg P ha^{-1} for the DL system, with a range of 31 to 53 kg P ha^{-1} for the DL system. Nitrogen and P balance before forage removal (Table 7.3) demonstrates that cows removed very little of the N and P imported to the site, leaving large amounts of nutrients potentially available for forage crop growth.

7.4.3 Balance and Recovery of N and P in Forage and Soil

Forage and soil sampling and analyses for the BGdg system were completed as described in Donohoe (2018b). In brief, forage samples were collected in the growing season and soil samples collected in the fall to determine residual soil nutrient status, in Year 1 and Year 2 following the winter feeding period (Donohoe 2018b). Forage sample DM mass and forage nutrient analyses were used to determine total mass of DM, N and P harvested from the BGdg site in the growing season Year 1 and Year 2 following bale grazing. Soil residual nitrate-N (NO_3-N) and Olsen P analyses for the BGdg system were used to estimate potentially available N and P for the forage crop in the following growing season.

In growing season Year 1, forage harvested from the DL field treatment plot area was estimated, along with soil residual nutrient status, using the measurements from the unamended control field. Forage and soil samples for the DL manure plots were sampled in the Year 2 growing season, following similar methods and analysis for the BGdg and control plots as described in Donohoe (2018b), with the exception that 15 quadrat forage sub-samples and 15 soil cores per DL spread manure treatment were collected randomly across the DL treatment prior to being composited for analysis, instead of using a grid pattern as was the case in the BGdg and BGdg control field sites.

Table 7.4 Net recovery of input feeds and bedding N and P in cow weight gain and forage harvested, and change in soil residual NO_3-N and Olsen P, for bale graze with distillers grains (BGdg) and drylot (DL) winter feeding systems

	BGdg		DL	
	g cow^{-1} d^{-1a}	kg cow^{-1} ha^{-1b}	g cow^{-1} d^{-1a}	kg cow^{-1} ha^{-1b}
Recovery in cow weight gain[c]				
N	10.40	1.72	4.09	0.52
P	4.46	0.73	2.75	0.35
Recovery in forage harvested[d]				
N	-1.86	-0.31	-5.04	-0.65
P	-0.53	-0.09	0.56	-0.07
Recovery in cows & forage				
N	8.54	1.41	-0.95	-0.13
P	3.93	0.64	2.19	0.28
Change in residual soil nutrients[e]				
NO_3-N	-5.87	-0.97	-3.22	-0.41
Olsen P	2.38	0.39	2.34	0.30

[a] Expressed on a per animal basis (BG n = 9 cows; DL n = 10 cows) for the 57-d winter feeding period

[b] Expressed on a per animal basis (BGdg n = 9 cows; DL n = 10 cows) per ha of forage land impacted by each system from manure deposition (BGdg = 0.35 ha) or stockpiled manure application (DL = 0.45 ha)

[c] Recovery of N and P in cow weight gain was determined as final minus initial mass of N and P of cows over the 57-d winter feeding period. Cow body weight gain (live weight basis) plus gravid uterus growth were 34 and 22 kg per cow over 57 days for BGdg and DL winter feeding systems, respectively

[d] Recovery of N and P in forage harvested was calculated as N and P uptake in treatment forage harvested minus N and P uptake in forage harvested from an adjacent untreated forage field (control). Cumulative gross forage DM yield over two growing seasons was 5409 kg ha^{-1} for the BGdg system and 5752 kg ha^{-1} for the DL. Gross forage DM yield for the unamended control was 6266 kg ha^{-1} over two growing seasons

[e] Change in residual soil nutrients was calculated as final (background) minus initial soil residual nutrient concentration

Removal of N and P in forage harvested from the BGdg system and from the land associated with the DL system occurred once in growing season Year 1, due to lack of moisture during the latter part of the first growing season and twice (i.e., two cuts) in growing season

Year 2. Total DM harvested over two growing seasons was 5408 and 5752 kg DM ha^{-1}, total N harvested was 73 and 70 kg N ha^{-1} and total P harvested was 8 and 8 kg P ha^{-1} from the forage associated with the BGdg and DL winter feeding systems, respectively (Table 7.3).

Nutrient balance was calculated as the total N and P input minus the total N and P output, where output included forage yield and cow weight gain, including gravid uterus. Nutrient balance following forage harvest in Year 2 was 448 and 285 kg N ha^{-1}, and 52 and 26 kg P ha^{-1}, for the BGdg and DL systems, respectively (Table 7.3). The DL system had balance values that ranged from 246 to 451 kg N ha^{-1} and 21 to 43 kg P ha^{-1}. Both systems therefore resulted in a substantial surplus of N and P on their respective field sites following two years of forage production and harvest.

To account for the effect of the winter feeding system, recovery of N and P in forage was determined. As is demonstrated in Table 7.4, despite the large nutrient surpluses, recovery of N and P in cow weight gain had the greatest impact on recovery in the first two years following winter feeding. Both systems resulted in negative forage recovery values, because neither management system improved forage yield significantly over the control forage yield in the first two years following winter feeding. As described in Donohoe (2018b), lack of forage response was due to a combination of forage smothering from manure, the slow, long-term release of the non-labile N contained in solid manure and waste feed, plus high background concentrations of soil nutrients, which allowed the control forage plots to remain relatively productive, despite limited inputs of N or P.

Changes in soil residual nutrients demonstrated that soil residual Olsen P was accumulating over time and at a similar rate in both systems. The soil residual nitrate changes were negative and again fairly similar in both treatments, with the BGdg system losing slightly more N over time, compared to the DL system.

7.4.4 Efficiency of N and P Recovery from Winter Feeding System Inputs

Efficiency in this study is defined as nutrient recovery (i.e., removal of N and P in cow weight gain and forage recovery), divided by the nutrient input to the system (i.e., cow feeds, supplements and bedding). Efficiency of N and P recovery for each economically important output of the system in Year 1 and Year 2 was determined, including: i) cow weight gain (including gravid uterus), ii) forage recovery (forage yield for treated minus unamended control) and iii) combined cow and forage removal. Efficiencies were calculated with and without changes in soil residual NO_3-N, which indicates potentially plant available N for the following growing season.

Efficiency of both winter feeding systems, including N and P recovered in cows and forage, was extremely low, particularly for N, at 2.4% and -0.3% N for the BGdg and DL systems, respectively (Table 7.5). The DL system had a range in efficiencies of +/- 0.2% to account for the variability in estimates for N supplied with the application of stockpiled manure. The negative N recovery in forage, at -0.5 and -1.8% of N inputs for the BGdg and DL systems, respectively, decreased the overall efficiency of N in the winter feeding systems, compared to the efficiency of N recovery in the cows, alone. Similar to the recovery results provided in Table 7.4, the values presented in Table 7.5 demonstrate that efficiency of N and P recovery in cows was greater than in forage, and cows were the most efficient nutrient output of the system at 2.9 and 1.5% efficiency for N inputs and 9.9 and 10.0% efficiency for P inputs in the BGdg and DL systems, respectively. The addition of soil residual nitrate nitrogen to the calculation did not improve efficiency over time, as the amount of available soil residual N decreased over time, likely due to plant uptake of available soil residual N as is indicated by increased DM harvested over time. Phosphorus efficiency was similar in both management systems, with overall efficiencies of 8.7 and 12.1 % P for the BGdg and DL systems, respectively, when P recovery in the cows and forage was added together.

