Utilization of Stockpiled Perennial Forages in Winter Feeding Systems for Beef Cattle

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By
Ruwini S. K. Dharmasiri Gamage
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ABSTRACT

Two experiments were conducted to determine the effects of grazing stockpiled perennial forage in field paddocks relative to feeding similar quality round bale hay in drylot pens on rumen degradation characteristics of forage; beef cow performance, cow reproductive efficiency, estimated dry matter intake and forage utilization, forage yield and quality, soil nutrients and system costs. Winter feeding systems were (i) stockpiled perennial forage (TDN = 58.9%; CP = 8.5%) grazing (SPF) and (ii) drylot feeding (DL) of round bale hay (TDN = 57.9%; CP = 8.4%).

Experiment I was an *in situ* study, where five Hereford heifers (398 ± 14 kg) fitted with rumen cannulae were fed a grass hay (DM = 93.2%; TDN = 50.8%; CP = 9.8%; NDF = 66.2%) diet. *In situ* degradability of both stockpiled forage (SPF) and round bale hay (BH) samples collected at start (October) and end (December) of the field study were determined. The soluble fraction (S) of DM was greater (P = 0.01) in SPF October forage compared to SPF December, BH October and BH December forages. The potentially degradable fraction (D) of CP was lowest (P = 0.04) in BH December forage than in SPF October, SPF December and BH October forages suggesting that hay quality declined more rapidly than stockpiled forage and method of preservation may have affected overall hay quality. Furthermore, D fraction of both ADF and NDF was higher in SPF samples suggesting stockpiled forage may be more digestible than hay. However, the D fraction of NDF in both SPF and BH forages declined with later sampling date possibly due to effect of weathering and leaf loss.

In Experiment II, 6, 4-ha paddocks consisting of meadow bromegrass (*Bromus riparius* Rehm**)** and alfalfa (*Medicago sativa*), were randomly assigned to 1 of 2 replicated (n = 3) winter feeding systems. In this study 58 dry pregnant (120 ± 16 d) Angus cows (675 kg ± 51 kg), stratified by body weight (BW; corrected for conceptus gain), were allocated to either the SPF or

DL systems. Cows in winter feeding systems were provided additional energy supplement (rolled barley) (TDN = 86.4%; CP = 12.4%) depending on environmental conditions to maintain body condition, with no weight gain above that of conceptus growth. Dry matter intake (DMI) and forage utilization were estimated using the herbage weight disappearance method. The effects of winter feeding systems on soil nutrients were determined the following spring after winter grazing. Forage yield in DL (4683 ± 495 kg ha^{-1}) and SPF (4032 ± 495 kg ha^{-1}) systems was not different ($P = 0.18$) between treatments. However, forage utilization was lower ($P < 0.01$) in SPF (83.5%) than the DL (94.4%) system, signifying lower accessibility to stockpiled forage due to snow depth, lower temperatures, freezing rain and wind. Cows in the SPF system had higher forage DMI ($P = 0.04$) and supplementation intake ($P < 0.01$) compared to cows in drylot pens likely a combined effect of effective ambient temperatures below the lower critical temperature (LCT) during the grazing period and the higher potentially digestible fraction of neutral detergent fiber in stockpiled forage than hay. Cow BW change, average daily gain, rib fat change and rump fat change were not different ($P > 0.05$) between winter feeding systems. Reproductive performance of beef cows was not affected ($P > 0.05$) by either winter feeding methods as cows in both systems maintained body condition score (BCS) at 2.5 to 3.0 throughout the study. Average total production cost was 19% lower in SPF system compared to DL system. In conclusion, the rumen degradation characteristics of stockpiled perennial forages focused in this study support the utilization these forages in a winter feeding system to meet the nutrient requirements of dry beef cows in early to mid-gestation. It may be cost effective to manage beef cows in field grazing of stockpiled perennial forages in western Canada, without any negative impact on beef cow performance or reproductive efficiency.

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ADF	Acid detergent fiber
AOAC	Association of official analytical chemists
BCS	Body condition score
BH	Round bale hay
CP	Crude protein
D	Potentially degradable fraction
DE	Digestible energy
DL	Drylot
DM	Dry matter
EDADF	Effectively degradable acid detergent fiber
EDCP	Effectively degradable crude protein
EDDM	Effectively degradable dry matter
EDNDF	Effectively degradable neutral detergent fiber
EE	Ether extract
IVDMD	*In vitro* dry matter digestibility
KCL	Potassium chloride
K_d	Rate of degradation
K_p	Rate of passage
LCT	Lower critical temperature
ME	Metabolizable energy
N	Nitrogen
NDF	Neutral detergent fiber
NE_m	Net energy of maintenance
NH_4-N	Ammonium nitrogen

$NO_{3-}N$	Nitrate nitrogen
NPN	Non protein nitrogen
OC	Organic carbon
P	Phosphorus
RUDP	Rumen undegradable protein
S	Soluble fraction
SO_4	Sulfate
SPF	Stockpiled perennial forage
T0	Lag time
TDN	Total digestible nutrients
TNZ	Thermoneutral zone
U	Undegradable fraction

1.0 GENERAL INTRODUCTION

In western Canada, the winter feeding period of a beef cow-calf operation is about 150 d (Larson 2010). It is a critical period for both beef cows and producers as cows need to maintain body weight in temperatures as low as -30 to -40 °C and producers need to expend nearly 60 to 65% of the annual production expenses on winter feed during this period (Kaliel and Kotowich 2002).

Traditionally, beef cows in western Canada are wintered using drylot pens which increase the cost of harvesting, storing, feeding and hauling manure from wintering sites (Hitz and Russell 1998; Johnson and Wand 1999; Kelln et al. 2011). Therefore, producers are investigating the adaptability and sustainability of new extensive winter feeding systems such as stockpiled forage grazing, bale grazing, swath grazing of annuals and crop residue grazing in western Canada (Krause et al. 2013).

Previous research on extensive feeding indicates that cows grazing in field systems performed similarly or greater compared to cows fed baled hay in drylot pens (Lux et al. 1999; Lardner 2005; Kelln et al. 2011). According to Kelln et al. (2011) the average total cost for drylot feeding was 40% greater than the total cost for swath grazing and there was a 38% less labour requirement for swath grazing than for traditional drylot feeding. However, when cows are managed in extensive feeding systems there is the potential risk of weathering on forage biomass, forage quality and utilization and impact on cow performance (Poore and Drewnoski 2010; McCartney et al. 2004).

In extensive grazing systems manure and urine can contribute to improving soil nutrients greatly (Jungnitsch et al. 2011). According to Bierman et al. (1999) a mature beef cow produces 28 kg of feces (0.4% N, 0.2% P) and 9 kg of urine (1.1% N, 0.01% P) per day. However, if manure nutrients are not managed properly, this can lead to eutrophication and environmental contamination may occur (Owens and Shipitalo 2006). Stockpiled forage or fall-saved pasture is forage that is allowed to grow and accumulate for use at a later time or during a period of forage deficit (Poore and Drewnoski 2010). Stockpiled forage is typically used from October to early December, or until weather and snow conditions prevent grazing or the forage can be used in early spring, before new pasture growth is available (Baron et al. 2005, Barnhart 2010). Kallenbach et al. (2003) indicated that stockpiled forage has greater nutritive value than summer-harvested, cool-season grass hay.

There has been little field research conducted on extensive grazing with beef cows on stockpiled perennial forages during the winter period under western Canadian environmental condition (Jungnitsch 2008).

The objectives of this review are to:

1. Evaluate how beef cow nutrient requirements correspond to the cold environment temperatures experienced in western Canada.
2. Evaluate the impact of different winter feeding systems on cow performance and reproductive efficiency.
3. Examine effect of winter feeding systems on forage yield, forage quality and soil nutrients.
4. Discuss techniques for measuring forage production, botanical composition and forage quality.
5. Examine economic analysis of different winter-feeding systems.

2.0 LITERATURE REVIEW

2.1 Beef cow nutrition

Beef producers can manage their cow herds cost effectively if they implement a good nutrition program throughout the year. Biological prioritization of nutrients is one of the important aspects, which should be considered before planning a good nutrition program (Short et al. 1990; Marston et al. 1998). The biological prioritization of nutrients consumed are as follows; maintenance, lactation, growth and reproduction. Nutrient requirements can be affected by stage of production, age, cow size, body condition, milking ability, weather and length of the breeding season (Rasby and Rush 1980). Table 2.1 summarizes nutrient requirements of beef cows at different stages of production according to NRC (2000).

Table 2.1. Nutrient requirements for a beef cow (533 kg) at different stages of production

Nutrient[z]	Post-calving (82 d)	Pregnancy and lactation (123 d)	Mid gestation (70 d)	Pre-calving (90 d)
TDN (kg d^{-1})	5.1	5.2	4.3	6.6
NE_m (Mcal d^{-1})	10.3	12.2	9.2	14.0
Protein (kg d^{-1})	0.7	0.9	0.6	1.0
Calcium (g d^{-1})	25	27	17	33
Phosphorus (g d^{-1})	20	22	17	25
Vitamin A (x 1,000 IU)	27,000	30,000	25,000	39,000

[z]TDN = total digestible nutrients; NE_m= net energy maintenance.
Adapted from NRC (2000) and Marston et al. (1998).

2.1.1 Energy

Energy intake of animals is usually measured in calories (cal) (1 Cal = 4.184 joules) and can be quantified as total digestible nutrients (TDN), net energy for maintenance (NE_m), net energy for gain (NE_g), metabolizable energy (ME), digestible energy (DE) or gross energy (NRC

2000). Digestible energy of a feed is determined by the factors affecting the digestibility of feed and can overestimate the energy value of high-fiber feedstuffs. Metabolizable energy accounts for the feed energy available for animal use after fecal energy (FE), gaseous energy (GE) and urinary energy (UE) are subtracted from gross energy value of feed. The ratio of ME to DE in most feedstuffs is estimated to be 0.8 (ARC 1980; CSIRO 1990).

The net energy value of a feed can be subcategorized to different physiological functions like net energy for maintenance (NE_m), growth (NE_g), lactation (NE_l) and for conceptus (NE_y) (NRC 2000). According to the NRC (2000) definition, NE_m is the amount of feed energy that will result in no net change in energy of body tissues and the animal will have no net gain or loss of energy. Net energy for maintenance can be affected by animal factors like body weight, breed, genotype, sex, physiological state and environmental factors like temperature and season (NRC 1981; Jenkins and Ferrell 1983; Taylor et al. 1986; Byers and Carstens 1991).

Cold environment temperature is one of the major environmental factors, that can increase the maintenance energy requirement of animals (NRC 2000). Effective ambient temperature is a function of the ambient temperature and the wind speed (Marston et al. 1998). When the effective ambient temperature is within the thermoneutral zone (TNZ) cattle will perform optimally. However, when the effective ambient temperature falls below the lower critical temperature (LCT), there is an increase in maintenance energy requirements (ME_c) (Equation 2.1). This is due to increased metabolism to produce adequate heat to maintain core body temperature and voluntary feed intake of beef cows can increase by 30 to 70% (Lister et al. 1972; Young 1983; Delfino and Matheson 1991; Scott and Christopherson 1993; NRC 2000). In contrast with severe heat stress, beef cattle feed intake will decrease and subsequently metabolic heat production and productivity will decrese.

Equation 2.1 ME_c = SA (LCT-EAT)/IN (NRC 2000)

Where, ME_c is the increase in maintenance energy requirement (Mcal d^{-1}), SA is surface area (m^2), LCT is lower critical temperature (°C), EAT is effective ambient temperature (°C) adjusted for thermal radiation, and IN is total insulation (°C $Mcal^{-1}$ m^{-2} d^{-1}).

2.1.2 Protein

Ruminants consume rumen-degradable protein (RDP) and rumen undegradable protein (RUP) in their diets (NRC 2000). Protein metabolism is a very complex process in the rumen and it is more accurate to use the metabolizable protein (MP) system than crude protein (CP) system when discussing protein requirements of the beef animal. Because the MP system defines the total protein which is absorbed across the intestine and can be used for maintenance, growth, lactation and fetal development while the CP system only accounts for RDP and RUP in the diet (NRC 1989; ARC 1992; NRC 2000).

Rumen degradable protein is supplied by true protein N and non-protein N (NPN) sources of the feed and true protein is degraded to peptides or amino acids (AA) and used by the microbes to produce microbial protein or deaminated to ammonia (NH_3) in the rumen (NRC 1989; Bach et al. 2005). Ammonia produced in the rumen is ultimately absorbed and metabolized to urea in the liver and excreted in the urine or recycled back to rumen. Ruminants can survive on NPN diets as rumen microbes can synthesize high quality protein and the majority of the total absorbable protein (50 to 80%) in the small intestine is supplied from microbial protein (MP) synthesized in the rumen (Ørskov 1982; Storm et al. 1983; Virtanen 1996; Bach et. 2005).

A dry cow in early to mid-gestation requires 7 to 8% of crude protein (CP) for maintenance whereas young growing or lactating cows have requirements of 11 to 13% CP (NRC 2000). Hao et al. (2009) reported that higher dietary inclusion levels (> 20%) of distillers' grain with soluble (DDGS) can increase the fecal and urinary N loss significantly in a feedlot cattle operation. Further, Erickson and Klopfenstein (2001) reported that only 10% of N is retained in the feedlot steers, while 90% of N is lost in excreta (urine and feces).

2.1.3 Mineral and water requirement

Sufficient intake of macro minerals and micro minerals is essential to maintain optimum reproductive performance and health throughout the production cycle of a beef cow. The most important macro minerals for beef cattle are calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), sodium (Na), chlorine (Cl) and sulfur (S) (NRC 2000). The required micro minerals include chromium (Cr), cobalt (Co), copper (Cu), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se) and zinc (Zn) (NRC 2000). Some feedstuffs are deficient in several minerals and will need mineral supplementation in organic or inorganic forms.

According to a two year study conducted by Ahola et al. (2004), when beef cows were supplemented with Cu, Zn and Mn, the pregnancy rate following artificial insemination (AI) and kg of calf weaned per cow exposed were improved, compared to a control group of cows who were not supplemented. However, over supplementation of minerals can bring many environmental problems such as ground water contamination as the excess minerals in the diet are lost in cattle waste (Roelofs and Houdijk 1991; NRC 2000; Ramos et al. 2006).

Water constitutes approximately 50 to 80% of the live weight of beef animals. Animals receive water from their feed and from drinking water. Water is the transportation medium for nutrients, waste products, hormones and chemical messengers in the body and also regulates body temperature and blood osmotic pressure (NRC 2000). The rates and composition of gain, pregnancy, lactation, activity, type of diet, feed intake and environmental temperature can influence the water intake of cattle (Hicks et al. 1988; Ali et al. 1994; NRC 2000).

Water quality can have a direct effect on cattle performance and according to Lardner et al. (2005), the weight gain of cattle increased by improving the water quality by aeration and pumping to a trough when compared to cattle drinking water from dugouts directly. The water volume (56 L d^{-1}) needed for a 409 kg BW lactating cow is close to double the amount of water requirement of a dry pregnant cow (27 L d^{-1}) (NRC 2000).

2.2 Beef cow performance

The effect of different winter feeding programs can be evaluated by animal performance data (Kelln et al. 2011; Krause et al. 2013). There are different techniques which can be followed to measure animal performance such as measuring live body weight (BW), average daily gain (ADG), body fat composition (e.g. rib and rump fat), body condition score (BCS) and reproductive efficiency (Lowman et al. 1976; Davis et al. 1977; Corbett 1978; Schröder and Staufenbiel 2006). However, to select the most appropriate technique some factors like desired output, market consideration in relation to output, animal husbandry procedures, grazing system, agronomic practices to be applied and relevant experimental design need to be considered (Coates and Penning 2000).

2.2.1 Measuring animal performance

2.2.1.1 Body weight

Live body weight (LBW) can be used to evaluate the effect of different winter feeding systems on beef cow performance (Landblom et al. 2007; Jungnitsch et al. 2011; Van De Kerckhove et al. 2011; Kelln et al. 2011). Body weight can be measured easily and accurately with the appropriate equipment; however, LBW has limitations due to the variation over short periods due to gut fill effect and changes in body water volume (Kennedy 1995; Coates and Penning 2000). Fasting animals overnight, withholding water and measuring LBW early in the morning over 2 consecutive days is often practiced to reduce the variation in gut fill as it accounts for over 20% of change in LBW (Corbett 1978; Cook and Stubbendieck 1986; Kennedy 1995).

Coates and Penning (2000) described other factors which influence feed and water intake and variation of LBW within or between days. When pasture forage matures and quality declines, gut fill is likely to increase progressively and ultimately affect live body weight (McLean et al. 1983; Coates and Penning 2000). Therefore, the effect of herbage quality needs to be minimized by taking a series of measurements at the beginning and end of a grazing period when LBW is considered as an indicator of treatment differences (McLean et al. 1983).

The live weight gain (LWG) of a pregnant animal is greatly affected by the conceptus weight and the amount of fluid associated with the developing fetus (Silvey and Haydock 1978; Coates and Penning 2000). Therefore, LBW needs to be adjusted for pregnancy in cows (Silvey and Haydock 1978) using the following equation from NRC (1996):

Equation 2.2 Conceptus weight (kg) = (CBW*0.01828)*e [(0.02*t)-(1.43e-005*t*t)]

Where, CBW = calf weight at birth and t = days of pregnancy.

2.2.1.2 Body condition score (BCS)

Body condition scoring (BCS) of beef cattle can be an effective management tool for evaluating the energy reserves of cows and the nutritional program (Kelln et al. 2011). It is a common subjective scoring system, which uses a numeric score to evaluate the fat deposits in relation to skeletal features. The advantages of body condition scoring is that it is easy to learn, fast, simple, cheap, does not require specialized equipment and is sufficiently precise for many research and management situations. The Canadian (Scottish system) system rates animals from 1 (very thin) to 5 (grossly fat) and the American scale rates animals from 1 to 9 (Marlowe et al. 1962; Lowman et al. 1976; Tennent et al. 2002).

It is recommended that BCS is evaluated at least 3 times year^{-1}; at weaning, 60-90 d before calving, and at calving (Eversole et al. 2009). Poor body condition is associated with reduced income per cow, increased post-partum interval, weak calves at birth, low quality and quantity of colostrum, reduced milk production, increased dystocia, and lower weaning weights (Selk et al. 1988; Osoro and Wright 1992; Eversole et al. 2009).

Previous studies have found that BCS at calving and the beginning of the breeding season is the most important factor which determines the reproductive performance of animals in subsequent years (Perry et al. 1991; Spitzer et al. 1995). Body condition score at calving has the greatest effect on pregnancy rate during a controlled breeding season (Selk et al. 1988; Lalman et al. 1997; John 2005). Cows with BCS ≤ 4 (US) at calving had a 9 to 29% lower pregnancy rate compared to cows calving at BCS ≥ 5 (US) (Selk et al. 1988; Makarechian and Arthur 1990).

2.2.1.3 Body fat composition (rib and rump fat)

Body fat composition can be estimated by measuring rib fat thickness between the 12th and 13th rib and rump fat thickness which refers to the depth of fat at the junction of the *gluteus medius* and superficial *gluteus medius* muscles (Schröder and Staufenbiel 2006). These measurements are used to evaluate the overall external body fat and recorded in mm or cm by a practiced technician using ultrasonography. Different methods have been developed to estimate chemical composition of fat-free empty body of live animals with respect to water, protein and mineral (ash) (Burton and Reid 1969; Graham and Searle 1972).

2.2.1.4 Reproductive performance

Reproductive efficiency of a beef cow herd is reflected by the proportion of females cycling, proportion of females served, conception rate, conception date, pregnancy rate, live calving rate, weaning rate, weaning weight, calving interval and incidence of dystocia (Coates and Penning 2000). Osoro and Wright (1992) described the number of calves born per cow exposed per year as the most important indicator of reproductive efficiency in a cow-calf herd. In a well-managed herd, heifers usually reach puberty early and conceive at the age of 14 to 15 months. Calving interval (CI) is defined as the time period which exists between one calving to the next calving and the optimum CI is approximately 12 months. However, to have optimum CI, usually the cow must rebreed within 80 d after calving. Body condition score at calving can affect reproductive performance of beef cows (DeRouen et al. 1994).

Osoro and Wright (1992) stated that spring-calving cows with good BCS (2.5 – 3.0) at calving had a shorter CI during their reproductive cycle. This is because the postpartum anestrus period has been shown to be shorter in animals maintaining a BCS around 2.5 (CAN 1-5 scale) prior to calving (Wiltbank 1965; Reardon et al. 1978; Osoro and Wright. 1992).

Energy is more vital than protein in winter rations of beef cows and has a positive effect on beef cow reproduction (Speth et al. 1962; Wiltbank 1965; Davis et al. 1977). Davis et al. (1977) found that higher energy supplementation of mature cows did not show any improvement in their reproductive performance, whereas reproductive performance was improved by energy supplementation in young cows within 2 to 3 years of age.

2.3 Winter-feeding systems in western Canada

2.3.1 Traditional drylot feeding

Traditional drylot feeding system confines cows in pens during late summer or fall and winter. Usually these animals are fed stored feed such as hay, silage, crop residue and grains. This management practice has both advantages and disadvantages (Anderson and Boyles 2007). Some of the advantages are flexibility in management as animals are confined to one place, easy health management, maximizing use of facilities and easy facilitation of breeding programs.

However, the traditional system which has been used to manage beef cows during the winter period is being replaced with extensive feeding systems due to costs associated with feed harvesting, post-cutting processing, hauling, storing, labour, infrastructure, manure hauling from wintering sites and usage of equipment (Hitz and Russell 1998; Johnson and Wand 1999; Riesterer et al. 2000; Baron et al. 2004; Kelln et al. 2011). Hauling manure from pens is one of the biggest challenges in intensive systems which increase the cost of labour, fuel and equipment (Johnson and Wand 1999; Rotz 2004; Baron et al. 2004, Riesterer et al. 2000; Kelln et al. 2011).

However, when beef cows were managed in drylot pens and fed silage, weight gain was greater than cows grazing swathed whole-plant barley in the field (0.42 vs. 0.04 kg d^{-1}) (McCartney et al. 2004). The study suggested that cows managed in the field needed extra energy to account for activities, such as grazing through snow and walking to find feed. In contrast, drylot cows had better protection from the cold environment and wind as they were in sheltered pens and they did not spend as much as energy searching feed.

The time of harvest, harvesting process and method of storage are important in making good quality hay. If moisture content of hay at bailing is greater than 20%, plant respiration and microbial activity can generate heat and ultimately lead to a chemical reaction which produces an indigestible component called the Maillard product and decrease hay digestibility (Collins et al. 1987; Collins and Sheaffer 1996). Further, if hay bales are stored outside and uncovered, there is a substantial loss of digestible dry matter and feeding losses as cattle will refuse to eat the unpalatable weathered hay (Belyea et al. 1985).

In western Canada, producers mostly use barley and corn for ensiling. However, there is a shift from barley to corn silage production due to the development of low-heat unit corn hybrids and higher dry matter yield of corn per hectare than barley (Addah et al. 2010). The main purpose of silage production is to preserve nutrients and improve their biological availability (Addah et al. 2010). Silage production is less dependent upon good weather than hay making and has lower field losses compared to hay production (Helm and Salmon 2002).

2.3.2 Extensive grazing systems

Extensive feeding systems like stockpiled forage grazing, swath grazing, bale grazing and crop residue grazing can extend the grazing season into the fall and winter (Kelln et al. 2011). Beef cows that remain on pasture during late fall and winter is cost effective compared to expensive traditional feeding systems (Jungnitsch 2008).

2.3.2.1 Stockpiled perennial forage

Stockpiled forage or fall-saved pasture is the forage that is allowed to grow and accumulate for use at a later time or during a period of forage deficit (Baron et al. 2004; Baron et al. 2005). This method can extend the usual grazing season beyond the growing season (Johnson and Wand 1999).

It is common practice to harvest and store forage as hay or silage to use during the winter period (Hitz and Russell 1998; Johnson and Wand 1999; Volesky et al. 2002); however, stockpiling forage for grazing at a later time is an excellent alternative to more expensive hay or silage feeding (Johnson and Wand 1999; Riesterer et al. 2000). The stockpiled forage can be used from October to early December, or until weather and snow conditions prevent grazing or can be used in early spring before new pasture growth is available (Ocumpaugh and Matches 1977; Riesterer et al. 2000; Burns and Chamblee 2000).

In the Canadian prairies the winter feeding period is usually the major expense for beef cow herds (Mathison 1993; Entz et al. 2002; Larson 2010). Research studies have found that feeding stored feed is more expensive than the cost of grazing forage to obtain the same amount of nutrients from pasture (Kallenbach 2000; Kelln et al. 2011). Extensive wintering systems can reduce feed costs by $0.58 per cow per day (Jungnitsch 2008).

To develop a successful stockpiled forage grazing system, producers need to consider the following aspects; species selection, accumulation or rest period between grazing or cutting, and soil nutrient management (Matches and Burn 1995). Almost any grass or legume species can be stockpiled; however, legumes are usually not as suitable as grasses for stockpiling as nutritive value declines rapidly as leaves are lost due to frost or maturity (Matches and Burn 1995; Baron et al. 2004). The species used for stockpiling should be able to regrow rapidly following early harvests to provide at least 2,000 kg of forage per ha for good fall grazing and should maintain high quality following fall frosts (Coleman 1992; Baron et al. 2005).

Grasses like tall fescue (*Festuca arundinacea* Schreb), Altai wild ryegrass (*Laymus angustus* Trin.) and some native grasses are more suitable for stockpiling as these species stand up and are more easily found by livestock and have timely regrowth under fall climatic conditions and resist weathering after growth ceases (Lawrence and Heinrichs 1974**;** Hitz and Russell 1998; Baron et al. 2004). Depending on these different plant characteristics, forage species can be grazed as a standing crop or as windrowed feed.

Generally, stockpiled forage is of moderate to poor quality; therefore, stockpiled forage generally only meets the nutrient requirements for mature, dry cows in early to mid-gestation and may not meet nutrient requirements for young, growing or lactating animals (Hollingsworth-Jenkins et al. 1996; Scarbrough et al. 2002; Poore and Drewnoski 2010). Some of the challenges of stockpiled forage grazing are: accessibility to the stockpiled forage due to snow depth; winter precipitation which can reduce both digestibility of dry matter and protein content and; water supply during months where temperatures are below 0 ^{O}C(Poore and Drewnoski 2010).

Livestock producers usually allow stockpiled pasture to accumulate during the last 70 to 80 d of the growing season. Longer periods of stockpiling can increase forage yield, whereas forage quality may be reduced (Baron et al. 2005).

Producers are encouraged to have temporary fences and strip graze smaller areas of stockpiled forage which can provide a more uniform forage quality throughout the grazing period, prevent selective grazing, and extend the grazing days further into the winter (Poor and Drewnoski 2010). However, there is a risk of using stockpiled perennial forage as a winter feeding system due to variation in yield, forage nutritive value and animal performance from year to year (Poore and Drewnoski 2010).

2.3.2.1.1 Meadow bromegrass (*Bromus riparius* Rehm)

Meadow bromegrass (MBG) is a long-lived, perennial bunchgrass, which has uniform seasonal production throughout the year (Knowles et al. 1993). Production of MBG is higher than smooth bromegrass (*Bromus inermis* Leyss) in July and September (Knowles et al. 1993). Meadow bromegrass can extend the grazing season and increase total forage production and is very compatible with alfalfa (*Medicago sativa* L.). Meadow bromegrass is winter-hardy, can tolerate drought conditions and has excellent ability to regrow (Smoliak et al. 1990; Knowles et al. 1993). Even in low level of N fertilizers, this grass species can produce higher yields and can provides excellent hay when mixed with a legume like alfalfa (Fairey 1991). Nevertheless, when compared to smooth bromegrass and crested wheatgrass (*Agropyron cristatum* (L.) Gaertn), meadow bromegrass is less winter-hardy (Limin and Fowler 1987) and tend to lodge under the weight of snow.

2.3.2.1.2 Alfalfa (*Medicago sativa* L.)

Alfalfa is by far the most widely used legume species in livestock feeds and can be grown with other legumes or grass species (Cook et al. 2005; Radovic et al. 2009). Alfalfa is rich in CP (12 to 20%) and is high in organic matter digestibility (NRC 2000; Dinić et al. 2005; Marković et al. 2007*)*. Alfalfa can also enhance soil fertility by fixing atmospheric nitrogen (N_2) into ammonia (NH_3) (Russel 2004). It contains high amount of Ca, Mg, K, S, Fe, Co, Mn, Zn and beta-carotene (Frame 2005). Alfalfa has a good adaptability to extreme winter conditions (-25 ^{O}C) and high temperatures and has high herbage yield (Frame 2005; Radovic et al. 2009). Alfalfa can be used as hay, silage, haylage or as a pasture for grazing. However, the harvesting losses (30 to 50%) are highest when alfalfa is dried in field (Radovic et al. 2009). It is recommended to graze alfalfa in September to October to prevent nutritive value loss due to exposure to heavy frost and leaf loss (Baron et al. 2005).

2.3.2.2 Swath grazing of annuals

Because of the variable growing conditions (environmental and different management factors) pasture growth and thus forage supply can fluctuate throughout the year (Fales et al. 1993; Matches and Burn 1995). The uneven forage supply creates an intermittent failure of the pasture system to meet livestock requirements. Therefore, livestock producers are looking for high quality forage from mid-December through to mid-March when there is the longest period of inadequate forage supply in winter grazing (Matches and Burn 1995; Kallenbach et al. 2003).

Swath grazing can reduce the winter feed cost for spring calving beef cows (Volesky et al. 2002; McCartney et al. 2004). According to Kaliel and Kotowich (2002), swath grazing can reduce 46% of the total feed cost when compared to a traditional feeding system. Both annual cool season crops and annual warm season crops are alternatives for extending the grazing season and can be swathed in the fall and then grazed in the field (McCartney et al. 2008; McCartney et al. 2009). However, May et al. (2007) described spring-seeded barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.) and cool-season cereals as the most common species used for swath grazing in western Canada.

Swathing can consolidate the forage and it is easier to access the swath than the standing forage (Baron et al. 2006). Early seeding and swath date will affect the quality and quantity of swathed forages. This is because, early seeding dates can increase forage biomass production while earlier swath dates can decrease quality of the forage due to effect of weathering (May et al. 2007).

There is recently been a developing tendency for grazing standing corn with beef animals to reduce the winter feeding cost in western Canada. However, this is still restricted to parts of Canada which receives a minimum of 2000 to 2100 corn heat units (Macaulay 2004; Erickson et al. 2005; Aasen and Bjorge 2009; McCartney et al. 2009). Swathing of corn is difficult due to height and volume of the crop (McCartney et al. 2009).

The biggest challenge in swath grazing is the accessibility to feed which can be decreased by snow fall, temperature, wind speed and icing of swath (Kelln et al. 2011). McCartney et al. (2004) conducted a winter feeding study over three production years. The authors did not observe any negative effect of swath grazing whole-plant barley, which was harvested at the soft dough stage, on cow reproductive performance and body condition score and concluded that swath grazing is an excellent alternative strategy for drylot feeding in western Canada and can increase the production efficiency of cow-calf system.

2.3.2.3 Bale grazing

Bale grazing can be either grazing large round hay bales, bales rolled out in the field, bales shredded with equipment such as bale processor or bales placed in a bale feeder. Feeding hay inside a bale feeder was a means to reduce wastage and wintering cost per cow relative to other methods while maintaining animal body condition (Landblom et al. 2007).