Table 7.5 Efficiency of net N and P recovery from feed and bedding inputs for bale graze with distillers grains (BGdg) and drylot (DL) winter feeding systems and two subsequent growing seasons of perennial forage

	BGdg			**DL**		
	Year 1	Year 2	Total	Year 1	Year 2	Total
	% of total feed and bedding inputs					
Efficiency of N recovery as:						
Cow weight gain[a]	2.9	na[b]	2.9	1.5	na[b]	1.5
Forage harvested	-0.9	0.4	-0.5	na[c]	-1.8	-1.8
Total recovery in cows + forage	2.0	0.4	2.4	1.5	-1.8	-0.3
Change in residual soil NO_3-N[d]	1.0	-2.7	-1.6[e]	na	-1.1	-1.1[v]
Total recovery in cows+forage+soil	3.0	-2.3	0.7	1.5	-2.9	-1.4
Efficiency of P recovery as:						
Cow weight gain[a]	9.9	na[b]	9.9	10.0	na[b]	10.0
Forage harvested	-1.4	0.2	-1.2	na[c]	2.1	2.1
Total recovery in cows + forage	8.5	0.2	8.7	10.0	2.1	12.1

[a] Cow weight gain includes cow body weight gain plus gravid uterus growth

[b] Output of cow weight gain only occurred in yr 1 of the case study

[c] Forage recovery was calculated as treatment forage harvested minus the unamended control. As DL manure was stockpiled during the summer of Year 1 and spread on the forage field in the fall of Year 1, control forage measurements were used to estimate forage harvested from the DL plots in Year 1

[d] Yearly change in soil residual NO_3-N (0 – 60 cm) was calculated from annual change in soil residual NO_3-N, expressed as a proportion of the total N imported

[e] Total change in soil residual NO_3-N was calculated as initial minus final soil residual NO_3-N

7.5 Discussion

7.5.1 Measuring Environmental Sustainability of Cattle Winter Feeding Systems

The system-scale nutrient budget approach provided new insights regarding the nutrient-use efficiency, and potential environmental sustainability, of two beef-cow winter feeding systems. The surplus of N and P, with low values of residual soil nitrate-N and Olsen P in soil, in both winter feeding systems, suggested possible environmental losses of N and P (Powell et al. 2002; van Beek et al. 2003; Cherry et al 2012) or, alternatively, indicated that these standard soil fertility tests were unable to account for stable forms of N and P stored in soil and organic matter.

A portion of the surplus N remaining on the BGdg field site may have been in organic forms, particularly in the waste feed areas or “hot spots” at bale locations, as these organic forms are largely unaccounted for in the soil measurements used in the case study. Twenty-one percent of hay delivered was estimated to be wasted in the BGdg system and left to decompose on the soil surface (Donohoe 2018a). The majority (90%) of the N excreted in feces from cows fed low-quality forage with and without DDGS supplementation (Bernier et al. 2014), as well as, in waste hay and straw, is in stable organic or non-labile forms. As forage production was monitored in the BGdg system for only two growing seasons following winter feeding, there is no data to indicate whether the BGdg system resulted in greater forage productivity from the slow release of organic and non-labile forms of N stored in soil, manure and waste feed in later years. However, visual observations at the site in subsequent years indicated that this was probably the case.

Other nutrient balance studies have found that surplus N balance is a good indication of increased N loss to water and mitigation practices to decrease surplus N balance have correlated with lower risk of nutrient losses to water (Schroder et al. 2003; van Beek et al. 2003; Cherry et al. 2012). Powell et al. (2002) also suggested that reducing P surplus will decrease environmental impact of P from farms. If a portion of the surpluses of N and P determined were in labile forms, these nutrients were at risk of being lost to the environment before being incorporated into stable pools of soil N and P, especially considering timing of nutrient input to the field sites did not coincide with nutrient uptake by plants.

Assuming some of the surplus N and P that was unaccounted for was lost, it is also important to note that the two winter feeding systems may have been vulnerable to different types of N and P losses at different times of the year. Losses of labile surplus N and P from the BGdg system may have occurred during the winter feeding period via ammonia volatilization from feces and urine deposited on the frozen soil or snow pack. Loss of ammoniacal N via ammonia volatilization has been reported at temperatures below 0^{o}C (Engel et al. 2011). The spring melt/thaw period may have also been a period of substantial loss or transport from the BGdg site, when available or labile N and P excreted onto snow and nutrients in waste feed can be transported in water moving laterally across the frozen soil surface (Chen et al. 2017). As well, gaseous losses of available N can occur in much more substantial quantities in the spring from patches of urine and feces on forage fields, once the temperatures increase above 0^{o}C, via ammonia volatilization and via denitrification (Donohoe 2011). It is important to note that losses of labile nutrients to the atmosphere or surface water from a BGdg site are also highly dependent on climate, landscape and soil conditions (Alberta Agriculture and Rural Development 2013).

Assuming the N loading rate (N input minus N removed in cow weight gain and gravid uterus) was calculated as 100% excreted N minus 21% hay delivered N (Table 7.2; Donohoe 2018a), and that 47 to 55% of the total N excreted by cows was in urine, and that 44 to 64% of this urine N was in labile forms (Bernier et al. 2014), we estimate that potentially 98-167 kg N ha^{-1}, or 22 to 37% of the surplus N, may have been in deposited as labile forms of N on the BGdg field during the winter feeding period, with the remainder (63 to 78%) in organic or non-labile forms. This pool of labile N may have been taken up by plants (64 kg ha^{-1} in year one following bale grazing), immobilized by microorganisms into soil organic matter, or may have been volatilized, denitrified or transported in snow melt or runoff following the winter feeding period. Low values of mean residual soil NO_3-N were measured in both years following bale grazing, ranging from 5 to 12 kg N ha^{-1}, with residual soil NO_3-N in the Control of 4 kg NO_3-N ha^{-1}, suggesting that very little available N remained in the soil surface (0-60 cm) following bale grazing (Donohoe et al. 2018b). Chen et al. (2017) found 3 to 11% of total N imported was lost in runoff from their BG site. The current study site had little to no slope compared to the site used by Chen et al. (2017); therefore, run-off losses of N were assumed to be minimal, although transport of N within the site via snow melt may have occurred. Chen et al. (2017) imported only 265 to 354 kg N ha^{-1} to their bale grazed sites, 50 to 66% of the total N imported to the BGdg field in our study, so there may be potential for runoff losses to be greater than 3 to 11% with increased available N imported to the site.

Phosphorus excretion is primarily in feces (98%), although DDGS supplementation can increase urine P excretion up to 26% of total P excretion (Bernier et al. 2014). Using the same strategy that was used to estimate N loading (i.e., P input minus P removed in cow weight gain, including gravid uterus) and assuming 100% P excretion via feces, with 39 to 44% of fecal P in a water soluble form (Bernier et al. 2014), up to 22 to 25 kg P ha^{-1} of fecal P, or 42 to 48% of the surplus P balance, may have been deposited in water-soluble forms on the BGdg field site. This water soluble P may have been taken up by plants (8 kg ha^{-1} first summer following bale grazing), retained by soil or transported in runoff water. Soil Olsen P in the first fall following bale grazing ranged from 10 to 11 kg ha^{-1}, similar to the ranges found in the Control treatment. Chen et al. (2017) observed that approximately 3 to 10% of total P input was lost in surface water runoff from their bale grazed site the year following bale grazing. Again, the lack of slope in the current study site would suggest a low range of P loss in runoff, although the Chen et al. (2017) study imported only 47 to 71 kg P ha^{-1} to their bale grazed sites, which is only 24 to 44% of the total P imported to the BG study in our study.