When bales were processed on a wintering site, forage yield on the site was increased in subsequent years, more than when bales were fed in drylot pens and the pen manure applied to similar site (Lardner 2005; Jungnitsch et al. 2011). Winter feed waste and costs were higher when bales were processed, than when bales were fed by bale unrolling during a 175 d winter feeding period (waste 19.2% vs. 12.9%; cost $56.25 vs. $52.50) (Yaremcio 2009).

The comparison of the nutritive value of tall fescue-based grass hay fed in feeders (HY) or as stockpiled tall fescue forage (STF) revealed that pre-grazing STF had higher CP content (15.6% vs. 7.7%), lower neutral detergent fiber (63.6% vs. 71.6%) and acid detergent fiber (34.0% vs. 40.3%) than the hay (Meyer et al. 2009). At the end of the 1-yr study, the authors observed that cows in the STF treatment where they were fed *ad libitum* tall fescue hay with grain supplementation to meet NRC (1996) and (2000) requirements, gained BW and cows in HY treatment lost body weight ($P = 0.06$). In this study cows in the STF treatment gained BW and maintained BCS when compared to cows in HY treatment as field cows had access to good quality forage (Meyer et al. 2009).

2.3.2.4. Crop residue grazing

Most part of the prairie provinces of Canada grow grain crops like oat (*Avena sativa* L.), barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L.) and rye (*Secale cereale* L) and crop residue grazing is a potential feeding strategy in western Canada (McCartney et al. 2006; Statistics Canada 2006). McCartney et al. (2006) defines cereal straw as the stem and leaf residue remaining after the grain is harvested and chaff as the parts of the spike left after the grain is harvested. Both straw and chaff can meet beef cow nutrient requirements during winter with adequate energy and protein supplementation (Weisenburger et al. 1976; Weisenburger and Mathison 1977; Mathison et al. 1981; NRC 2000).

A winter grazing study which was conducted for three production cycles observed that the average total production cost of oat residue grazing system was \$0.77 cow d^{-1} less than a drylot pen feeding system (Krause et al. 2013). Similarly a pea residue grazing system was \$0.59 cow d^{-1} less than a drylot pen feeding system suggesting that crop residue grazing can reduce winter feed costs significantly (Krause et al. 2013). However, reduced performance of cows in the pea and oat residue grazing systems revealed the requirement of a moderate acclimatization period for naïve cows before grazing in extensive systems and provision of 18 to 20% more energy supplementation than cows in drylot pens (Krause et al. 2013).

2.3.5 Supplementation of winter beef cow rations

The beef cow may need supplementation when there is a deficiency in feed quality, quantity or to improve cow performance. When cows are fed only low quality forage during winter, this can lead to rumen impaction, starvation, decreased rumen function and ultimately death of the animal (Anderson and Boyles 2007). Carbohydrate supplements are good energy sources and can be categorized as non-structural carbohydrates (NSC) or non-forage fiber source (NFFS). Non-structural carbohydrates are found inside the plant cell and can consist of starch, pectin, organic acids and sugars (Van Soest 1965; NRC 2000). Non-forage fiber source are usually plant by products obtained after extraction of starch, sugar and oil and have a lesser negative effect on fiber digestion in rumen compared to starch based energy supplements (Holt et al. 2010). Some examples of NFFS are soybean hulls, dried distillers' grains and solubles (DDGS), beet pulp, corn gluten meal, corn gluten feed and wheat middlings (Holt et al. 2010).

Different categories of protein supplements are rumen degradable protein (RDP), rumen undegradable protein (RUP) and non-protein nitrogen (NPN). These supplements are available as high-quality forage, co-product feedstuffs, range cubes, protein blocks and liquids. When low quality forages are consumed, RDP can increase the digestibility and feed intake of ruminants (Clanton and Zimmerman 1970; Beaty et al. 1994; Mathis et al. 1999; DelCurto and Olsen 2000). Urea is an NPN supplement used in beef cattle diets, with consideration regarding the inclusion level, as too high level of urea can be toxic (Rush et al. 1976; Clanton 1979). However, NPN is very compatible with high grain diets as starch rapidly degrades in the rumen (Sindt et al. 1993; NRC 2000). Schauer et al. (2005) concluded that protein supplementation frequency have little or no effect on cow BW, BCS and dry matter intake (DMI).

2.4 Dry matter intake (DMI)

2.4.1 Factors affecting dry matter intake

Feed intake regulation of ruminants is a complex process and up to now all regulatory factors have not been discovered (NRC 2000). However, DMI can be predicted from various models which were developed from different research studies based on factors such as BW, environment and nutritive value of feed (Montgomery and Baumgardt 1965; Ketelaars and

Tolkamp 1992; Mertens 1994). Feed intake regulation is a multi-factorial phenomenon and can be categorized into animal, dietary and environmental factors (NRC 2000).

Overall regulation of voluntary feed consumption of ruminants is dependent on animal factors such as genotype, physiology (rumen fill, age, sex, body size and composition), production demand (e.g. lactation, pregnancy), diseases and nutrient metabolism (Baumgardt 1970; Forbes 1970, Forbes 1971; Forbes 1980; Allen 1996).

The generally accepted theory is that feed intake of beef cattle on high roughage (low nutritive value) rations is limited by physical means (distention of rumen) while feed intake of cattle on high nutritive diets (e.g. grain) is limited by chemical or thermal mechanism as shown in Figure 2.1 (Montgometry and Baumgardt 1965).

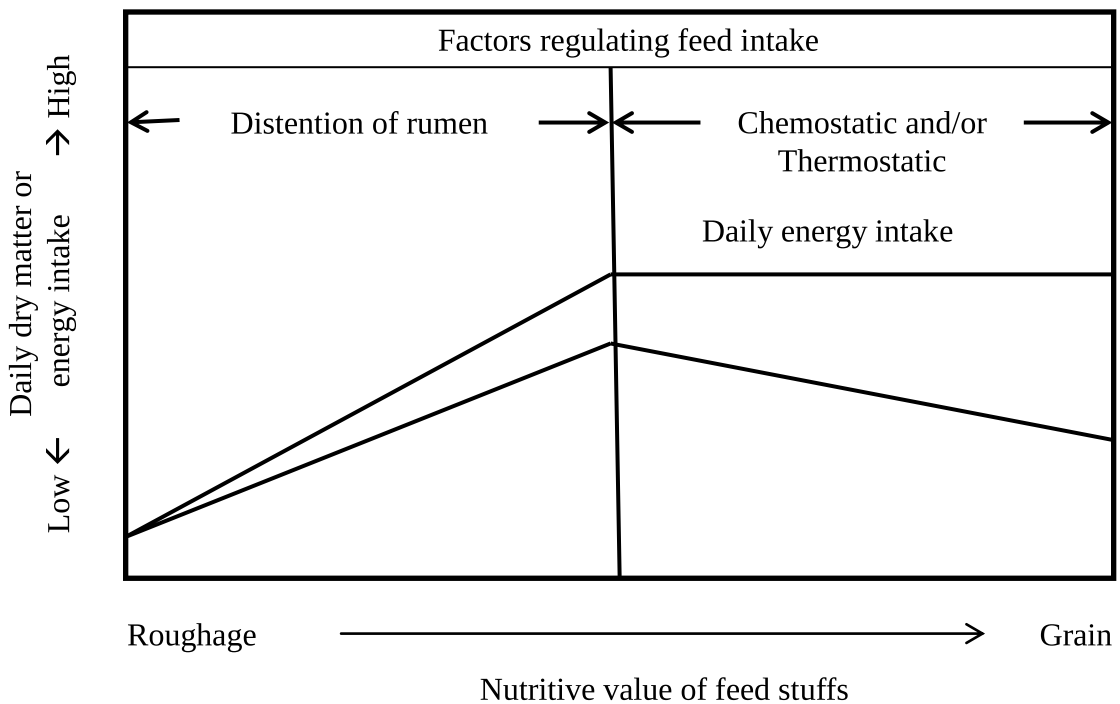

Fig. 2.1. Factors regulating feed intake (Montgometry and Baumgardt 1965)

There are many studies evaluating the effect of ambient temperature on feed intake and digestive function of ruminants (NRC 1981; Kennedy et al. 1986; Young 1986; Minton 1986;

Young et al. 1989). According to findings of these studies, feed intake increases as the temperature falls below the thermoneutral zone (TNZ) and decreased as temperature rise above the thermo neutral zone. However, the response of feed intake to environment temperature can be influenced by thermal susceptibility of the animal, acclimation, diet and other environmental factors such as mud, dust, accessibility to feed and photoperiod (NRC 1981; Young 1986; NRC 2000).

2.4.2 Estimation of dry matter intake

Feed intake of ruminants can be measured using either direct or indirect methods (Decruyenaere et al. 2009). Numerous methods of measuring forage utilization have been reviewed by previous studies (Dasmann 1948; Heady 1949). One of the direct methods of measuring feed intake of ruminants is estimating herbage mass before and after grazing (Macoon et al. 2003; Smit et al. 2005). Herbage mass is regularly estimated by hand clipping and weighing the forage in the pasture or paddock. However, a "sward height meter" or "rising plate meter" or "disk meter" can be used to estimate grass density and quantity. The feed intake is either underestimated if the growth of herbage during the grazing period is ignored, or overestimated if trampled herbage is not easily seen or measured or if there is grazing by feral animals and if herbage is lost by decomposition, insect activity and wind (Corbett 1978). The bite count technique is another direct method which estimates bite mass and multiplying by total bites per 24 h or using reverse feeding standards to calculate intake from energy retention and outputs and the metabolizable energy level of the diet (Coates and Penning 2000). Further, biting mass can be determined by oesophageal fistulated animals and the biting rate and grazing time can be estimated by visual observation (Rook et al. 2004) or by recording animal activities such as displacement, rumination or intake times (Laca et al. 2000).

Intake of grazing ruminants can be estimated by indirect methods which are basically categorized in ratio techniques and index procedures (Cordova et al. 1978). Ratio techniques calculate digestibility and fecal output based on their ratio to an indigestible marker while for index procedures a regression equation is developed to relate digestibility or feed intake to some component in the feces. Individual animal DMI can be determined by natural indigestible plant components (internal markers) such as lignin, alkanes, or insoluble ashes, which are excreted in faeces and external markers which are administered in known amounts (Cordova et al. 1978; Mayes et al. 1986). Feed intake is estimated based on concentration of marker (natural and synthetic) in plant and animal faeces using the following equation (Coates and Penning 2000).

Equation 2.3 $I = (Fi/Fj) \times Dj / (Hi - (Fi/Fj) \times Hj)$

Where, I = intake; Fi and Fj = concentration of natural and synthetic alkanes in faeces; Dj = dose rate of synthetic alkanes; Hi and Hj = concentration of natural and synthetic alkanes in forage.

In grazing animals, DMI is frequently estimated by measuring both faecal output (FO) and digestibility (D) of the grazed herbage (ratio technique) (Coates and Penning 2000; Lippke 2002; Decruyenaere et al. 2009). Faecal output can be estimated by the total faecal collection method. However, this technique is usually not satisfactory because of errors which arise from incomplete collection of faeces, contamination of urine in female animals and the effect of collection equipment on grazing behavior and hence DMI (Langland 1975; Adesogan et al.

2000). The FO can be estimated more accurately by an indirect indigestible indicator technique. Chromium sesquioxide (Cr_2O_3) has been used as an indicator for many years (Kotb and Luckey 1972). According to Moore (1996) markers and ingestive behavior are suitable when estimating intake of individual animal while herbage disappearance methods or prediction from forage characteristics are suitable for intake estimations of groups of animals.

2.5 Measuring forage production

Measuring forage production or dry matter (DM) yield indicates the amount of feed available for animals and evaluates the effect of management practices. Techniques used can be categorized as destructive or non-destructive methods. The method of measuring DM yield of forage depends on several factors like the scale of operation (small plot/paddock/regional), the purpose of data collection and the resource availability (Mannetje 2000). For example, direct visual estimation is not suitable for research purposes but can be used by farmers to monitor their pasture yields.

2.5.1 Destructive techniques

These techniques use simple hand operated equipment like scissors, shears, secateurs, sickles, knives and scythes, or hand-held power-driven tools like self-propelled weight recording plot harvesters, sheep shears, clippers and lawn or hedge trimmers (Mannetje 2000). However, the type of equipment used and the cutting height above ground level need to be determined based on the data required. After cutting the herbage, total fresh weight needs to be recorded and subsamples are taken to determine the dry matter percentage.

2.5.2 Non-destructive techniques

These techniques can be categorized in to three major groups: (i) visual estimations; (ii) height and density measurements and; (iii) measurement of non-vegetative attributes (capacitance meters). Only experienced operators or farmers can do visual estimations for day-to-day evaluation of their pasture lands (Tothill and Partridge 1998). Murphy et al. (1995) suggested that non-destructive techniques are not very accurate but are very quick and need less labour and equipment compared to destructive techniques.

2.6 Forage quality

2.6.1 Methods of measuring forage quality

Forage quality analysis is one of the most important requirements in accurate ration formulation of ruminant animals. The two main methods of forage quality analysis are wet chemistry and near-infrared reflectance spectroscopy (NIRS) analysis.

2.6.1.1 Wet chemistry

Wet chemistry uses chemicals and established standard laboratory procedures for quality analysis of protein, fiber, fat and minerals. Crude protein composition is usually measured using the Kjeldahl technique where the forage sample is digested with acid and distilled with a base to convert N to NH_3, which can be trapped and then measured (AOAC 2000). The LECO (combustion method) is another N determining method which is less accurate compared to Kjeldahl technique as it can measure some additional N containing compounds like nitrates compared to Kjeldahl (Adesogan et al. 2000). However, both methods determine the CP from the N concentration in samples but do not estimate true protein (Adesogan et al. 2000).

The extent of digestion of feedstuffs primarily depends on the cell wall content and lignification or maturity (Van Soest 1982). Neutral detergent fiber (NDF) includes cellulose, hemicellulose, and lignin whereas acid detergent fiber (ADF) contains only cellulose and lignin (Jarrige 1960; Van Soest 1965). Van Soest et al. (1991) described the method of NDF and ADF analysis by digesting feed samples from neutral detergent or acid detergent solutions, respectively. When the NDF procedure is applied to starchy foods and feed, heat-stable amylases facilitate the removal of starch and obtain more accurate estimations (Van Soest et al. 1991). Sodium sulfite also can be used in NDF procedure to cleave sulfite bonds of insoluble protein to reduce protein level of the residue and remove keratinaceous residues of animal origin (Van Soest et al. 1991). Acid detergent fiber and NDF can be used to estimate the energy content in feed (Adams 1995). For mineral analysis, samples are first ashed at 550 ºC and atomic absorption spectrophotometry is used to estimate mineral contents (AOAC 1990).

2.6.1.2 Near-infrared reflectance spectroscopy (NIRS)

The NIRS technique is based on the association of chemical composition of the feed sample with absorption of certain wavelength regions of light (from about 800 nm to 2500 nm) (Adesogan et al. 2000). In this technique a prediction equation is developed by calibration of reference laboratory analysis data with NIR spectra data of the desired material (Shenk and Westerhaus 1991; Stuth et al. 2003). Near-infrared reflectance spectroscopy is a more rapid method of evaluating feedstuff components than wet chemistry (Norris et al. 1976; Baker et al. 1990; De Boever et al. 1995; Givens et al. 1997; Ren et al. 2009).

Batten (1998) and Stuth et al. (2003) describe some of the advantages of this method such as minimal sample preparation, several analyses can be done at the same time, samples are not destroyed during analysis, skilled personnel is no requirement of hazardous chemicals. However, the equipment is expensive and the calibrating procedure may be tedious and time consuming (Givens et al. 1997).

2.7 Forage digestibility

Digestibility is an important index of relative feeding value of herbage and it varies with the proportion of cell and cell wall constituents (Minson 1990). Digestibility can be measured using *in vivo*, *in vitro* or *in situ* techniques. However, measuring digestibility *in vivo* and *in situ* are expensive, time consuming, labor intensive and need fistulated animals (Damiran et al. 2008). However, *in vitro* techniques (Daisy; Tilly and Terry and *in vitro* gas production), which predict digestibility from laboratory methods have a high degree of correlation to *in vivo* digestibility measurements (Tilley and Terry 1963; Adesogan et al. 2000; Damiran et al. 2008).

2.7.1 *In vivo* technique

In vivo digestibility techniques measure the difference between amount consumed and the amount excreted in the feces (Minson 1990). This technique is more accurate when compared to indirect techniques such as *in vitro* and *in situ* (Minson 1990). Forage digestibility vary depend on species differences, cultivar differences, plant part, stage of maturity, soil fertility and climate (Minson 1990). Forage digestibility can be determined using the following equation (Corbett 1978; Coates and Penning 2000).

Equation 2.4 $$\text{Digestibility (\%)} = \frac{(I - F)}{I} * 100$$

Where I is intake and F is the output in faeces (Coates and Penning 2000).

It is usual to measure apparent digestibility of feed not true digestibility, as faeces can contain some metabolic endogenous excretions (Coates and Penning 2000). For total faecal collection the animal is housed in tie stalls and fitted with a harness which collects voided faeces (Corbett 1978; Coates and Penning 2000).

In addition to direct measuring faecal output by total collection, indirect estimate techniques like faecal marker methods are being used (Cochran and Galyean 1994; Van Soest 1994; Coates and Penning 2000). Markers can be either internal markers which are the indigestible components in feed or external markers which are added to the feed (Corbett 1978; Van Soest 1994). Some of the internal markers are silica, chromogen, potentially indigestible cellulose, lignin, indigestible NDF and insoluble ash (Streeter 1969). Similarly chromic oxides (Cr2O3), ytterbium chloride (YbCl3), titanium oxide and paraffin-coated magnesium ferrite are some of the external markers which have been used (Van Soest 1994; Coates and Penning 2000).

2.7.2 *In vitro* technique

2.7.2.1 Tilly and Terry (conventional *in vitro* technique)

The Tilley and Terry technique is a two-stage, *in vitro* technique which determines the digestibility of dried forages (Tilley and Terry 1963; Galyean 1997; Damiran et al. 2008). This method uses a simple apparatus and many samples can be handled in a single experiment. In the first stage of the analysis samples are incubated with rumen liquor to resemble the digestion inside the rumen. During the second stage incubation is done with an acid pepsin solution to provide similar conditions of digestion in the small intestine (Tilley and Terry 1963).

A previous study compared dry matter digestibility measures of Italian rye grass (*Lolium multiflorum* L.) and alfalfa (*Medicago sativa* L.) obtained from conventional *in vitro* technique and the Daisy technique, and concluded that conventional *in vitro* technique was more accurate than the Daisy technique (Wilman and Adesogan 2000).

2.7.2.2 Daisy Technique

In vitro dry matter digestibility (IVDMD) is estimated by performing anaerobic fermentation in the laboratory to simulate digestion as it occurs in the rumen. This technique was developed by ANKOM Technology Corporation (Fairport, NY, USA). Rumen fluid is collected from ruminally-cannulated cows and ANCOM filter bags with dried forage (0.25 to 0.5g) samples are incubated with buffer-inoculum (1.6 L) and rumen inoculum (0.4 L) for 48 h at 39 ºC (Vogel et al. 1999; Holden 1999; Damiran et al. 2008). At the end of incubation period filter bags are rinsed and boiled in a neutral detergent solution in an ANKOM^{200} fiber analyzer (ANKOM Technology Corporation, Fairport, NY, USA) (Van Soest et al. 1991).

When comparing Daisy and other *in situ* methods to Tilly and Terry technique, those methods overestimate ($P < 0.01$) dry matter digestibility of forages (Damiran et al. 2008). The results obtained from the Daisy technique can be variable, depending on the sample size, processing method, the proximity of the incubation jar to the heat source and the extent each bag is submerged inside the incubator (Adesogan 2002; Damiran et al. 2008).

2.7.2.3 *In vitro* gas production

In this technique a feed sample is incubated with rumen liquor and gas production is measured relative to the amount of substrate fermented (Ørskov 1993). This technique can measure digestion of soluble and insoluble carbohydrates and can reflects production of volatile fatty acids in rumen. Getachew et al. (2003) studied the relationship between in vitro true digestibility of dry matter (IVTD) and in vitro gas production using 38 samples of 12 feedstuffs. They observed a poor correlation ($r^2 = 0.09$) between rate of gas production and IVTD and no correlation with the CP or NDF level of feed. However, there was a strong correlation ($r^2 = 0.76$) between in vitro gas production at 24 h and total VFA production.

2.7.3 ***In situ*** **forage degradation method**

The in situ method was developed in order to expose feed samples to a more realistic microbial growth environment. This technique needs less labour and equipment than conventional *in vitro* technique (Damiran et al. 2008). In this method feed samples are placed in small nylon bags made of indigestible synthetic fabric and then incubated in the rumen of fistulated animals following the sequential-in all-out procedure (Ørskov and McDonald 1979; Yu et al. 2004). The bags have small pores that allow entry and exit of rumen microbes and efflux of digestion products. However, the pores must be small enough to prevent loss of undigested feed particles from the bags. As for the *in vitro* method, animals are fed a diet containing the types of feeds being tested and given an acclimatization period prior to start the incubation (Ørskov and McDonald 1979). Rumen degradation kinetics for DM, OM and CP can be calculated using the nonlinear model proposed by Ørskov and McDonald (1979).

Equation 2.5 $P = a + b^* (1- e^{-c^*t})$

Where, P is percentage of degradability for response variables at t, t is time relative to incubation (h), a is highly soluble and readily degradable fraction, b is insoluble and slowly degradable fraction, c is the rate constant for degradation and e equals to 2.7182 (natural logarithm base).

When comparing *in situ* technique to *in vitro* techniques, the *in situ* method is more accurate with greater correlation to *in vivo* digestibility estimates and is able to simulate the reticulo-rumen system (Damiran et al. 2008; Ferret et al. 1997). However, *in situ* estimates can be affected by sample preparation, washing and drying procedures, animal effects, bag type, pore size of bags and modelling and may have higher variability than *in vitro* tests (Adesogan et al. 2000). When samples were finely ground to 1 mm particle size, forage digestibility was overestimated by *in situ* method (Damiran et al. 2008). The animals used in *in situ* analysis must be similar both in physiology and feeding program to the animal for which the ration is to be formulated (Ørskov and McDonald 1979; Yu et al. 2004). Another disadvantage of this technique is that undigested feed can escape through pores of the bag and overestimate the digestibility. On the other hand, feed particles and microorganisms from the rumen of the cow can pass into the bag and be measured as undigested feed and underestimate the digestibility (Mertens 2000).

2.8 Measuring botanical composition

Previous management systems can affect the botanical composition of grassland vegetation (Whalley and Hardy 2000). Repeated sampling of forages helps to monitor management effects on botanical composition of vegetation (Whalley and Hardy 2000). Further Whalley and Hardy (2000) have described the three objectives of measuring botanical composition as: 1) to partition the total herbage mass into the component species or group of species; 2) to carry out specialized procedures for individual research projects and; 3) to measure the species composition of grasslands in terms of species abundance and species diversity for environmental purposes.

There are different methodologies available to measure the botanical composition of grasslands. Different scales of measurements like global scale, national and regional scale, farm scale, paddock scale and patch scale are used to gather different levels of detail (Whalley and Hardy 2000). However, the paddock scale is used more often to estimate botanical composition in grazing studies.

Forage sampling can be either random, fixed grid or stratified random (Whalley and Hardy 2000; Magcale-Macandog and Whalley 1991). Random samples are taken when treatments are assigned to different parts of the pastureland whereas fixed grid samples are collected when the location of each sampling point is precisely fixed and different grassland communities are identified and mapped (Whalley and Hardy 2000; Magcale-Macandog and Whalley 1991). Botanical composition can be measured using a clipping technique, NIRS and an estimation technique.

2.8.1 Clipping and sorting techniques

In this technique vegetation within quadrats is harvested and hand sorted into each grass and legume species. However, this is a very time consuming if there are more than 2 or 3 important species in the sample or when large numbers of samples are to be analyzed (Whalley and Hardy 2000). A clipping and sorting technique is the appropriate technique if the botanical composition of the grassland is relatively simple and materials can be adequately identified (Whalley and Hardy 2000). If it is difficult to identify leaves of grasses in clipped material, therefore identifying individual plant species before harvesting and cutting separately, collecting the material of each species into separate bag for drying and weighing (Whalley and Hardy 2000).

2.8.2 Near-infrared reflectance spectroscopy

This technique is usually available for analysis of organic and some mineral components in forage (Shenk et al. 1979). Near-infrared reflectance spectroscopy has been extended to the analysis of species composition of forage samples (Coleman et al. 1985; Pitman et al. 1991; Wachendorf et al. 1999). Forage samples are harvested from the grasslands, dried, ground, and reflectance spectra are determined. This method is relatively rapid when compared to clipping and sorting technique. However, the samples must be harvested, dried and ground and appropriate calibration equations must be available (Whalley and Hardy 2000).

2.8.3 Estimation technique

The visual estimate of the field is a very rapid procedure and allows the collection of data from a large number of quadrats. The three different methods of visual estimates are: (i) dry-weight-rank (DRW) (Mannetje and Haydock 1963); (ii) direct estimation of percentage composition and; (iii) the percentage rank method. The DRW technique estimates forage species composition of grassland swards based on dry weight. There is no cutting and hand-separation of samples; an observer will decide whether there is a greater weight of one species than another (Neuteboom et al. 1998). Disadvantages of this method are differences in dry matter content between species and overestimation of some species as they are more prominent to the eye. Because of these disadvantages, estimation techniques are not as accurate as NIRS or clipping and sorting technique (Waite 1992; Whalley and Hardy 2000).

2.9 Soil nutrients

2.9.1 Soil nutrients in extensive winter feeding systems

Extensive winter feeding systems improve soil fertility and increase plant growth where fecal manure and urine are deposited during winter season (Jungnitsch et al. 2011). Soil can receive external nutrient input from biological fixation of atmospheric N_2, fertilizer, livestock manure and feeds (Javis and Oenema 2000). In extensive feeding systems nutrients are recycled back to the soil from manure, urine and feed residue and therefore more efficient in terms of nutrient recycling (Jungnitsch et al. 2011).

According to Bierman et al. (1999) a mature beef cow (630 kg) produces 28 kg of feces (0.4% N, 0.2% P) and 9 kg of urine (1.1% N, 0.01% P) per day. Significantly higher inorganic N (NO_3-N + NH_4-N) (59 to 73 kg acre^{-1}) and K levels (964 to 1058 kg acre^{-1}) were observed in extensive wintering sites when compared to control and treatment sites which received manure or compost.

However, cattle manure has lower plant available N and manure P has low solubility due to high Ca concentration and high fecal pH (Barrow 1987; Beckwith et al. 2002; Salazar et al. 2005). Livestock urine is a good source of plant available N, which can improve soil nutrients (Lardner 2005). The nutrition deposition area of urine in a pasture is much larger when compared to the manure deposition area and N deposition of a urine patch is 300 - 1000 kg ha^{-1} (Ball and Ryden 1984; Afzal and Adams 1992). Furthermore, manure is a good organic fertilizer and good for eroded soil as well (Schoenau et al. 2000; Lardner 2003).

Although extensive winter feeding systems are cost effective, one of the challenges in these systems is nutrients which become mobile during snow melt or rain fall. This makes them less available for pasture growth and potentially contaminates surface water, ultimately leading to eutrophication **(**Jarvis et al. 1989; Shipitalo and Owens 2006). With high stocking densities, bale grazing systems can cause P overloading and lead to potential environmental risks (Kelln et al. 2012). Hutton et al. (2004) suggested moving portable wind breaks frequently to reduce accumulation of manure nutrients in a single area of the pasture or crop land.

In conventional systems, manure is hauled from drylot pens which increases the cost associated with labour, machinery and fuel and can lead to nutrient overloading on land areas close to pens (Henry 2003; McCartney et al. 2004). A winter feeding study which was conducted over three production cycles by McCartney et al. (2004) reported that labour cost for manure removal and spreading from drylot pens was \$0.08 cow^{-1} d^{-1}. This labour cost for swath grazing was only \$0.02 cow^{-1} d^{-1} ($P < 0.001$). Equipment costs for manure removal and spreading in the traditional system (\$0.20 cow^{-1} d^{-1}) was different ($P < 0.001$) from the swath grazing system (\$0.04 cow^{-1} d^{-1}).

2.9.2 Soil sampling and measurements

Taking a representative sample is the basis for accurate soil analysis. The recommended number of samples per ha for agricultural fields and pasture lands is 15 to 25 and 35 to 45, respectively (Pennock et al. 1993; Poon and Schmidt 2010). Samples can be collected in a random, quadrant, diagonal or zigzag pattern. However, the zigzag method is preferred as this technique covers the study area well (Pennock et al. 1993).

For analysis of P and K, samples can be collected from 0 - 30 cm depth, whereas for NO_3-N analysis, soil samples need to be collected from the > 30 cm depth (Pennock et al. 1993; Brubaker et al. 1993). For sampling, the easiest method is to use a probe or auger. Soil samples should be labeled properly with date, field name and sample depth and store in a cool place like refrigerator or cooler. Samples can be analyzed for pH, total N, organic matter, exchangeable bases (Ca, Mg, K and Na), exchangeable acids (H^+ and Al^{3+}) and P (Ashworth and Mrazek 1995; Wang and Anderson 1998; Jungnitsch et al. 2011).

2.10 Economic analysis of winter-feeding systems

One of the biggest challenges for beef cattle producers in western Canada is high winter feeding costs (Lardner 2005; Larson 2010; Kelln et al. 2011). A proper economic analysis of winter-feeding systems is important. Economic data collection in the cow-calf sector has improved in the last decade in western Canada (Saskatchewan Forage Council 2011).

Economic analysis of an operation is mainly based on income, feeding cost, direct cost (bedding and vet medicine) and yardage cost (machinery cost, building repairs, depreciation, manure removal and labour) (Larson 2010; Kelln et al. 2011). In western Canada, 60 to 65% of the total production cost of a cow-calf operation comes from winter management of beef cows (Kaliel and Kotowich 2002). However, extensive winter feeding systems can reduce feed costs compared to traditional feeding systems (Krause et al. 2013). McCartney et al. (2004) reported swath grazing costs were \$0.84 cow^{-1} d^{-1} to feed and manage the beef cow during the winter period, whereas traditional feeding costs were \$1.54 cow^{-1} d^{-1}.

Traditional pen feeding is more expensive because of the high machinery and labor cost associated with forage harvesting, storing, feeding and manure removal (Volesky et al. 2002;

McCartney et al. 2004; Jungnitsch 2008; Kelln et al. 2011; Larson 2012). McCartney et al. (2004) reported that swath grazing had 38% less labor cost than drylot feeding and this significantly reduced total production cost. Finally it was estimated that producers can save at least \$0.25 cow^{-1} d^{-1} by keeping cows out on pastures in the fall (Hutton et al. 2004).

2.11 Summary of literature review

With increasing expenses for harvested and stored feed, beef cow producers are looking for alternative strategies such as stockpiled perennial grazing, swath grazing of annuals, crop residue grazing and bale grazing to extend the grazing days during long winter period in western Canada. Everyday cows remain grazing in field can decrease cost for feed harvesting, storing, transportation, machinery, equipment, labour and manure removal. Further, extensive grazing systems can contribute to improve soil nutrients as field grazing animals can deposit manure and urine on the soil during winter. There is the potential to utilize stockpiled perennial forages as an extensive grazing strategy in western Canada to improve performance of beef cows in early to mid-gestation and decrease annual production costs of cow-calf operations. However, the large year-to-year variation in weather, forage yield, nutritive value and accessibility of forage due to snow may impact cow performance and reproductive efficiency.