In the DL system, heat generated in manure bedding packs (Boadi et al. 2004) may have promoted ammonia volatilization from the manure pack during the winter feeding period resulting in losses of labile N. Losses of total N, ranging from 0.4 to 49%, and total P, up to 36%, were also expected to occur from the DL manure over the stockpiling period (Larney et al. 2006). Furthermore, losses of inorganic N from the DL manure may have occurred following field application (up to 41% losses of total ammoniacal N; McGinn and Sommer 2007). Using N loading rates, we can estimate that up to 15 to 180 kg N ha^{-1} and up to 128 kg P ha^{-1} may have been lost during the stockpiling period alone, depending on temperature and moisture conditions of the year. The lack of a heat-generating manure pack and lack of stockpiling and application of manure may have reduced losses of N and P from the BGdg system over the winter feeding period, compared to those that occurred throughout the DL system.

The use of DDGS supplementation in the BGdg system resulted in greater field loading of N and P compared to the DL system, and may have resulted in the addition of more labile N and P to the BGdg soil and forage system (Bernier et al. 2014). However, the use of DDGS in the BGdg system did not substantially change the recovery and efficiency of N in forage harvested compared to the DL, as both were similarly low, suggesting that plants did not have opportunity to use the imported N and P on the field sites, due to timing of application of labile nutrients. The similar recoveries of soil residual nitrate-N and Olsen-P in both winter feeding systems also support this hypothesis. The inclusion of DDGS supplementation in the BGdg system is not unrealistic in cold environments. As noted in Donohoe. (2018a) and previous studies (Kelln et al. 2012b), cows overwintered extensively on the Canadian Prairies may require extra energy and protein supplementation, such as DDGS, to maintain body weight in years with extreme cold winter weather. Grass forage harvested across the Canadian Prairies may be low in crude protein and energy, as indicated in a survey of 17 samples collected across Saskatchewan (Ministry of Agriculture 2013) with crude protein ranging from 6.0 to 12.7 % (average 9.3%, DM basis), and total digestible nutrients ranging from 47.7 to 59.0% DM (average 57.6%, DM basis). As mid to late stage gestation beef cows require 7 to 10% crude protein and 55 to 60% energy, grass hay may not meet the nutrient requirements of extensively grazed cattle. An intensive overwintering system, with less walking, less foraging, and heat generated from the bedding pack (Boadi et al. 2004; Donohoe 2018a), may not need supplementation to the same extent as an extensive winter feeding environment to meet animal nutrient requirements. The addition of DDGS to the extensive system in this case study ensured that animals did not lose body weight and condition during the trial. The use of DDGS also helped keep inputs (i.e., labour and fuel/equipment usage) to a minimum by enabling supplementation every third day, which is not possible with a high starch supplement such as barley.

One might speculate that the inclusion of a supplement with a low concentration of N and P, like barley, might have led to a different conclusion in terms of nutrient use efficiency for the BGdg treatment. Using the nutrient budget spreadsheet to test this hypothesis, we calculated that total efficiency (cows + forage) would have been only slightly greater, 2.5% for N and 17.6% for P if barley had been fed in the BGdg treatment at a rate of 1.2 kg cow^{-1}d^{-1}, assuming no change in cow and forage productivity.

Jungnitsch et al. (2011) reported 30 to 40% N efficiency and 20 to 30% P efficiency from their bale graze site after a 130-d wintering period and two years of forage growth. The difference in the efficiencies observed by the Jungnitsch et al. (2011) study and our case study appears to be largely due to the difference in forage recovery of N and P. Jungnitsch et al. (2011) reported a 3-fold increase in bale graze forage yields over control forage yields, with a control forage yield of 2355 kg ha^{-1} over two growing seasons. These yields for the control treatment are much lower than our BGdg control plot forage yield of 6266 kg ha^{-1} over two growing seasons. The soil type and climate in the Jungnitsch et al. (2011) study were not as productive as the soil type and climate in the Red River Valley, probably due to lower soil nutrient status and soil moisture limiting forage productivity in Jungnitsch's study. These differences in climate and soil productivity may affect response of forage to manure application.

The nutrient budget spreadsheet was used to test the hypothesis that low N and P recovery and efficiencies in our study were attributed mainly to treatment forage yields that were less than or equivalent to the control forage yield. Using a hypothetical forage yield increase of 2500 kg ha^{-1} in both Year 1 and Year 2 following bale grazing, similar to the mass of increased forage yield achieved in Jungnitsch et al. (2011), total efficiency values (cow + forage) would have been 13.5% N and 18.3% P for the BGdg treatment. Therefore, if cattle manure and waste feed application from our winter feeding systems had increased harvestable forage yield, it would have increased the efficiency of both the BGdg and DL systems substantially. The low forage yield and recovery values measured in this study may be, in part, due to immobilization of N following manure application (Holt and Zentner 1985; Qian and Schoenau, 2002; Jungnitsch et al. 2011) and the smothering of forage by waste feed in the extensive system (Donohoe 2018b). However, it is also important to recognize that the potential for increased forage yield of the grass forage species in this study may have already been near maximum potential. Honey (2013) reported average tame forage yields across Manitoba of 3715 kg ha^{-1} in 2012, 4171 kg ha^{-1} in 2011 and 3629 kg ha^{-1} in 2010, with tame hay including alfalfa and other legume forage crops. The control forage yields measured at our study site therefore suggest that the control plots were close to the provincial average forage yields in 2012 without inputs of N and P. Site selection is therefore an important consideration for realizing maximum benefits of bale grazing and beef cow manure application, and sites with low forage yields due to poor soil fertility may realize greater efficiency of N and P inputs from bale grazing or manure application.

The potential to increase cattle productivity as a means to increase nutrient use efficiency is unlikely in the overwintering system studied. Predicted average daily gain of the gravid uterus for cows by the end of the trial, approximately 238 days of gestation, was 0.49 kg cow^{-1} d^{-1} (NASEM 2016). The BGdg treatment had an average daily gain over the study of 0.54 kg cow^{-1} d^{-1}, with 0.79 kg cow^{-1} d^{-1} achieved in the DL (Donohoe 2018a). Therefore a scenario to increase nutrient uptake above these weight gain values is unlikely.

7.5.2 Value of the Nutrient Budget Approach

Cattle winter feeding systems are highly complex, including livestock, soil and forage components. As a consequence of the complexity and heterogeneity of these systems, there is merit in utilizing a simplified nutrient budget approach to help standardize the methodology needed to evaluate the potential sustainability of these systems (Oborn et al. 2003; Oenema et al. 2003). Jungnitsch et al. (2011), for example, provided a wealth of information regarding nutrient balance on winter feeding system field sites. However, direct comparison of their results to the current case study is challenging due to differences in methodology, as well as differences in other variables in the sites and production systems that may affect interpretation of the results.

The system-scale nutrient budget template allows a robust approach to measure inputs and outputs. The measurement of cow weight gain, including gravid uterus, to determine cow recovered N and P, rather than using a nutrient excretion based model, is an example of the merit of this approach. In fact, using excretion based models to determine N balance is not recommended by the NRC (National Academies of Science, Engineering and Medicine 2016). Models based on nutrient excretion can contain uncertainty, particularly for N, as it is readily lost to the environment prior to and during excreta collection, resulting in overestimation of N retention and overestimation of N efficiency for cows. Similarly, using total DL inputs, instead of manure analysis, to determine N and P inputs to the DL field site, eliminates much of the uncertainty associated with nutrient concentrations in solid cattle manure. The highly variable physical nature of solid manure, especially manure with bedding, can lead to substantial errors in the accuracy of sampling and analyses (Haas et al. 2002; Larney et al 2006).