The hypothesis is that stockpiled perennial forage grazing as a winter feeding system will have no impact on cow performance and reproductive efficiency, forage yield, botanical composition, forage utilization and soil nutrients compared to drylot feeding system. In addition, system costs will differ between stockpiled perennial forage grazing and managing cows in drylot pens.

3.0 Rumen degradability of stockpiled perennial forages and harvested hay collected on two calendar dates measured by the *in situ* nylon bag technique.

3.1 Introduction

Forage plants consist of six different tissues: (i) vascular bundles (phloem and xylem); (ii) parenchyma bundle sheaths; (iii) sclerenchyma patches; (iv) mesophyll cells; (v) epidermal cells; and (vi) cuticle (Minson 1990). These tissues differ in rumen digestibility and are in different proportions in forages based on species, plant structure (stem vs leaves), stage of growth and management factors (Minson 1990). Each forage plant cell consists of several cellular constituents (organic acids, soluble carbohydrates, crude proteins, fats and soluble ash) and cell wall constituents (hemicellulose, cellulose, lignin, cutin and silica) (Jarrige 1960; Van Soest 1965). Therefore, the variation in the anatomical structure of tissues and the chemical composition of cells leads to a wide range of ruminal digestibility in forage diets of ruminant animals (Minson 1990). Wilkins (1969) defined the potential digestibility as "the maximum digestibility attainable when conditions and duration of fermentation are not limiting factors". When forages are in a vegetative growing phase, dry matter digestibility (DMD) is relatively constant but it decreases when stems start to elongate as the proportion of leaf sheath, stem and flowering head increase (Minson et al. 1960; Tilley and Terry 1963; Minson 1990).

Proteins, amino acids or their precursors, non-protein nitrogen (NPN) and sulfur in supplements can increase the DMD of low quality forage with low-nitrogen composition (Campling et al. 1962; Hungate 1966; Graham 1967; Bird 1974). Ruminal degradation properties of feeds can assist producers to determine the inclusion levels of feed and supplementation (Hollingsworth-Jenkins et al. 1996; Batajoo and Shaver 1998). The following bioassay techniques have been developed to estimate the digestibility of feeds and forages; rumen fluid-pepsin technique (Shelton and Reid 1960), *in vitro* cellulose technique (Jarrige et al. 1970) and *in sacco* or nylon bag technique (Ørskov and McDonald 1979). The nylon bag technique can be used to evaluate the effect of maturity of forage regrowth, seasonal changes, species variation and breakdown of seeds in the rumen (Burton et al. 1964; Miller et al. 1965; Lowrey et al. 1968; Monson et al. 1969; Playne et al. 1972).

Stockpiled forage (SPF) grazing is an alternative to extend the grazing season into the fall and winter (Johnson and Wand 1999; Cherney and Kalenback 2003). However, stockpiled forage is usually mature and moderate to poor in nutritive value. Therefore, SPF can potentially meet the nutrient requirements of dry cows in early to mid-gestation as the pregnant cow has lower nutrient requirements when compared to a lactating cow (Hollingsworth-Jenkins et al. 1996; Scarbroug et al. 2002; Poore and Drewnoski 2010). In a study by Hitz and Russell (1998) body condition score (BCS) and body weight (BW) of pregnant beef cows grazing stockpiled cool-season forages were equal to or greater than BCS and BW for cows fed large round hay bales of the same forage in drylot. The fiber content and the digestibility of the feed can have a direct effect on DMI of beef cows and ultimately on beef cow performance (Montgometry and Baumgardt 1965). Therefore, it is important to ensure that stockpiled forage can meet the nutrient requirements of beef cows managed in the field with increasing maintenance energy requirements during cold conditions when grazing during the winter.

Further, baled hay may change in digestibility during storage and therefore, the nutritive value of stockpiled forage and baled hay needs to be evaluated. Currently, there is limited information available describing ruminal digestive kinetics of stockpiled perennial forages during winter months in western Canada. The objectives of this study were: (i) to evaluate the nutritive value of stockpiled and sun-cured hay harvested forages collected over two years; (ii) to determine *in situ* disappearance kinetics of stockpiled and sun-cured hay harvested forages which were collected at two different calendar dates over 2 years.

3.2 Materials and Methods

3.2.1 Sample collection

A 2-yr study was conducted at the Western Beef Development Center's (WBDC) Termuende Research Ranch located 8 km east of Lanigan, Saskatchewan. A 24 ha field with meadow brome (*Bromus biebersteinii*) and alfalfa (*Medicago sativa*) was subdivided into six, 4-ha paddocks and each paddock was randomly assigned to 1 of 2 treatments; either stockpiled perennial forage grazing (SPF) or drylot feeding (DL). The perennial forage was allowed to grown in all paddocks during spring and early fall and swathed in mid September each year (Appendix Table A.1). In drylot treatment paddocks, all swathed forages were baled using a New Holland BR 780 round baler in mid-September each year. Samples were collected from stockpiled perennial forage (SPF) in field paddocks and from harvested round bale hay (BH) at

Table 3.1. Summary of sample collection

	Treatment	
Item	Stockpiled perennial forage (SPF)	Round bale hay (BH)
Year	2011, 2012	2011, 2012
Sampling time^z	October, December	October, December
Run^y	2	2

^{z}October = start of test; December = end of the test.
^{y}Number of runs treatment^{-1} sampling time^{-1}.

the start (October) of test and at the end (December) of test over 2 years (Table 3.1). At each sampling time, three random grab samples were taken for *in situ* experimental analysis and five random grab samples were taken for chemical composition analysis from each SPF paddock. In the drylot system, 3 cored samples were taken for the *in situ* study and 5 cored samples were taken for chemical composition analysis from bales in each pen.

3.2.2 Experimental animals

Five Hereford heifers (2 years) (398 ± 14 kg) fitted with rumen cannula were housed in a drylot pen at the Beef Cattle Research Unit, Department of Animal and Poultry Science, University of Saskatchewan. The cannulated heifers were fed a grass hay (DM = 93.2%; TDN = 50.8%; CP = 9.8%; NDF = 66.2%) diet during the *in situ* experiment. All animals were supplied adequate water and no grain or mineral supplementations were given. The *in situ* trial was approved by the Animal Care Committee of the University of Saskatchewan (Protocol Number 20100021) and all animals were managed according to the Canadian Council of Animal Care Guidelines (1993).

3.2.3 *In situ* rumen incubation technique

The study was conducted according to the *in situ* procedure as described in Ørskov and MacDonald (1979) and Yu et al. (2004). All samples were ground to pass through a 2 mm screen using a Thomas-Wiley Laboratory Mill Model 4 (Thomas Scientific, Swedesboro, NJ, USA). Approximately 7 g of sample was weighed into numbered #BG510 (5×10 cm) nylon bags with 40 µm size pores (Bar Diamond Inc., USA) and bags were sealed and labeled. The weight of the bag and bag and forage sample were recorded for each respective sample. The numbers of bags weighed for each treatment and incubation time are shown in Table 3.2. The nylon bags were randomly allocated to the five cannulated heifers and placed inside 5 mesh laundry bags before they were inserted into the rumen (30- 40 bags/laundry bag). Each bag was secured with an 80 cm cord between the cannulae cap and knot on the laundry bag (Damiran et al. 2008). All the samples were incubated for 0, 2, 4, 8, 12, 24, 48, 72 and 96 h according to the gradual addition/all out procedure described in Yu et al. (2004).

Table 3.2. Nylon bags used for a single run of treatments

Incubation time (hours)	Treatment			
	Stockpiled perennial forage[z]		Round baled hay[z]	
	October	December	October	December
96	6	6	6	6
72	5	5	5	5
48	4	4	4	4
24	3	3	3	3
12	2	2	2	2
8	2	2	2	2
4	2	2	2	2
2	2	2	2	2
0	2	2	2	2
Total	28	28	28	28

[z]October = start of the test; December = end of the test.
*Total bags per run 112.

At the end of incubation all bags were removed from the ventral rumen sac at the same time and excess ruminal contents were removed by a stream of cold tap water. Following this, all samples including 0 h incubation bags were rinsed in cold tap water in six plastic tubs and excess water was removed by gently pressing the rinsed samples.

The rinsed bags were then dried in a forced air oven at 55 ºC for 48 h and residue samples were ground to pass through a 1mm screen with a Wiley mill grinder (Philadelphia, PA). The ground samples were then pooled according to treatment (SPF/BH), time of collection (SOT/EOT) and incubation time (0, 2, 4, 8, 12, 24, 48, 72 and 96 h). The composite samples which contained residue from each time point and forage samples collected at the start and end of the study from both treatments were analyzed for DM, CP, NDF and ADF. Dry matter was determined according to the procedures outlined by the Association of Official Analytical Chemists (method #930.15; AOAC 2000). Crude protein (N x 6.25) composition was determined using the Kjeldahl procedure (method #984.13; AOAC 2000) where the samples were digested, distilled and titrated to measure the N content using the 2400 53 Kjeltec Analyzer Unit (FOSS Tecator, Hoganas, Sweden). NDF and ADF were analyzed using an ANKOM ^{TM}200 Fiber Analyzer (ANKOM Technology, Fairport, NY). The ground samples (1 mm) were weighed to around 0.45 - 0.55 g and sealed inside Ankom filter bags and followed the method # 973.18, AOAC (2000) to determine the ADF and NDF content of samples. Heat stable α-amylase and sodium sulfite were included in the NDF procedure.

3.2.4 Rumen degradation kinetics

In situ data was fitted to the first-order kinetic degradation model (Orskov and McDonald 1979):

Equation 3.1 $R(t) = U + D \times \exp(-K_d \times (t - T_0))$

Where, R (t) is the amount of residue at t h of incubation (g kg^{-1}), U is the undegradable fraction (%), D is the potentially degradable fraction (%), T_0 is the lag time (h) and K_d is the degradation rate (% h^{-1}).

This model describes the rumen degradation of DM, CP, NDF and ADF and was solved with the use of the NLIN procedure of SAS with iterative least-square regression (Gauss-Newton method) (Version 9.3, SAS Institute, Cary, NC). Effectively degradability (ED) of each nutrient component was determined using the nonlinear (NLIN) parameters calculated by the Equation 3.1 (S, U, D, and K_d) (Orskov and McDonald 1979) as:

Equation 3.2 EDCP (or EDDM, EDNDF or EDADF) (g Kg^{-1}) = S + D × Kd / (Kp+ Kd)

Where, S is the soluble fraction (%) and Kp is the rate of passage (2.0% h^{-1}) for NDF and ADF and 4.5% h^{-1} for CP and DM (Ørskov and McDonald 1979; Yu et al. 2004; Ohlsson et al. 2007).

3.2.5 Statistical Analysis

All data were analyzed as a two way factorial arrangement on a RCBD design using the PROC Mixed model procedure of SAS version 9.3. The model used for the analysis was,

Y (Y_{ijk}) = mean (μ) + block (ρ_i) + factor1 (α_j) + factor2 (β_j) + factor1*factor2 ($(\alpha\beta)_{ij}$) + error (e_{ijk})

Where, μ is the overall mean, ρi is the random effect of the ith year, αi represents the main effect of factor A, j = 1, 2; βj represents the main effect of factor B, k = 1, 2, (αβ)jk represents the interaction of factor A level i with factor B level j, eijk is the error associated with rep k of factor level ij, k = 1, 2. Significant differences were reported when $P < 0.05$, and Tukey's multiple range test was used as the multiple comparison method (Steel et al. 1997).

3.3 Results and Discussion

Table 3.3 summarizes the average nutritive values of stockpiled perennial forage (SPF) and round hay bales (BH) sampled at the start (SOT) and end of the test (EOT). At the start of study, CP content of SPF was 7 % (DM) greater than the CP content of baled hay (10.2 vs 9.5%)

Table 3.3. Chemical composition of forages used in *in situ* experiment averaged over two years

	Time of sample collection[z]					
	October			December		
Nutrient	SPF	BH	SEM	SPF	BH	SEM
Dry matter (%)	94.5	93.5	0.45	95.2	95.5	0.46
Organic matter (%)	92.1*a*	90.3*b*	0.34	90.3	90.8	0.57
Crude protein (% DM)	10.2	9.5	1.35	9.2	8.7	0.73
Neutral detergent fiber (% DM)	63.8	62.3	0.64	66.8*a*	64.0*b*	0.84
Acid detergent fiber (% DM)	44.3	44.7	0.96	45.6	44.5	0.95

[z]Means (± SEM) are forage samples collected from each treatment. October = start of test; December = end of test; SPF = stockpiled perennial forage; BH = round baled hay.
[a–b]Within each nutrient and each time of sample collection, means followed by different letters are significantly different ($P < 0.05$).

which may be due to the harvesting leaf loss at baling. However, based on NRC (2000), the CP content of stockpiled perennial forage or baled hay from both sampling dates was adequate to meet the crude protein requirements of dry cows in early to mid gestation.

Further, when comparing forage CP content at start and end of the test, CP declined in both SPF and baled hay by 10 and 8%, respectively which is similar to the findings of Taliaferro et al. (1987). Similarly, NDF concentration in both SPF and BH samples increased over time. These changes in CP and NDF may be due to leaf loss, maturity, respiration process and leaching of cell solubles in both stockpiled forage and baled hay over time (Ocumpaugh and Matches 1977; Hoffman et al. 1993; Matches and Burn 1995; Scarbroug et al. 2002; Baron et al. 2004). However, Volesky et al. (2002) found that CP content of windrowed and baled forage was similar over all sampling months in winter, whereas there was a 5.7% decline in CP of standing forage. Fiber composition of stockpiled forage can be affected by numerous factors such as weather, leaf senescence and presence of winter annual weeds (primarily at the pasture site) (Scarbrough et al. 2001). Similar to the results of Scarbrough et al. (2001), the ADF composition of forages in the current study was within the range of 44 - 46% in both stockpiled perennial forage and baled hay collected at two different times. A previous study showed that fiber component of forage can increase due to wet and cold weather (Kelzera et al. 2010).

The effect of winter feeding systems on *in situ* DM, CP, ADF and NDF degradation kinetics are presented in Tables 3.4 and 3.5. The dry matter soluble fraction (S) was (Table 3.4) highest (P = 0.01) in SPF October, BH October, BH December samples (15.6, 13.8, 15.2% respectively) and lowest for SPF December (10.6%) forage samples. Higher soluble DM fraction reflects the higher cell soluble content in SPF October, BH October, BH December samples than SPF December sample. Leaching of cell solubles from swathed forage over time may have decreased the cell soluble content in SPF December sample compared to SPF October, BH October and BH December samples.

All degradation fractions and rumen degradation rate of perennial forages can be affected by species and maturity (Hoffman et al. 1993). In this study the lag time, U, Kd, EDDM and RUDM values were not different (P > 0.05) between stockpiled forage and round bale hay at either sample date (Table 3.4) since we used similar grass (*Bromus riparius* Rehm) and legume species (*Medicago sativa*) in both treatment and SPF and BH were harvested at similar stage of maturity. In situ CP degradation characteristics (lag time, S, Kd, EDCP, RUDP) were not different (P > 0.05) among treatments. This is similar to Flores et al. (2007) who found no effect of treatment, sampling date or grazing status on CP rumen degradation characteristics of stockpiled tall fescue (*Festuca arundinacea*) forages. However, differences were detected in the potentially degradable fraction (D) and undegradable fraction (U) (P = 0.04) of CP among stockpiled and baled forages collected at two different sampling dates. The potentially degradable fraction of CP was lower (P = 0.04) in December baled hay samples compared to SPF October, SPF December and BH October samples (25.7 vs 37.2, 52.2 and 52.3%

Table 3.4. Effect of forage harvesting method on rumen degradation characteristics of dry matter and crude protein

Item	Treatment[z]				SEM	*P* value
	SPF October	SPF December	BH October	BH December		
Dry matter						
Lag time (T0; h)	0.8	0.3	0.5	0.8	0.44	0.11
Soluble fraction (S; %)	15.6*a*	10.6*b*	13.8*a*	15.2*a*	1.79	0.01
Potentially degradable fraction (D; %)	56.2*a*	58.3*a*	53.6*a*	39.2*b*	2.88	0.04
Undegradable fraction (U; %)	28.2	31.2	32.7	45.7	4.28	0.11
Degradation rate (k_d; h^{-1})	0.03	0.03	0.04	0.04	0.012	0.75
Effectively degradable DM (%)	37.3	33.9	38.3	32.4	1.53	0.48
Rumen undegradable DM (%)	62.7	66.1	61.8	67.6	1.53	0.48
Crude protein						
Lag time (T0; h)	2.7	2.8	0.6	2.1	2.08	0.34
Soluble fraction (S; %)	26.1	10.8	9.6	19.5	7.64	0.17
Potentially degradable fraction (D; %)	37.2*ab*	52.2*a*	52.3*a*	25.7*b*	6.66	0.04
Undegradable fraction (U; %)	36.7*b*	37.1*b*	38.2*b*	54.9*a*	2.98	0.04
Degradation rate (k_d; h^{-1}))	0.07	0.04	0.04	0.05	0.024	0.45
Effectively degradable CP (%)	43.5	33.5	35.3	32.1	6.63	0.63
Rumen undegradable CP (%)	56.5	66.5	64.8	67.9	6.63	0.63

[z]SPF October = stockpiled perennial forages start of test (October); SPF December = stockpiled perennial forage end of test (December) ; BH October = baled hay start of test (October); BH December= baled hay end of test (December).

[a - b]Across a row, means followed by different letters are significantly different (*P* < 0.05).

Table 3.5. Effect of forage harvesting method on rumen degradation characteristics of acid detergent fiber (ADF) and neutral detergent fiber (NDF)

	Treatment[z]			Time[y]			*P* value		
Item	SPF	BH	SEM	October	December	SEM	Trt	Time	Trt*Time
ADF									
Potentially degradable fraction (D; %)	74.9	58.7	7.39	72.4	61.2	7.39	0.04	0.09	0.18
Undegradable fraction (U; %)	25.1	41.3	7.39	27.6	38.8	7.39	0.04	0.09	0.18
Degradation rate (k_d; h^{-1})	0.02	0.03	0.007	0.03	0.03	0.007	0.34	0.84	0.92
Effective degradable ADF (%)	37.3	33.7	1.69	38.2	32.8	1.69	0.19	0.09	0.12
Rumen undegradable ADF (%)	62.7	66.3	1.69	61.8	67.2	1.69	0.19	0.09	0.12
NDF									
Potentially degradable fraction (D; %)	77.0	59.1	2.67	74.4	61.8	2.67	<0.01	0.01	1.00
Undegradable fraction (U; %)	23.0	40.9	2.67	25.6	38.2	2.67	<0.01	0.01	1.00
Degradation rate (k_d; h^{-1})	0.03	0.03	0.005	0.03	0.03	0.005	0.27	0.82	0.45
Effective degradable NDF (%)	41.4	35.0	3.15	42.0	34.5	3.15	0.20	0.15	0.63
Rumen undegradable NDF (%)	58.6	65.0	3.15	58.1	65.5	3.15	0.20	0.15	0.63

[z]SPF = stockpiled perennial forages; BH = baled hay.
[y]October= start of test ;December = end of test.

respectively) and the U fraction of CP was higher (P = 0.04) in December baled hay compared to either October or December stockpiled forage and October baled hay (54.9 vs 36.7, 37.1 and 38.2% respectively). The result suggest that leaching of cell soluble from hay bales which were stored outside may have increased undegradable fraction of CP over time.

In a previous study on rumen degradation characteristics of different perennial forages, species were not significantly correlated with EDCP while, a high correlation (r = 0.86) was observed for EDCP with CP (Hoffman et al. 1993). Therefore, the numerically higher EDCP in SPF October samples compared to SPF December, BH October and BH December was likely due to higher CP content (Table 3.3) in SPF October samples. According to the forage quality and rumen degradation characteristics results obtained can suggest that CP content in stockpiled perennial forage was adequate to marginal to meet the CP requirement of beef cow and the source of CP was highly digestible compared to hay.

In situ ADF and NDF degradation characteristics of D and U were significantly different among treatments (Table 3.5). Stockpiled perennial forage had a higher (P = 0.04) potentially degradable fraction of ADF (74.9 vs 58.7%) and lower (P = 0.04) undegradable fraction (25.1 vs 41.3%) when compared to baled hay. The D fraction of ADF numerically decreased from October to December forage samples collected from both stockpiled forages grazing system (77 to 73%) and baled hay feeding system (68 to 49%). Similar to the rumen degradation characteristics of ADF, the D fraction of NDF was higher (P = 0.04) in SPF than baled hay (77.0 vs 59.1%) and the U fraction of NDF was lower (P = 0.04) in SPF than baled hay (23 vs 40.9%). The results were likely due to the leaf loss at harvesting and baling of hay. However, the effect of treatment or sampling time was not observed for EDNDF (P = 0.20 and P = 0.15) and RUNDF (P = 0.20 and P = 0.15). Maturity of forages can have a higher correlation (r2 = -0.65) with

EDNDF (Hoffman et al. 1993). In current study both forages were harvested at similar maturities and can explain similar EDNDF values in both SPF and BH samples. The D fraction of NDF in both SPF and BH samples decreased ($P < 0.01$) from October to December (74.4 to 61.8%) and same time U fraction of NDF in both SPF and BH samples increased ($P < 0.01$) from October to December (25.6 to 38.2 %). The potential leaf loss in both stockpiled forage and baled hay over time can decrease the leaf: stem ratio and may have decreased the D fraction and increased the U fraction of NDF in samples collected in December compared to October collected samples. Further, weathering can affect the rumen degradation characteristics of NDF in stockpiled perennial forage and may have increased the lignin component and decreased the digestibility over time (Scarbrough et al. 2001). When swathed forage is exposed to rain, soluble nutrients can be lost due to leaching which can decrease the DM and increases the proportion of fiber in tissue over time (Kormos and Chestnutt 1968; Mark and Murray 1994). The method of storing hay can contribute to decreases in grass-legume hay quality over time. Laflamme (1989) found that in large round hay bales DM content decreases and nondigestible fractions increase mainly as a result of precipitation. However, the deterioration of forage is mostly restricted to the first 15 cm layer of the bales. Therefore, in the present study weather deterioration may have contributed to the decrease in the quality of hay which was stored outside without a proper shelter.

The soluble fraction was not considered in fiber degradation characteristics as both NDF and ADF are insoluble in water (Van Soest 1982). Both NDF and ADF were digested at the same rate (0.03 h^{-1}; $P = 0.27$) and no effect of treatment or sampling time were observed (Table 3.5). In addition, the rate of degradation obtained for stockpiled perennial forage (0.03 h^{-1}) were similar to the K_d values obtained for ungrazed (0.032 to 0.052 h^{-1}) and grazed (0.037 to 0.041 h^{-1}) fall-stockpiled bermudagrass by Scarbrough et al. (2001). The rate of degradation can be affected by cell wall physical characteristics like porosity, degree of polymerization and crystallinity and chemical factors like lignin (Smith et al. 1971; Cross et al. 1974; Moore and Cherney 1986; Scarbrough et al. 2001). Jung and Allen (1995) indicated that fiber digestibility is not affected by overall fiber content but it is affected by the undegradable fraction, rate of digestion and rate of passage. Therefore, increasing rate of passage may increase voluntary dry matter intake of animal. The rumen degradation characteristics obtained in this study may have affected estimated beef cow forage intake and cow performance which will be discussed in the second experiment of this thesis.

3.4 Summary and Conclusions

The BH December sample had a lower potentially degradable fraction of CP and DM than SPF October, SPF December and BH October samples. The results suggest that hay quality declined during the two months of this experiment compared to stockpiled perennial forage and the method of preservation (stockpiled vs. baled) may have affected the rate of change in digestibility kinetics during extended storage of hay. The potentially degradable fraction of ADF and NDF were greater in of stockpiled perennial forage than that of hay. However, potentially degradable fraction of NDF decreased from October to December in both stockpiled perennial forages and baled hay suggesting possible effects of weathering, leaching of cell solubles, and leaf loss over time. These results suggest that stockpiled perennial forages can be utilized in extensive winter feeding system for beef cow and may need additional supplementation when forage digestibility decreases over time and animal requirements increases due to very cold environmental temperatures.

4.0 Effect of field grazing stockpiled perennial forage or feeding round bale forage in drylot on forage yield, forage utilization, forage quality, botanical composition, soil nutrients, cow performance, reproductive efficiency and system economics

4.1 Introduction

The province of Saskatchewan can experience very extreme winter climate conditions. The average winter temperature in Saskatchewan is -10 to -15 ºC; however there can be very cold temperatures such as -40 ºC (www.climate.weatheroffice.gc.ca). These environmental conditions can be an economic disadvantage for beef producers, as additional conserved feed and supplement needs to be provided to manage cows during this cold period (Kaliel and Kotowich 2002; Lardner 2005; Larson 2010; Kelln et al. 2011).

In extensive winter feeding systems, where cows are managed in field paddocks, there is the potential to maximize the number of days that cattle are able to continue grazing and reduce production costs and mange manure nutrients more efficiently (Jungnitsch et al. 2011; Kelln et al. 2011). Therefore, producers are looking for alternative methods to extend the grazing season into fall and winter (McCartney et al. 2004; Lardner 2005; Van De Kerckhove et al. 2011; Kelln et al. 2011). Extensive feeding systems can decrease the cost for feed harvesting, transportation, storage, labour, machinery and manure removal (Hitz and Russell 1998; Johnson and Wand 1999; Volesky et al. 2002). According to Volesky et al. (2002), feed costs in an extensive swath graze system were \$0.16 head^{-1} d^{-1} compared to \$0.30 head^{-1} d^{-1} for baled-hay fed in drylot.

Among the many extensive wintering systems, stockpiled perennial forage grazing is a viable alternative (Johnson and Wand 1999; Riesterer et al. 2000). Forage regrowth during the late summer and early fall is allowed to accumulate for grazing during the late fall and winter in a stockpiled forage grazing system (Hitz and Russell 1998).

Maintenance energy requirements of a pregnant beef cow will increase with decreasing environment temperature (NRC 2000). Therefore the pregnant cow needs to be supplemented with additional energy during harsh environmental conditions in order to maintain body condition (NRC 2000). Energy is one of the important limiting nutrients which can affect the reproductive efficiency by decreasing the release of gonadotropin-releasing hormone (GnRH), luteinizing hormone (LH) and follicle-stimulating hormone (FSH) from the hypothalamo-pituitary axis and thereby increasing the length of the postpartum anestrous interval (PPI) (Bellows et al. 1982; Houghton 1990).

Legumes are usually not as suitable as grasses for stockpiling as the nutritive value declines rapidly as leaves are lost due to frost or maturity (Matches and Burn 1995; Baron et al. 2004). Meadow bromegrass (*Bromus riparius* Rehm) is a winter-hardy grass and very compatible with alfalfa (*Medicago sativa*) (Smoliak et al. 1990; Knowles et al. 1993). Stockpiled forages usually meet the nutrient requirements for mature, dry pregnant cows in early to mid-gestation and may not meet nutrient requirements for young, growing or lactating animals (Hollingsworth-Jenkins et al. 1996; Scarbroug et al. 2002; Poore and Drewnoski 2010).

There are limited number of studies evaluating extensive grazing systems, especially those focus on the effects of using stockpiled forage on beef cow performance and reproductive efficiency under western Canadian environmental conditions. The objectives of this study were: (i) to determine the effect of grazing stockpiled perennial forages on beef cow performance (body weight and condition) and reproductive efficiency compared to cows fed similar quality baled forage in drylot pens; (ii) to compare the effect of field grazing stockpiled forages or harvesting similar quality forage as baled hay on herbage biomass, forage quality and botanical composition (grass-legume) at different calendar dates; (iii) to compare the effect of stockpiled perennial forage grazing system and drylot feeding system on soil nutrients over consecutive years and; (iv) to conduct an economic analysis of stockpiled perennial forage grazing system and drylot feeding system.

4.2 Materials and Methods

4.2.1 Study location and winter feeding systems

A 2-yr study was conducted at the Western Beef Development Center's (WBDC) Termuende Research Ranch located 8 km east of Lanigan, Saskatchewan. The research site was a 24 ha field and was subdivided into six, 4-ha paddocks using permanent wire fences. The field site was located in the Black Soil Zone of Saskatchewan and the soil was classified as Chernozemic Black Oxbow soil (Saskatchewan Soil Survey 1992). Each 4-ha paddock was randomly assigned to one of two treatments; stockpiled perennial forage grazing (SPF) or drylot feeding (DL) (Appendix Figure D.1).

The study area was established in 1998 with a 90% meadow bromegrass (*Bromus riparius* Rehm) and 10% alfalfa (*Medicago sativa*) blend at a seeding rate of 9 kg per ha^{-1}. Barley was seeded as a cover crop and harvested as greenfeed in the establishment year. Historically the site was used for summer grazing prior to year one of the current study which started in 2011. In 2011, perennial forages (meadow bromegrass-alfalfa) were stockpiled until early fall and swathed mid September each year. The stockpiled perennial forage grazing treatment was assigned to paddock 2, 3 and 5 and was left for swath grazing in early October in both years, while for the drylot treatment all swathed forage was baled as large round hay bales (598 ± 48 kg) using a New Holland BR780 round baler. The bales for the DL treatment were hauled to a yard site and fed in drylot pens. All animals were supplemented with rolled barley (Appendix Table B.2) (CP = 12.4 g kg^{-1}, TDN = 86.4 g kg^{-1}) depending on environmental conditions to maintain body condition, with no weight gain above that of conceptus growth. All rations were formulated using the CowBytes ration formulation program (Version 5.31) to meet NRC (2000) requirement for dry beef cows. All cows had *ad libitum* access to a commercial 2:1 mineral supplement (20.0% Ca, 10.0% P, 60 ppm Se, 70 ppm Co, 200 ppm I, 3000 ppm Cu, 9000 ppm Mn,10 000 ppm Zn, 3700 ppm Fe, 1000 ppm F (max), 1 000 000 IU/kg Vitamin A (min), 150, 000 IU/kg Vitamin D (min), 1000 IU/kg Vitamin E (min)) (FeedRite Ltd., Humboldt, Saskatchewan, Canada).

Stockpiled swathed forage (Appendix Table B.1) (CP = 8.5%; TDN = 58.9%) was allocated on a 3-d basis using moveable electric fences. Two portable windbreaks (100 × 50 m) were allocated for each group in the field grazing system. Water was supplied in stock troughs to all cow groups and monitored on a daily basis. In the drylot system, cows were wintered in replicated (n = 3) drylot pens with 28 to 46 m^2 per cow. All pens were surrounded by wooden slatted fences contained a water trough and round bale feeder. Round hay bales (598 ± 48 kg) (Appendix Table B.1) (CP = 8.4%; TDN = 57.9%) were fed on a 3-d basis throughout the study.

4.2.2 Experimental animals

Each year dry, pregnant (average body weight (BW) = 675 ± 51 kg; 120 ± 16 d in gestation) multiparous Angus cows were used in the research study. All animals were stratified according to body weight (BW) and randomly allocated to the replicated (n = 3) winter feeding systems: (1) stockpiled perennial forage grazing (SPF); or (2) drylot feeding (DL) of round hay bales. In 2011, 58 cows were manged in winter feeding systems from October 11 to December

22 (71 d) and in 2012, 15 cows were removed from the study due to injury or failure to conceive, therefore 43 cows were manged in winter feeding systems from October 12 to December 5 (54 d).

Animals in both treatments were provided sufficient bedding and water in portable troughs. All animals were managed according to the Canadian Council for Animal Care (CCAC 1993).