Nevertheless, it is important to note that there are many variables that must be considered when interpreting or applying nutrient balance, recovery and efficiency results (Oborn et al. 2003). For extensive winter feeding systems, these variables may include environmental factors such as temperature, soil type, snow pack depth, the time of year of winter feeding, as well as management factors such as the size, quality and spacing of bales, supplements and bedding provided and type of field used; all of which can vary on an annual basis. An intensive overwintering system may differ in many of these aspects, as well as, length of time of stockpiling manure and manure application rate. Despite using a standardized methodology, comparison of the results from the BGdg and DL overwintering systems was difficult due to the fundamental differences in the systems. However, there is merit in comparing the results, in order to identify differences in terms of soil and field nutrient dynamics. Further, it is important to note that many producers use both types of overwintering systems, but vary their preference with different times of the year.

7.5.3 Gaps in Knowledge and Direction for Future Research

The nutrient budget approach used in this study served to identify several important gaps in knowledge associated with beef cow winter feeding systems that should be the subject of future research in this area. Although measuring inputs and outputs in cow and gravid uterus was considered a more robust approach than using a nutrient excretion based model, there were several shortcomings which included a lack of literature values for nutrient retention in the pregnant, non-lactating beef cow fed low-quality forages. Nutrient losses to the environment were unaccounted for in the model; however, literature suggests they account for at least a portion of the observed low recovery and efficiency values for N and P, with 22 to 37% of the surplus N and 42 to 48% of the surplus P in the BGdg system estimated to be desposited in labile forms and vulnerable to losses during the winter and spring thaw periods. In the DL system, 15 to 180 kg N ha^{-1} and 128 kg P ha^{-1} may have been lost during the winter and manure stockpiling periods. Quantifying all forms of N and P remaining on the field sites in soil, waste feed and manure, is necessary to improve our ability to forecast the agronomic and environmental availability of these nutrients. Measuring long-term forage yields, beyond the two years following the overwintering period measured in this study from the winter feeding field sites is also necessary for this evaluation.

7.6 Conclusions

A system-scale nutrient budget approach was used to provide a description of overall N and P inputs, outputs, balance, recovery and efficiency for BGdg and DL winter feeding system and provided insight regarding possible gains and losses from the system. Bale grazing and drylot manure application on fertile clay soil in a sub-humid climate had inputs of 361 and 281 kg N cow^{-1} d^{-1} and 45 and 30 kg P cow^{-1} d^{-1} for BGdg and DL overwintering systems, respectively. Recovery of input nutrients in cows and forage harvested was 1.41 and -0.13 kg N ha^{-1} and 0.64 and 0.28 kg P ha^{-1} for BGdg and DL overwintering systems, respectively. Efficiency of recovery of nutrients in cows and forage was 2.4 and -0.3 % N and 8.7 and 12.1 % P for BGdg and DL overwintering systems, respectively. Increased nutrient uptake in forage harvested was identified as the management practice with the greatest potential to increase nutrient use efficiency, estimated to increase N and P efficiency to 13.5% and 18.3%, respectively, in the BGdg treatment. The large surpluses of N and P in both systems suggest potential losses of P and N during and after the winter feeding period. Long-term studies are needed to further understand and potentially improve the efficiency of using surplus N and P to increase crop production over time.

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8.0 SYNTHESIS

8.1 Significance and Implications

The overwintering period represents a significant portion of the cow-calf production cycle and can include a variety of management strategies, including both intensive and extensive practices. Assessing the sustainability of these overwintering systems in order to identify appropriate management practices for producers is a key step for improving the overall sustainability of the beef cattle industry. The biggest challenge in assessing sustainability is a lack of knowledge in some of the key areas of the overwintering production cycle. The information gathered in this thesis will help to build the database of overwintering system knowledge. Chapter 4 provided much needed information on animal intake and productivity, enteric methane and animal energetics for pregnant overwintering beef cows in both intensive and extensive overwintering systems, with or without supplementation with DDGS. Chapter 5 characterized forage and soil nutrient response in the first two years following winter grazing of pregnant beef cows supplemented with DDGS in a subhumid climate on clay soils. Chapter 6 evaluated soil sampling strategies used to determine soil nutrient status following bale grazing on a forage field in order to accurately determine field mean nutrient status. Chapter 7 combined animal productivity and soil and forage measurements from Chapters 4 and 5 to calculate nutrient balance of N and P in extensive and intensive overwintering systems, and the resulting N and P efficiency. Overall, bale grazing on clay soils in a sub-humid climate had similar N and P efficiency compared to overwintering in a drylot when measured over a two-year period. Long-term (i.e., greater than two years) implications of bale grazing in a sub-humid environment on clay soils need to be taken into consideration when evaluating the sustainability of winter management practices. Ensuring diet as well as site selection and management are not increasing risk of loss of labile N and P to the environment are important considerations when selecting an overwintering management strategy.

8.1.1 Animal Response to Extensive vs. Intensive Overwintering

Our hypothesis, that energy requirements of cows in an extensive overwintering management system (BGcon) would be greater than in an intensive system (DL), was proven to be true. Cows in the BGcon overwintering system had similar DMI, decreased ADG and increased CH_4 emissions compared to cows on the same diet in the DL overwintering system in P1. Although the difference in energy requirements could not be quantified, we believe that the cows in the extensive system were unable to increase DMI and that low protein to energy ratios prevented them from compensating for increased energy demands in the extensive overwintering environment.

This is the first dataset to determine individual DMI from extensively overwintered cows. Dry matter intakes are necessary to determine if nutrients consumed meet nutrient requirements in these extreme environments, characterized by increased exposure to wind, increased walking and foraging compared to traditional overwintering environments. Estimates of intake in concert with accurate animal requirements can in turn be used to calculate excretion rates and nutrient deposition to the field site. Intake and animal weight gain data is essential in terms of suppling data on system nutrient dynamics and necessary for determining N and P inputs and outputs for nutrient balance and efficiency indicators.

As this is the first study to measure enteric methane from extensively overwintered beef cows, this data has the potential to be used to track energy inputs and outputs throughout the system as well, as methane is a form of energy loss. The negative ADG during Period 1 for the BGcon treatment highlights the importance of ensuring nutrient requirements are met and that wind and temperature extremes can lead to increased energy expenditure.

Further, the different diets used in the trial will aid in assessing strategies for reducing enteric methane emissions from both an ecological and economic perspective. Balancing increased supplementation and the costs associated with supplementation compared to decreased methane emissions and increased nutrient excretion requires further exploration. In Manitoba, for example, protection of surface water quality may prove to be more important than decreased methane emissions. However, decreased methane emissions often equates to improved energy efficiency and long-term profitability of the cow herd.

Finally, NRC 2016 recommended nutrient requirements were not adequate for animals in extensive overwintering environments, which fundamentally differ as a consequence of increased exposure to wind and cold, as well as increased activity levels and lack of a heated bedding pack. Therefore, more research is still needed in the areas of animal behavior and energetics in extensive winter grazing systems in order to address these gaps in knowledge.

8.1.2 Characterization of Forage and Soils

The impact of winter bale grazing cattle extensively on forage and soil nutrient status in a sub-humid climate on clay soils was surprising, as forage yield was decreased in the first growing season following bale grazing, and therefore, our hypothesis was rejected. As such, these results emphasize the need for longer-term studies and studies in different climates and locations in order to ensure that indicators developed for overwintering practices will accurately assess the impact of bale grazing across a range of forage and soil conditions. Strategies such as harrowing waste feed packs might help to alleviate the depressed forage yields in the first year following bale grazing. However, a producer must consider the cost of increased mechanization and labour compared to the potential increase in forage productivity, from both an economic perspective and a nutrient and energy balance perspective. The forage DM yields and N and P removal in forage harvested, along with soil N and P status, were key components of determining system balance and efficiency indicators. Measuring N and P remaining in waste feed left on the soil surface is important to measure in future trials, to help understand the rates of decomposition and turnover of available nutrients to the soil surface.