4.2.3 Forage measurements

4.2.3.1 Botanical composition and forage yield

In early September before swathing forages, 15 pasture clips (0.25 m^2 quadrats) were taken using hand shears in each of the six paddocks (Appendix Figure D.1). A random sampling method was used by starting from one corner of the paddock and walking diagonally across the paddock (Appendix Figure D.2). All clipped samples were placed in a forced air oven and dried at 55 ºC for 72 h to determine dry matter (DM) weight of each sample (g/ 0.25 m^2). Each dried sample was hand separated into grass and legume components and weighed separately to determine average botanical composition of each paddock and total forage biomass (kg ha^{-1}).

4.2.3.2 Forage utilization and estimation of dry matter intake

Approximate weight of forage allocated in each treatment was determined by randomly weighing pre-grazed forage and hay as described by Volesky et al. (2002) and Kelln et al. (2011). Prior to grazing, all forages were swathed mid-September in each paddock. In each SPF paddock 15: 3 m lengths of swath were randomly selected and weighed using a portable platform scale. At the same time 3 random stockpiled forage moisture samples were collected from each paddock to determine the swathed forage DM percentage. Total weight of available forage in the paddock was calculated by multiplying the forage DM weight by total swath length.

All bales harvested from DL paddocks were weighed before moving to the main yard. Hay losses at baling were estimated by subtracting the weight of bales from weight of swath yield from each DL paddock. Three random moisture samples were taken from numerous bales in each replicate pen to determine hay DM percentage. Post-grazed residual forage remaining in each pen and paddock area was estimated each spring by random weighing of residue following the procedure as described by Kelln et al. (2011). Fecal matter and foreign debris were removed from residue prior to weighing. The number of residual samples weighed each year was 10: 3 × 1m sections of swath in each SPF paddock and 3 bale sites per drylot (DL) pen. Estimated residual feed weight was then subtracted from the weight of allocated feed to calculate forage dry matter intake (DMI) using the following equation:

Equation 4.1 DMI (kg cow^{-1} d^{-1})) = (kg DM p^{-1} allocated – kg DM p^{-1} residual)/ (n/p)

where, p=3-d feeding period; n= number of cows per experimental unit.

Estimated forage utilization was calculated according to the following equation:

Equation 4.2 Forage utilization (%) = (total forage intake/ total forage allocated) × 100

4.2.3.3 Forage quality sampling and wet chemistry

Forage samples were collected from both SPF and DL systems at the start and end of study and every 14 d during the winter feeding period. At each sampling time, five random grab samples were taken from each field paddock and in drylot system, eight bales were selected for sample coring. A power-driven hay probe with 46 cm probe length and sharp serrated tip was used for sampling at 90^{O} to the but ends of bales. All forage samples were placed in a forced air oven at 55 ºC for 72 h to determine DM percentage.

All samples were ground to pass through a 1 mm screen using a Thomas-Wiley Laboratory Mill (Model 4, Thomas Scientific, Swedesboro, NJ, USA), labeled and stored in sealer bags. All samples were analyzed for moisture, ash, CP, ADF, NDF and mineral content. Moisture and ash were determined according to the procedures outlined by the Association of Official Analytical Chemists (method #930.15; AOAC 2000) and minerals were analyzed following the method # 985.01 (AOAC 2000). Crude protein was determined using the Kjehldahl technique where samples were digested, distilled and titrated to measure the N content (method #984.13; AOAC 2000). The CP was calculated by multiplying N% by a factor of 6.25.

Equation 4.3 CP % (DM basis) = N % (DM) X F (AOAC 2000)

where, F = conversion factor (6.25) for all forages.

Neutral detergent fiber and ADF were analyzed using an ANKOM™200 fiber analyzer (ANKOM Technology, Fairport, NY). Ground samples were weighed (0.55 g) and sealed inside ANKOM filter bags and method # 973.18 (AOAC 2000) was followed to determine the ADF content of samples. Neutral detergent fiber was analyzed according to the procedure of Van Soest et al. (1991). Heat-stable α-amylase (A3306, Sigma Chemical Co., St. Louis, MO) and sodium sulfites were included in the NDF analysis. Total digestible nutrient (TDN) and digestible energy (DE) were calculated using the following equations from Adams (1995).

Equation 4.4 TDN (% DM) = 4.898 + {89.796*[1.0876-(0.0127*ADF)}

where, ADF is expressed on a DM basis.

Equation 4.5 DE (Mcal kg^{-1}) = 0.04409 × (4.898 + [1.044-{0.0119 × ADF (%)}] × 89.796

4.2.4 Soil sampling and laboratory analysis

Soil samples were collected from each paddock prior to the start of the winter feeding trial and again the following spring. In each paddock, soil samples were collected from 10 random locations at two depths (0 - 30 cm and 30 - 60 cm) using a Dutch auger. All samples were stored at 4 ºC until they were air-dried and ground to 2 mm particle size. Samples were analyzed for nitrate-N, ammonium-N, phosphorus (P), potassium (K) and organic carbon. The modified Kelowna test was used to extract the available P and K from soil as described by Ashworth and Mrazek (1995) and following this, P and K were measured using an auto-analyzer and the atomic absorption technique, respectively. The percentage of organic carbon was determined using the LECO CR-12, which burns the soil sample in a ceramic boat at high temperatures (Chichester and Chaison 1992; Wang and Anderson 1998). Potassium chloride (KCL) 2 M solution was then used to extract NO_3 and NH_4 from the soil samples and then colorimetric analysis was conducted using a Technicon Autoanalyzer II (Technicon Industrial System, 1973).

4.2.6 Weather data

Daily minimum and maximum temperatures were obtained from the Termuende

Research Ranch Benchmark Site meteorological station located 1.5 km from study site. Precipitation data including total rain (mm), total snow (cm) and total precipitation (mm) were obtained from the Environment Canada, Climate data online website (www.climate.weatheroffice.gc.ca) for ESK, Saskatchewan, which was the closest weather station to research field (Appendix C).

4.2.7 Cow performance

Cow were weighed at the start of test (SOT) and end of test (EOT) prior to feeding on two consecutive days at approximately the same time each day to minimize the gut fill effect on live body weight. Body weight was also measured every 14 d during the study period. All cows BW data was corrected for conceptus growth using the following equation (NRC 1996):

Equation 4.6 Conceptus weight (kg) = (calf birth weight x 0.01828) x $e^{[(0.02xt) - (0.0000143xtxt)]}$

where, t= days of pregnancy.

Body condition score and rib and rump fat reserves were used as indicators of cow performance and were measured at the start and end of the trial. Body condition score (BCS) was assessed by the same experienced technician in each year on a scale of 1 to 5 (1 = emaciated to 5= grossly fat) (Lowman et al. 1976). Ultrasonography was conducted at two locations to estimate body fat reserves between the 12^{th} and 13^{th} rib (site for 'grade fat') and rump fat (hip or thurl) by using the Echo Camera SSD-500 diagnostic real-time ultrasound unit (Overseas

Monitor Corporation Ltd., Richmond, BC, Canada) equipped with a UST 5044-17-cm, 3.5MHz linear array transducer.

Pregnancy stages of spring calving beef cows were recorded at the start of test. Each year calf birth date, birth weight (within 24 h), date of first and last calf born, calving span (d), calving interval and calving pattern (1 to 21 d, 22 to 42 d, 43 to 63 d) were recorded. Julian dates were calculated by considering 1 January equal to day 1. Each year calving pattern was determined by taking the first day of calving into account as the first day of calving cycle and included number of calves from day 1 to 21, 22 to 42 and 43 to 63.

4.2.8 Statistical analysis

The fixed effect of cow performance data (BW, rib and rump fat, DMI), reproductive data (calf birth date, calf birth weight, Julian date of first calf born, Julian date of last calf born, length of calving span, calving interval and calving pattern), forage data (botanical composition, forage quality, yield and utilization) and soil data were analyzed considering the experimental design as randomized complete block design (RCBD). Year was considered as a random effect and the experimental unit was each replicate paddock or drylot pen. Data were analyzed using PROC Mixed Model procedure in SAS version 9.3 (SAS Institute Inc. Cary, NC).

The experimental model was:

$$Y_{ij} = \text{Mean } (\mu) + \text{Block } (\rho_i) + \text{Trt } (\alpha_j) + \text{Error } (e_{ij})$$

Where, μ is the overall mean, ρi is the block effect to the *i*th year, αj is the fixed effect of the *j*th treatment, and *e*ij is the error term specific to the replicate group assigned to the *j*th treatment within the *i*th year.

Body condition score data was considered as a discrete value and was analyzed using the PROC Glimmix procedure of SAS (9.3). All significant differences were reported when $P < 0.05$. Soil data significance was noted when $P < 0.10$. An adjusted Tukey's was used as the multiple comparison method (Steel et al. 1997).

4.2.9 Economic analysis

Economic analysis was conducted to determine the production cost of each winter feeding systems. Total production cost was categorized into three compartments, feed costs, other direct costs, and yardage costs.

Feed cost included supplementation cost (energy and minerals) and calculated cost for the forage. In 2011, minerals were valued at $1.19 and in 2012 at $1.30 per kilogram. Salt blocks cost $5.25 per block in 2011 and $5.59 in 2012. Rolled barley was fed as an energy supplement during the winter feeding period in yr 1 and yr 2 and was valued at $0.22 and $0.24 kg^{-1}, respectively.

The cost for stockpiled forage considered fixed costs such as rent, fencing, fertilizer and establishment cost (cost of cultivation, seed, seeding based on pasture renovation) (Campbell et al. 2008). The stockpiled perennial forage (meadow bromegrass-alfalfa) was valued as $0.25 cow^{-1} d^{-1} and was adjusted according to Campbell et al. (2008) and current market prices. Hay value was based on the cost for swathing, baling, land rent and transportation. Round bale hay was valued at $0.06 $kg^{-1}$and total cost for hay was calculated based on number of bales fed to cows and average bale weight.

Other direct costs included bedding, medicine and veterinary services. Machinery and labour cost were calculated for the SPF treatment. For the DL treatment, building repair, depreciation and manure removal were also included in yardage cost. Depreciation cost was calculated using the original investment cost ($20,000) for building drylot pens and facilities (windbreak, waterers and shed), salvage cost and expected life span. Labour was valued at $15.00 per hour and rates for equipment such as truck, tractor and bale processor were obtained from SMA (2006). Final total production cost ($) and total overhead production cost ($ cow^{-1} d^{-1}) was calculated by adding total feed cost, other direct cost and yardage cost.

4.3 Results and Discussion

4.3.1 Forage biomass, botanical composition and forage utilization

Forage biomass, botanical composition and utilization data are summarized in Table 4.1. No significant effect (P = 0.18) of grazing system was observed on forage biomass in paddocks. The forage accumulation period in the current study in all paddocks was the same resulting in similar forage quantity.

Table 4.1. Effect of winter feeding system on averaged forage yield, forage utilization and botanical composition

	Treatment[z]			
Item	SPF	DL	SEM	*P* value
Yield (kg ha^{-1})	4032.5	4683.1	495.29	0.18
Botanical composition (% DM)				
Grasses	75.9	76.2	7.41	0.95
Legumes	24.1	23.8	7.41	0.95
Utilization (%)	83.5	94.4[x]	2.29	<0.01

[z]SPF = stockpiled perennial forage grazing; DL = drylot feeding; n = 3.
[y]An average 9% forage loss in each DL paddock at baling was not considered in utilization.

The estimated grass composition from SPF (75.9%) and DL paddocks (76.2%) was not different (P = 0.95). Meadow bromegrass has consistent yield in subsequent years regardless of other factors (Baron et al. 2005). The greater changes in forage botanical composition can be observed in continuously or heavily stocked pasture compared to rotational light stocked pasture due to heavy selection and repeated defoliation. However, in current study effects of forage selection and defoliation were minimal in SPF system as forages were swathed and low stocking densities were maintained in each paddock leading to similar grass and legume compositions in both treatments. In all treatment paddocks legume composition (24%) was similar (P = 0.95) and therefore, legumes must have contributed to a same extent for fixing nitrogen and improve soil fertility in all those paddocks is likely a reason which affect to have similar forage yields in both treatments. The recommended minimum forage yield to maintain a desirable grazing efficiency and facilitate grazing through snow is reported to be 2000 kg ha^{-1} (Coleman 1992; Baron et al. 2005) suggesting that the forage yield from SPF paddocks in the current study was more than adequate for field grazing during winter.

Forage utilization relative to the amount of forage allocated in each system was lower in SPF paddocks (83.5%) compared to DL pens (94.4%) (Table 4.1). Animal accessibility to swathed forage in the field can be affected by snow depth and drifting, freezing rain, wind and lower temperatures all which can reduce utilization (Lawrence and Heinrichs 1974; Baron et al. 2006; Meyer et al. 2009). In contrast, cows housed in drylot pens had no difficulty in accessing feed as they were better protected from snow by surrounding fences and the hay bale was in a bale feeder. Swathed forage in a field covered by deep snow (> 40 - 50 cm) can negatively affect accessibility to graze the stockpiled forage (McCartney et al. 2001; Meyer et al. 2009). The monthly precipitation was greater than or equal to the 30 yr mean during grazing study (October to December) in both years (Figure 4.1), possibly affecting forage utilization.

Adams et al. (1986) reported a linear effect of minimum daily temperature on grazing time and cow activity, and suggested that lower temperatures (≤ 0 ^{O}C) can decrease the grazing

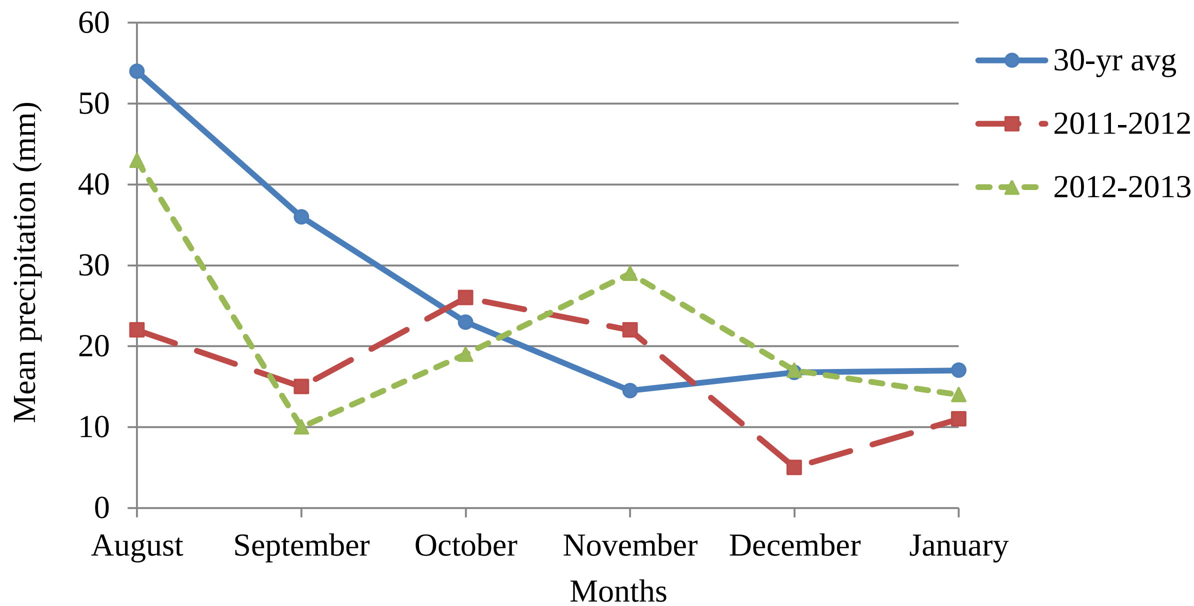

Fig. 4.1. Average monthly total precipitation from August to January for 2011 to 2012 and 2012 to 2013 compared with 30-yr average precipitation at Lanigan, Saskatchewan.

time and utilization of forage. Further, Landblom et al. (2007) concluded that feeding hay in round bale feeder can minimize the hay waste when compared to shredding round hay bales on the ground with bale processor or conventional method of rolling round bales out on the ground. In this winter feeding study we use round bale feeders in all DL pens and likely have improved utilization of hay compared to SPF. Poor and Drewnoski (2010) concluded that the method, frequency and amount of forage allowance are the most important factors which help to maximize the utilization of forages in extensive winter grazing systems. According to their findings, the most effective way of improving utilization was to use a strip grazing or frontalgrazing method which allows for a 1 to 3 d allocation of forage controlling forage allowance and maintaining cows at a BCS of 2.5-3.0.