8.1.3 Soil Sampling Strategies for BG Fields

Our hypothesis that a systematic sampling protocol was required, rather than a random field sampling protocol, was proven true for soil sampling residual NO_3-N. Residual Olsen P variability was not as great as NO_3-N, and if a bale grazing site is sampled only for P, a random sampling strategy may be sufficient, provided enough composite samples are collected.

The error associated with collecting too few samples, particularly in hot-spots, can lead to errors in fertility recommendations, in particular overestimation of plant available soil N. Overestimating soil nutrient status can result in overestimating the nutrient capture and efficiency of the system and underestimating potential losses of N as well. As long-term studies on winter bale grazing sites are recommended, the suggested soil sampling protocols will provide a more economical and accurate approach for future research projects.

8.1.4. Nutrient Balance Model

Our hypothesis that bale grazing would increase efficiency of N and P capture compared to an intensive overwintering system was rejected. Although numerical values for the efficiency of N and P capture in the animal, forage and soil system components, as well as overall, were slightly greater for the BG treatment compared to the DL treatment, efficiencies were extremely low across both intensive and extensive overwintering systems. The low forage DM yields following bale grazing, as reported in Chapter 5, was likely the primary factor associated with these results.

The nutrient balance reported in Chapter 7 utilized data from Chapter 4 (animal data) and Chapter 5 (forage and soil) and synthesized the data to create an overall indication of nutrient sustainability. This was a challenging exercise in terms of converting measurements taken from animals and soil/forage into similar units of measure, and ensuring limitations of these measurements were accurately described, interpreted, and expressed. Developing indicators using systematic strategies and protocols ensures that results are collected and interpreted in a manner that can be compared against other management strategies and systems. Using a field scale nutrient balance approach was a key strategy used in Chapter 7 to ensure calculations were expressed from an equivalent landbase perspective for both intensive and extensive systems. Using measurements of system inputs and outputs, instead of mapping internal flows of nutrients was another key strategy used in the nutrient balance model. Errors in measurements can lead to large errors in estimating outputs, particularly when determining N content in animal excreta. Measurements of sustainability are not possible without coordination of both animal and soil and forage measurements and planning of trials to incorporate these measurements into trial design is a necessary strategy to ensure quality data collection.

The results of the nutrient balance calculator suggest that beef cow overwintering systems are poor at recycling N and P back into forage production over the short-term. However, long-term N and P efficiency is unknown, as long-term studies have not been conducted for extensive or intensive beef cow wintering systems. This is surprising given the large portion of the beef production cycle that takes place overwinter and the increasing popularity of extensive winter mananagemnt strategies.

It is important to note that N and P recovery represent only a portion of overall system sustainability and conclusions regarding sustainability of overwintering management practices must include other components of sustainability, such as GHG emissions, water quality and energy balance, as well as the social and economic implications. We can conclude that, based on the data collected in this study and literature references, the ecological sustainability of overwintering management practices will depend greatly on the location of the farm, quality of feed for cattle, period of time of measurement, and implementation of management strategies such as dispersion of waste feed, field size, bale size and spacing and forage quality, which all have economic benefits and consequences as well. Determining the overall benefit to the producer and the environment in the long-term is an important challenge that still remains for future beef cow research on the Canadian Prairies. Furthering these studies to include soil GHGs as a measurement of unknown losses of N would be an important next step in determining system sustainability.

8.2 Limitations

Several key limitations complicated the data analysis and interpretation of results that are important to note for the design of future overwintering studies.

The addition of barley to the BGcon diet in Period 2 restricted use of the alkane technique to estimate individual animal intake, as delivery of alkane-marked barley to cows individually in the field was neither practical nor feasible. Alkane fecal analysis revealed that quantities of C_{27} in feces was extremely variable between cows and days, indicating that cows were not consistently eating the same amount of barley at each feeding, leading to highly variable and inconsistent estiamtes of intake via the alkane technique. Determining new methods of measuring intake in extensive environments or designing a method to deliver supplementation individually in the field is essential for future research for extensive overwintering systems, considering the importance of supplementation to maintain productivity during extremely cold weather.

The use of DDGS supplemented paddocks in the forage and soils studies, due to spring flooding of the other treatment paddocks, complicated the results of the forage and soil nutrient dynamics and the interpretation of the nutrient balance and efficiency indicators. Although supplementation is more likely to be required in extensive than confined overwintering systems, we were not able to determine whether the efficiency of nutrient recovery by cows would be greater than in a feeding system that did not provide supplemental feed. We can only speculate that if DDGS was not supplied, cow weight gain may have been decreased and nutrient input of N and P to the system would have been decreased, as well. Increasing nutrient input did not directly correlate to increased forage yields and nutrient outputs in winter beef cow feeding systems, and balancing animal productivity with forage and soil recovery is an important consideration when recommending management strategies.

Estimating mass of drylot manure and land base required for manure spreading added additional uncertainty to the nutrient balance calculator. With more resources, these values could have been measured more directly and future trials should include these measurements in their trial design. Measuring the quantity of N and P remaining in waste feed on the soil surface would have been a useful measure to help understand whether N and P imported to the site had been lost to the environment or was simply in forms that we were unable to account for with our measurement techniques. Lastly, longer-term study of the forage fields would have allowed us to determine if the waste feed on the soil surface would have continued to provide nutrient input to the soil in future years (i.e., 5, 10, 15 years), increasing forage productivity over the long-term. Increased forage producity over time may increase the nutrient use of efficiency for N and P in bale graze overwintering sites.

8.3 Future Work

There are still many gaps in knowledge required to complete our understanding of beef cow overwintering system sustainability. The research presented in this thesis provides several key pieces of information which will aid in our understanding of the environmental implications of winter feeding systems. Other gaps in knowledge that should be addressed include:

- Soil and manure GHG (N_2O, CH_4, CO_2) and ammonia emissions from overwintering beef cow practices

- Impact of overwintering management strategy on C sequestration, biodiversity of flora and fauna in the soil and forage systems and energy flows
- Beef cow behavior and energy expenditure associated with extensive grazing systems
- Long-term impact of bale grazing and other extensive management strategies on forage productivity in various soils and climates (i.e. 5 years, 10 years, 15 years)
- Social and economic implications of beef cow overwintering practices

Sustainability includes economic and social implications as well as long-term effects on the environment. Future, long-term research projects need to be designed to address these gaps in knowledge, keeping in mind the linkages between the animal, forage and soil components of the system. Understanding how these linkages work together, on different soil types and in different climates, will help us make management decisions that promote environmental sustainability, economic feasibility and social acceptability of beef cattle production systems.

9.0 APPENDICES

9.1 Appendix 1: Characterization of Forage and Soils Following Bale Grazing

Table 9.1 Descriptive statistics for DM yield, and forage quality including crude protein (CP), total digestible nutrients (TDN), P, K, Ca and Mg in forage subsamples harvested from the bale graze (BG) and control (CON) plots during the first (GS1) and second (GS2) growing seasons following winter bale grazing (*n* = 100 subsamples for each treatment)

Year	**Treatment**	**Statistic**	**Yield**	**CP**	**TDN**	**P**	**K**	**Ca**	**Mg**
			kg DM ha^{-1}	**g kg^{-1} DM**					
GS1	**BG**	**Median**	2791	68.3	585	1.30	16.2	3.20	1.80
		Minimum	0	51.4	559	0.80	11.6	1.62	1.21
		Maximum	9090	231	629	4.21	32.2	9.73	3.43
		Mean	3096	75.3	585	1.47	17.6	3.61	1.92
	CON	**Median**	3831	61.1	573	1.30	14.2	2.50	1.50
		Min	1861	40.4	548	0.52	11.3	1.54	1.11
		Max	7374	108	598	1.63	20.4	6.21	2.43
		Mean	3962	63.7	573	2.01	14.3	2.71	1.54
GS2	**BG**	**Median**	2080	91.1	615	1.46	14.9	4.93	2.61
		Minimum	725	69.2	474	1.09	8.66	3.23	1.83
		Maximum	6553	164	649	3.41	24.7	10.4	4.29
		Mean	2312	96.0	614	1.59	15.0	5.31	2.73
	CON	**Median**	2258	94.3	615	1.62	13.5	5.22	2.47
		Min	727	77.6	596	1.26	9.5	3.73	1.98
		Max	4641	150	632	2.52	18.9	10.5	3.94
		Mean	2304	95.2	615	1.64	13.7	5.47	2.56

Table 9.2 Descriptive statistics for grass tetany ratio (determined in mEq kg^{-1}) as measured in forage subsamples harvested from bale graze (BG) and control (CON) plots in the first (GS1) and second (GS2) growing seasons following winter bale grazing (*n* = 100)

Year	Treatment	Statistic	Grass tetany ratio
GS1	**BG**	**Median**	1.40
		Minimum	0.85
		Maximum	2.33
		Mean	1.41
	Control	**Median**	1.44
		Min	0.95
		Max	2.10
		Mean	1.44
GS2	**BG**	**Median**	0.81
		Minimum	0.25
		Maximum	1.92
		Mean	0.82
	Control	**Median**	0.78
		Min	0.34
		Max	1.73
		Mean	0.80

Table 9.3 Descriptive statistics for percent species composition measured in the second (GS2) growing season following winter bale grazing on the bale graze (BG) and control (CON) plots (*n* = 50)

Year	Treatment	Statistic	Legumes	Grass	Weeds	Other
			%			
GS2	**BG**	**Median**	5	80	10	0
		Minimum	0	30	0	0
		Maximum	60	100	54	30
		Mean	12	75	12	1
	CON	**Median**	15	75	5	0
		Min	0	15	0	0
		Max	80	100	25	10
		Mean	23	70	7	0.2

Table 9.4 Descriptive statistics for residual soil NO_3-N (0-60 cm), and Olsen P and exchangeable (Exch.) K, Mg, and Ca (0 to 15 cm) for the bale graze (BG) and ungrazed (CON) plots during the first fall (Fall1) and second fall (Fall2) after winter bale grazing (*n* = 250 individual soil subsamples for each treatment)

Year	Treatment	Statistic	NO_3-N	Olsen P	Exch. K	Exch. Ca	Exch. Mg
			kg ha^{-1}				
Fall1	BG	Median	6.12	8.06	947	9480	3851
		Minimum	1.43	2.15	622	7575	2181
		Maximum	240	33.7	1462	15808	7801
		Mean	21.2	10.2	965	9698	3650
	CON	Median	3.61	9.63	1026	10096	3940
		Min	1.11	4.17	835	8089	3240
		Max	69.5	29.3	1247	11944	4665
		Mean	5.91	9.75	1025	10074	3961
Fall2	BG	Median	4.00	7.88	914	9456	3657
		Minimum	0.21	2.51	521	8054	2577
		Maximum	106	55.2	1666	11469	4944
		Mean	8.01	11.4	936	9524	3557
	CON	Median	4.56	8.08	987	10230	3947
		Min	1.51	2.51	819	8729	3522
		Max	18.3	20.7	1144	12466	4572
		Mean	5.30	8.49	991	10218	3943

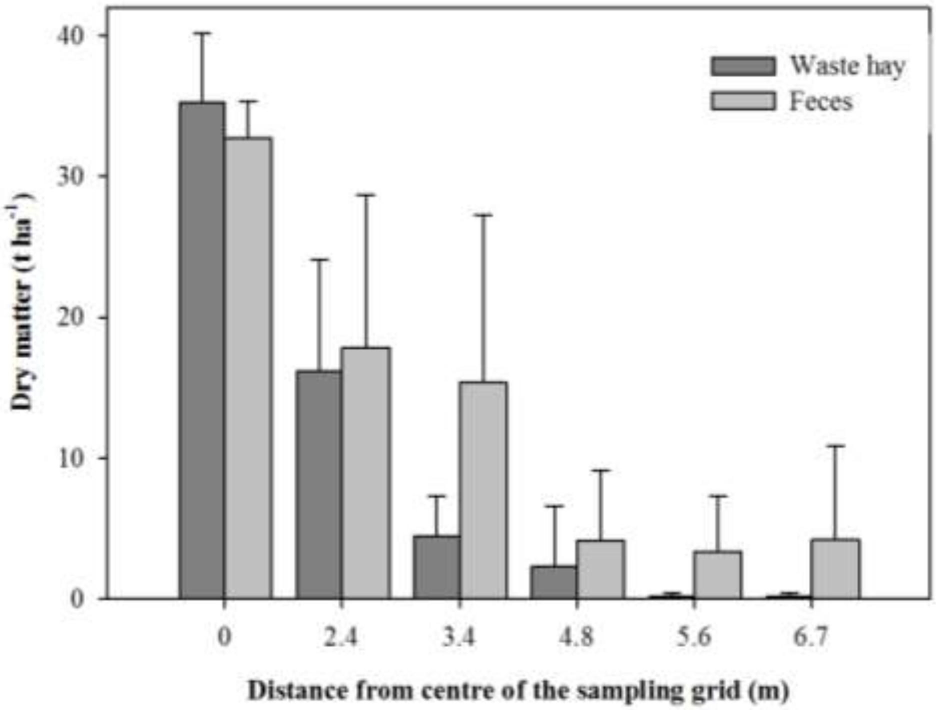

Figure 9.1 Distribution of waste hay and feces measured after spring thaw following winter bale grazing of two bales grazed overwinter. Error bars indicated standard deviation of the mean (*n* = 2 bales, with 1 to 8 cells per distance from the centre of each bale grazed plot)

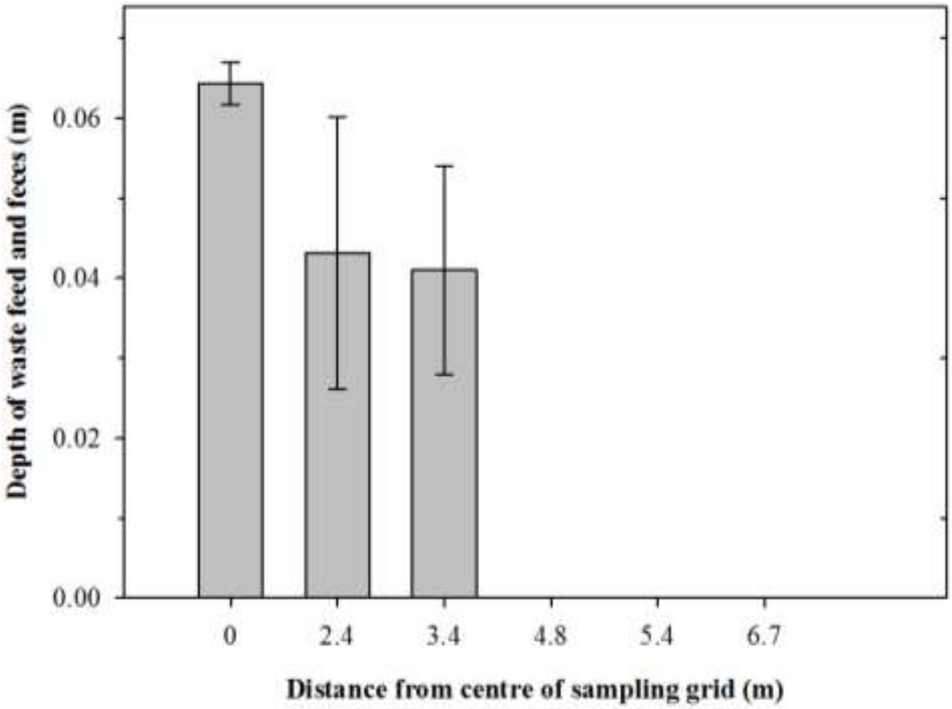

Figure 9.2 Depth (m) of waste feed and feces remaining on the soil surface as measured from two BG plots in the second (Fall2) fall following winter bale grazing. Error bars indicate standard deviation of the mean (*n* = 2 bales, with 1 to 8 cells per distance from the centre of each bale grazed plot)

9.2 Appendix 2: Soil Sampling Methodology

Table 9.5 Variables used for the test of homogeneity of coefficients of variation for soil Olsen P using Sampling Strategy 1, with estimated means determined by using an increasing number of randomly collected soil subsamples (0 to 15 cm) from a bale grazed and ungrazed (control) forage field at the end of the growing season in the first fall (Fall1) and second fall (Fall2) after winter bale grazing

Treatment and sampling time	**Number of subsamples**[a]	**Estimated mean Olsen P**[a]	**CV**[a]	**V*p***[b]	**Z**[c]	***P***
	N	*kg P ha*$^{-1}$				
BG Fall1	20	9.46	0.17	0.08	7.50	<.0001
	30	9.58	0.13	0.08	5.91	<.0001
	40	9.69	0.14	0.08	6.72	<.0001
	50	9.61	0.09	0.07	3.42	0.0002
	60	9.63	0.08	0.07	2.70	0.0017
	70	9.65	0.08	0.07	1.94	0.0131
	80	9.71	0.07	0.06	0.62	0.1338
	90	9.87	0.06	0.06	-0.20	0.2891
	100	9.64	0.06	*na*[d]	*na*[d]	*na*[d]
CON Fall1	20	9.69	0.06	0.03	6.43	<.0001
	30	9.61	0.05	0.03	6.60	<.0001
	40	9.78	0.04	0.03	5.10	<.0001
	50	9.71	0.04	0.03	3.76	<.0001
	60	9.69	0.03	0.03	2.40	0.0041
	70	9.77	0.03	0.03	1.15	0.0629
	80	9.75	0.02	0.02	0.39	0.1745
	90	9.74	0.02	0.02	-0.81	0.3950
	100	9.73	0.02	*na*[d]	*na*[d]	*na*[d]
BG Fall2	20	9.49	0.19	0.08	9.15	<.0001
	30	9.56	0.16	0.08	8.08	<.0001
	40	9.72	0.14	0.08	7.69	<.0001
	50	9.43	0.10	0.07	4.45	<.0001
	60	9.60	0.10	0.08	5.11	<.0001
	70	9.54	0.10	0.07	4.39	<.0001
	80	9.60	0.09	0.07	3.57	<.0001
	90	9.58	0.08	0.07	2.86	0.0011
	100	9.68	0.06	*na*[d]	*na*[d]	*na*[d]
CON Fall2	20	8.74	0.10	0.04	9.21	<.0001
	30	8.80	0.06	0.04	6.21	<.0001
	40	8.74	0.06	0.04	6.26	<.0001
	50	8.78	0.05	0.04	4.52	<.0001
	60	8.83	0.04	0.03	2.85	0.0011
	70	8.86	0.04	0.03	2.05	0.0102
	80	8.77	0.04	0.03	2.71	0.0017
	90	8.68	0.03	0.03	0.91	0.0901
	100	8.72	0.03	*na*[d]	*na*[d]	*na*[d]

[a] Each estimated mean represents 100 means randomly generated from 20 to 100 subsamples (n_c) in the original dataset (n = 200). Coefficient of variation (CV) describes the percent deviation of the estimated

mean, divided by 100, for each subsample number category. The maximum number of soil samples that could be practically collected from a field site was considered to be $n = 100$

[b] Pooled variance of the estimated mean for a given n and the maximum number of subsamples

[c] Test statistic Z was used to determine if the pooled variance is common to all populations ($P \geq 0.05$) or if the variances between the two populations are different ($P < 0.05$)

[d] Not applicable (*na*) to be compared in the test for homogeneity of coefficients of variation as $n = 100$ was considered the maximum number of soil subsamples collected

Table 9.6 Table of variables used for the test of homogeneity of coefficients of variation for soil residual nitrate-nitrogen (N) using Sampling Strategy 1, with estimated means determined by using an increasing number of randomly collected soil subsamples (0 to 15 cm) from a bale grazed and ungrazed (control) forage field at the end of the growing season in the first fall (Fall1) and second fall (Fall2) after winter bale grazing

Treatment and sampling time	**Number of subsamples**[a]	**Estimated mean nitrate-N**[a]	**CV**[a]	**V*p***[b]	**Z**[c]	***P***
	n	*kg N ha*$^{-1}$				
BG Fall1	20	15.87	0.71	0.29	8.85	<.0001
	30	16.96	0.55	0.29	7.23	<.0001
	40	16.45	0.42	0.27	5.23	<.0001
	50	15.12	0.42	0.28	5.54	<.0001
	60	15.83	0.36	0.27	4.31	<.0001
	70	16.22	0.35	0.27	4.31	<.0001
	80	16.47	0.29	0.25	2.78	0.0014
	90	16.77	0.26	0.24	1.83	0.0167
	100	17.20	0.21	*na*[d]	*na*[d]	*na*[d]
CON Fall1	20	2.55	0.25	0.16	10.47	<.0001
	30	2.44	0.18	0.13	8.07	<.0001
	40	2.39	0.14	0.11	5.76	<.0001
	50	2.46	0.14	0.11	5.79	<.0001
	60	2.49	0.12	0.10	4.47	<.0001
	70	2.44	0.11	0.09	3.73	<.0001
	80	2.42	0.10	0.09	2.94	0.0008
	90	2.45	0.08	0.08	0.96	0.0837
	100	2.46	0.08	*na*[d]	*na*[d]	*na*[d]
BG Fall2	20	1.60	1.05	0.43	8.17	<.0001
	30	2.01	0.77	0.42	6.32	<.0001
	40	1.73	0.63	0.40	6.08	<0001
	50	1.92	0.55	0.39	4.26	<.0001
	60	1.82	0.52	0.39	3.96	<.0001
	70	1.72	0.42	0.36	2.39	0.0042
	80	1.77	0.43	0.37	2.62	0.0022
	90	1.78	0.36	0.33	1.06	0.0728
	100	1.81	0.36	*na*[d]	*na*[d]	*na*[d]
CON Fall2	20	1.05	0.17	0.07	9.75	<.0001
	30	1.07	0.12	0.06	6.85	<.0001
	40	1.05	0.11	0.07	6.39	<.0001
	50	1.05	0.09	0.06	5.09	<.0001
	60	1.06	0.08	0.06	3.66	<.0001
	70	1.05	0.06	0.06	2.23	0.0064
	80	1.05	0.06	0.05	1.48	0.0350
	90	1.05	0.05	0.05	0.73	0.1167
	100	1.05	0.05	*na*[d]	*na*[d]	*na*[d]

[a] Each estimated mean represents 100 means randomly generated from 20 to 100 subsamples (*n*) in the original dataset (*n* = 200). Coefficient of variation (CV) describes the percent deviation of the estimated mean, divided by 100, for each subsample number category. The maximum number of soil samples that could be practically collected from a field site was considered to be *n* = 100

[b] Pooled variance of the estimated mean for a given n and the maximum number of subsamples

[c] Test statistic Z was used to determine if the pooled variance is common to all populations ($P \geq 0.05$) or if the variances between the two populations are different ($P < 0.05$)

[d] Not applicable (*na*) to be compared in the test for homogeneity of coefficients of variation as $n = 100$ was considered the maximum number of soil subsamples collected

Table 9.7 Variables used for the test of homogeneity of coefficients of variation for soil Olsen phosphorus (P) using Sampling Strategy 2, with estimated means determined by using an increasing number of randomly collected soil subsamples (0 to 15 cm) from areas of a bale grazed forage field affected and unaffected by waste feed at the end of the growing season in the first fall (Fall1) and second fall (Fall2) after winter bale grazing

Treatment and sampling time	Number of subsamples	Mean Olsen P	CV	V*p*	Z	*P*
	n	*kg P ha*$^{-1}$				
Waste feed - affected Fall1	4	17.6	0.41	0.07	12.33	<.0001
	8	17.5	0.28	0.08	10.10	<.0001
	10	17.7	0.25	0.08	9.28	<.0001
	16	17.0	0.15	0.07	6.93	<.0001
	20	71.6	0.11	0.07	5.48	<.0001
	25	17.1	0.10	0.08	1.73	0.0210
	30	17.5	0.07	0.05	3.32	0.0002
	32	17.1	0.07	0.07	-0.59	0.3615
	35	17.5	0.07	*na*[d]	*na*[d]	*na*[d]
Unaffected Fall1	20	8.0	0.09	0.03	10.68	<.0001
	30	7.9	0.06	0.03	8.03	<.0001
	40	7.7	0.06	0.03	7.47	<.0001
	50	7.8	0.05	0.03	5.61	<.0001
	60	7.9	0.04	0.03	5.38	<.0001
	70	7.9	0.03	0.03	3.31	0.0005
	80	7.9	0.03	0.03	3.22	0.0003
	90	7.9	0.03	0.03	1.31	0.0476
	100	7.9	0.03	*na*[d]	*na*[d]	*na*[d]
Waste feed - affected Fall2	4	19.5	0.29	0.07	7.43	<.0001
	8	18.1	0.20	0.08	6.04	<.0001
	10	17.2	0.16	0.08	5.18	<.0001
	16	19.9	0.13	0.08	4.49	<.0001
	20	19.5	0.11	0.08	3.76	<.0001
	25	18.9	0.05	0..06	0.05	0.2398
	30	20.4	0.06	0.06	0.49	0.1559
	32	19.8	0.06	0.06	0.002	0.2494
	35	19.8	0.06	*na*[d]	*na*[d]	*na*[d]
Unaffected Fall2	20	6.64	0.08	0.04	5.21	<.0001
	30	6.79	0.07	0.05	5.39	<.0001
	40	7.12	0.08	0.05	6.96	<.0001
	50	7.12	0.06	0.05	4.47	<.0001
	60	7.22	0.06	0.05	4.37	<.0001
	70	7.14	0.05	0.04	1.81	0.0176
	80	7.21	0.04	0.04	0.04	0.2407
	90	7.18	0.03	0.03	-1.22	0.4442
	100	7.16	0.03	*na*[d]	*na*[d]	*na*[d]

[a] Each estimated mean represents 100 means randomly generated from 4 to 100 subsamples (*n*) in the original dataset of a areas affected (*n* = 165) or unaffected (*n* = 35)by waste feed. Coefficient of variation (CV) describes the percent deviation of the estimated mean, divided by 100, for each subsample number

category. The maximum number of soil samples that could be practically collected from a field site was considered to be $n = 100$ for areas unaffected or $n = 35$ for areas affected by waste feed

[b] Pooled variance of the estimated mean for a given n and the maximum number of subsamples

[c] Test statistic Z was used to determine if the pooled variance is common to all populations ($P \geq 0.05$) or if the variances between the two populations are different ($P < 0.05$)

[d] Not applicable (*na*) to be compared in the test for homogeneity of coefficients of variation as n=100 or n = 35 was considered the maximum number of soil subsamples collected for areas unaffected or affected by waste feed, respectively

Table 9.8 Variables used for the test of homogeneity of coefficients of variation for residual soil nitrate-nitrogen (N) using Sampling Strategy 2, with estimated means determined by using an increasing number of randomly collected soil subsamples (0 to 15 cm) from areas of a bale grazed forage field affected and unaffected by waste feed at the end of the growing season in the first fall (Fall1) and second fall (Fall2) after winter bale grazing

Treatment and sampling time	Number of subsamples	Mean NO_3-N	CV	V*p*	Z	*P*
	n	*kg N ha*$^{-1}$				
Waste feed - affected Fall1	4	73.4	0.75	0.13	12.53	<.0001
	8	72.3	0.43	0.13	9.17	<.0001
	10	74.7	0.36	0.13	8.13	<.0001
	16	76.7	0.26	0.13	6.54	<.0001
	20	72.7	0.20	0.12	5.52	<.0001
	25	74.4	0.15	0.08	7.38	<.0001
	30	75.4	0.09	0.08	1.44	0.0377
	32	74.8	0.07	0.07	-4.4	0.2500
	35	74.5	0.07	*na*[d]	*na*[d]	*na*[d]
Unaffected Fall1	20	4.87	0.27	0.11	10.15	<.0001
	30	4.82	0.20	0.10	8.28	<.0001
	40	4.60	0.15	0.09	5.68	<.0001
	50	4.64	0.14	0.10	5.37	<.0001
	60	4.62	0.12	0.09	4.40	<.0001
	70	4.66	0.12	0.09	3.96	<.0001
	80	4.70	0.07	0.07	-0.05	0.2601
	90	4.66	0.08	0.08	0.20	0.2113
	100	4.68	0.07	*na*[d]	*na*[d]	*na*[d]
Waste feed - affected Fall2	4	6.32	1.30	1.04	4.16	<.0001
	8	7.08	0.80	0.65	4.72	<.0001
	10	7.15	0.74	0.61	4.72	<.0001
	16	7.32	0.47	0.40	4.17	<.0001
	20	7.24	0.38	0.26	3.50	0.0001
	25	6.89	0.31	0.24	2.62	0.0022
	30	7.07	0.23	0.21	1.01	0.0777
	32	4.59	0.17	0.18	-0.62	0.3665
	35	7.01	0.19	*na*[d]	*na*[d]	*na*[d]
Unaffected Fall2	20	0.63	0.21	0.09	9.20	<.0001
	30	0.64	0.20	0.09	9.39	<.0001
	40	0.64	0.16	0.09	7.56	<.0001
	50	0.63	0.12	0.08	5.08	<.0001
	60	0.62	0.11	0.08	5.15	<.0001
	70	0.64	0.10	0.08	3.62	<.0001
	80	0.63	0.07	0.07	0.99	0.0803
	90	0.63	0.07	0.06	0.27	0.1975
	100	0.63	0.06	*na*[d]	*na*[d]	*na*[d]

[a] Each estimated mean represents 100 means randomly generated from 4 to 100 subsamples (*n*) in the original dataset of a areas affected (*n* = 165) or unaffected (*n* = 35)by waste feed. Coefficient of variation (CV) describes the percent deviation of the estimated mean, divided by 100, for each subsample number category. The maximum number of soil samples that could be practically collected from a field site was considered to be *n*=100 for areas unaffected or *n* = 35 for areas affected by waste feed

[b] Pooled variance of the estimated mean for a given *n* and the maximum number of subsamples

[c] Test statistic Z was used to determine if the pooled variance is common to all populations ($P \geq 0.05$) or if the variances between the two populations are different ($P < 0.05$)

[d] Not applicable (*na*) to be compared in the test for homogeneity of coefficients of variation as $n = 100$ or $n = 35$ was considered the maximum number of soil subsamples collected for areas unaffected or affected by waste feed, respectively