There was an average 9% hay loss from the DL paddocks at baling which was not considered when calculating forage utilization. Typical dry matter losses during baling round bales of legume or grass hay range from 3 to 9% (Anderson and Mader 1985; Rotz and Muck 1994). Although, utilization was higher in the DL feeding system, this unaccounted loss of hay at baling would increase the total production cost.

4.3.2 Forage quality

At the start of study in October, and end of study in December, forage CP, ADF, Ca, TDN and DE were not different ($P > 0.05$) between winter feeding systems (Table 4.2). At the start of study in October organic matter was greater ($P < 0.01$) in SPF samples (92.1%) compared to DL samples (90.3%) and at end of the study in December NDF was greater ($P = 0.04$) in SPF samples (66.8%) than DL samples (64.0%) (Table 4.2). Although P content in October forage was higher in baled hay ($P = 0.01$), the value was within the normal range for alfalfa hay (2.2 ± 0.5 g kg^{-1}) and bromegrass hay (2.2 ± 0.1 g kg^{-1}) as reported by NRC (2000).

Lower organic matter and higher ash compositions in hay compared to stockpiled forages can be due to contamination of hay with dirt or sand at the time of harvesting, baling and transportation. According to previous studies (Ocumpaugh and Matches 1977; Matches and Burns 1995; Baron et al. 2004) the nutritive value of forages declines during the stockpiling process due to respiration, frost, leaf-drop and leaching of cell solubles. In the current study, forages were allowed to grow until swathing in mid-September each year. However, increasing the accumulation period can have a negative correlation with forage nutritive value and can decline due to leaf death and loss of ability to regrow new leaf materials rapidly (Ocumpaugh and Matches 1977; Matches and Burns 1995; Johnson and Wand 1999; Burns and Chamblee

Table 4.2. Effect of winter feeding system on forage quality

	Chemical composition[z]								
Item[y]	OM	CP	Ash	ADF	NDF	P	Ca	TDN[x]	DE[x]
	……………… % DM ………………								Mcal kg^{-1}
October									
SPF	92.1	10.3	7.9	44.3	63.8	0.20	0.6	51.1	2.3
DL	90.3	9.2	9.7	44.7	62.3	0.22	0.7	50.7	2.3
SEM	0.34	1.35	0.34	0.96	0.63	0.01	0.04	0.84	0.03
P value	<0.01	0.2	<0.01	0.7	0.1	0.01	0.2	0.8	0.97
December									
SPF	91.1	9.5	8.9	45.6	66.8	0.13	0.6	50.6	2.2
DL	90.8	8.7	9.2	44.5	64.0	0.10	0.7	51.8	2.3
SEM	0.57	0.73	0.57	0.95	0.84	0.09	0.04	1.08	0.04
P value	0.7	0.2	0.7	0.4	0.04	0.17	0.5	0.4	0.43

[z]OM = organic matter; CP = crude protein; ADF = acid detergent fiber; NDF = neutral detergent fiber; P = phosphorus; Ca = calcium; TDN = total digestible nutrient; DE = digestible energy.
[y]SPF = stockpiled perennial forage grazing; DL = drylot feeding.
[x]Calculated using Penn State equations (Adams 1995).

2000). Further, there can be a rapid nutritive loss of alfalfa due to the impact of frost and therefore, the recommendation is to graze alfalfa in early fall (Baron et al. 2004).

Both CP and TDN content of SPF and DL forages slightly decreased from October to December date (Figure 4.2). This may be due to leaf loss of both stockpiled forage and baled hay, which would increase leaf to stem ratio and increase fiber composition over time (Baron et al. 2004). Weathering can decrease CP and energy content of stockpiled forages compared to hay due to snow and ice cover of the swath (Hoffman et al. 1993; Coblentz et al. 1998; Coblentz et al. 1999; Scarbrough et al. 2002; Poor and Drewnoski 2010). However, in this study CP

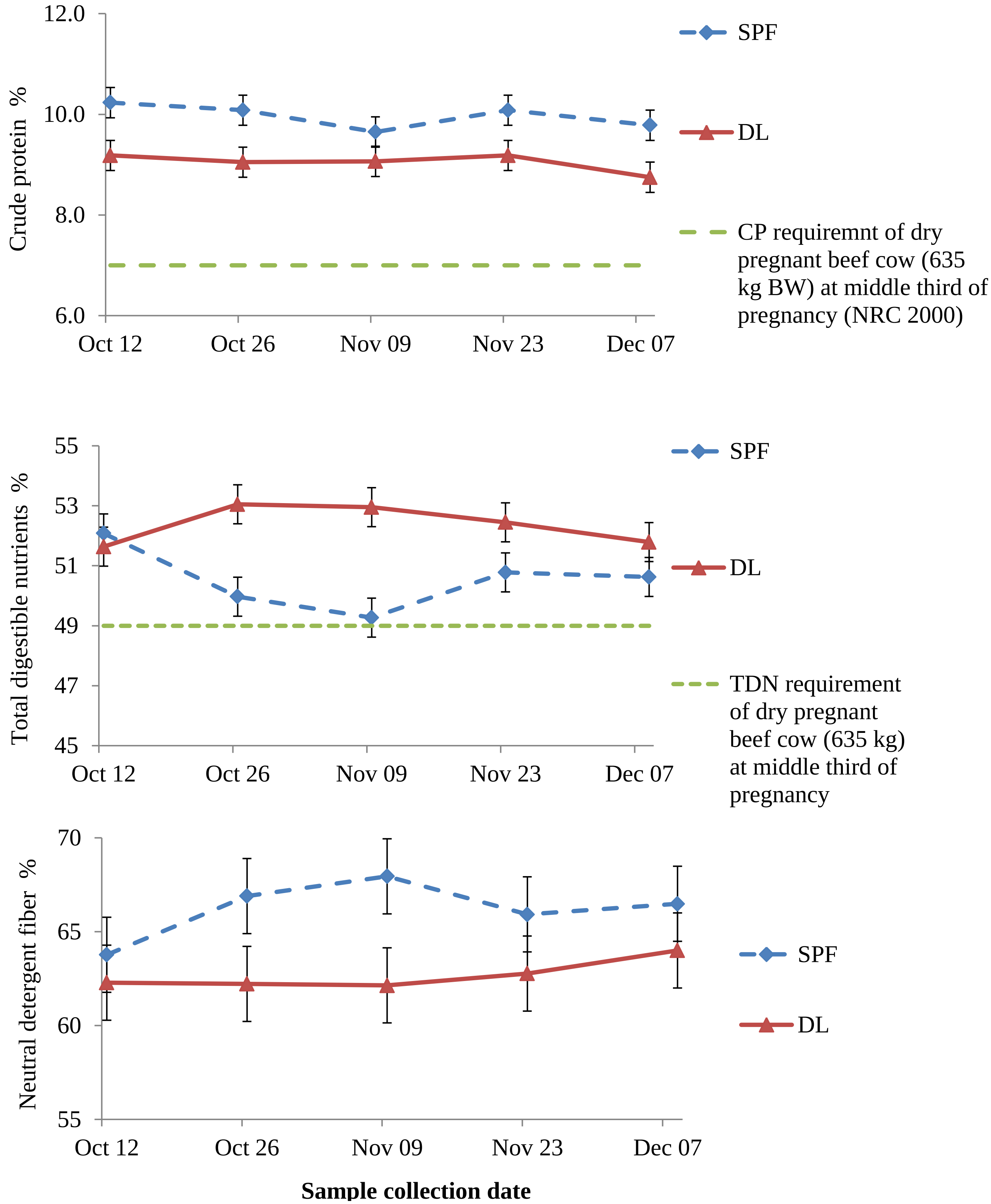

Fig. 4.2. Nutritive value (DM basis) of stockpiled perennial forage (SPF) and round bale hay (DL) collected at different sampling dates.

concentration of hay samples collected in both October and December was numerically lower than SPF samples suggesting leaf loss at baling. Dry pregnant beef cows (635 kg) at the middle third of gestation require 7% of CP (NRC 2000) in the diet suggesting both stockpiled perennial forages and round bale hay consumed throughout the winter feeding period were more than adequate to meet protein requirements of the cows used in the current study (Figure 4.2).

Energy content (TDN) of SPF and DL forage was adequate (Figure 4.2) to meet the energy requirement of dry pregnant beef cows in mid-gestation (NRC 2000). Neutral detergent fiber was greater in stockpiled forage compared to round bale hay collected in December and was likely an effect of weathering (Nayigihugu et al. 2007). Nutritive value of SPF can decrease when rain and snowmelt have leached cell soluble from leaves (Ocumpaugh and Matches 1977; Matches and Burns 1995; Johnson and Wand 1999; Burns and Chamblee 2000). The NDF content in both SPF and DL increased from the October to December sampling dates. Earlier studies (Lux et al. 1999; Munson et al. 1999; Baron et al. 2004) found that as the winter season progressed, stockpiled forage NDF content increases as leaves senesce, translocation of nutrients out of these senescing leaves, leaf-drop, decay and increase dead material which has more structural carbohydrate than non-structural carbohydrates. Hay quality may have decreased due to weather deterioration as all hay bales were uncovered and stored outside (Laflamme 1989). This increase in fiber content may suggest providing additional supplementation to the beef cow, when extending the grazing season in a stockpiled forage grazing system.

4.3.3 Average DMI, nutrient and energy intake

Estimated DM, nutrient and energy intake is presented in Table 4.3. Forage DMI of SPF beef cows was 4.8 kg d^{-1}greater ($P = 0.04$) than DMI of cows in the DL system. In addition, supplement intake (P < 0.01) and total DMI (P = 0.01) were also higher for SPF cows compared to DL cows. Differences observed in DMI, may correspond to the effect of environment and rumen degradation characteristics (Chapter 2) of stockpiled perennial forages.

During the winter feeding period, cold temperatures, wind, snow and rain can affect maintenance energy requirements of beef cows (NRC 2000). The thermo neutral zone is defined as the temperature range in which an animal performs optimally and needs less energy for maintenance NRC (2000). However, if the effective ambient temperature drops below the lower critical temperature (LCT), feed intake increases because extra energy is needed for body thermoregulation (Kennedy et al. 1986; Young 1986; Minton 1986).

Table 4.3. Effect of winter feeding system on estimated dry matter, nutrient and energy intake

	Treatment[z]			
Item	SPF	DL	SEM	*P* value
Dry matter intake (kg d^{-1})				
Forage	16.7	11.9	3.82	0.04
Supplement	1.2	0.2	0.49	<0.01
Total	17.9	12.1	3.34	0.01
Dry matter intake (% BW)				
Forage	2.5	1.8	0.56	0.04
Supplement	0.18	0.03	0.071	<0.01
Total	2.6	1.8	0.49	0.01
Crude protein intake (kg d^{-1})[y]				
Forage	1.6	1.1	0.24	0.01
Supplement	0.15	0.02	0.060	<0.01
Total	1.7	1.1	0.18	<0.01
Total digestible nutrient intake (kg d^{-1})[y]				
Forage	8.5	6.2	2.04	0.05
Supplement	1.0	0.1	0.42	<0.01
Total	9.6	6.4	1.63	0.01

[z]SPF = stockpiled perennial forage grazing; DL = drylot feeding.
[y]Average CP and TDN contents of stockpiled perennial forage and hay collected over the study period were considered in the calculation.

Each year the winter feeding study was conducted from October to December. The mean ambient environment temperature recorded at Lanigan, SK from September to January in both years was lower than the LCT (0 ^{o}C) of beef cattle with average BCS (2.5 – 3.0) and a dry winter coat (Figure 4.3). However, the effective ambient temperature would be lower than the air temperature recorded as wind velocity plays a major role in determining effective ambient temperature especially when the temperature drops below -15 to -20 ^{o}C (Ames and Insley 1975; Christophersen et al. 1978). Webster (1970) found a greater elevation of metabolic heat production (MHP) in pregnant range cows when exposed to a cold ambient temperature (-27 ^{o}C) with wind (3.6 to 5.3 m s^{-1}) compared to the same temperature under calm conditions (≤ 0.16 m s^{-1}).

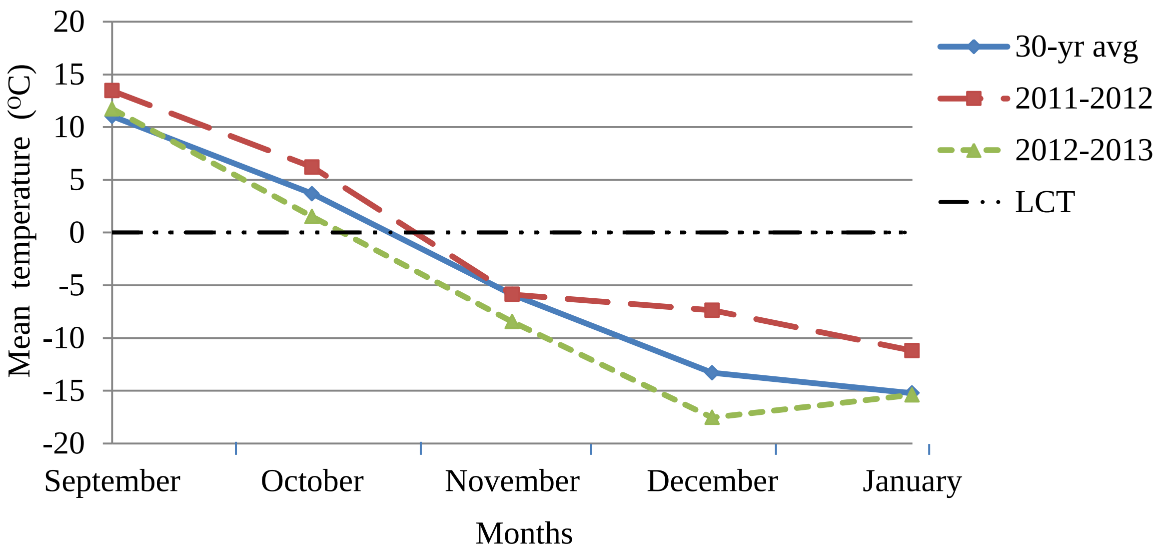

Fig. 4.3. Average monthly temperature from September to January for 2011 to 2012 and 2012 to 2013 compared with 30-yr average temperature at Lanigan, Saskatchewan. Lower critical temperature (LCT) of cattle with average BCS (2.5 – 3.0) and dry winter coat.

In the current experiment, cows grazing stockpiled perennial forages in the field paddocks were exposed to cold temperatures and wind more so than the cows housed in drylot pens which may explain the greater DMI of both forage and energy supplementation (rolled barley) for cows in the extensive stockpile grazing system. The drylot pens had fences and sheds providing adequate protection from the cold temperature, wind and snow, resulting in the observed lower forage and supplement intake for cows in the DL system. According to Christopherson and Young (1986), there is an increase in metabolic rate of 2 kcal kg^{-1} of $BW^{0.75}$ for each degree that the environmental temperature is below the LCT, which would support the greater intake response of cows in the field grazing system due to cold stress.

Voluntary dry matter intake of ruminants is related to the filling capacity of forage which is determined by fiber mass or NDF composition, initial particle size, particle fragility and rate and extent of NDF digestion (Balch and Campling 1962; Van Soest 1965; Allen 1996). Oba and Allen (1999) found *in vitro* or *in situ* NDF digestibility of forages to be better indicators of DMI of ruminants. They observed a 0.17 kg increase in DMI of dairy cattle when *in situ* NDF digestibility increased by one unit. The results from the *in situ* study (Experiment 1; Chapter 2) concluded that stockpiled perennial forage had higher a potentially degradable fraction of ADF ($P = 0.04$) (74.9 vs 58.7%) and NDF ($P < 0.01$) (77 vs 59.1%) than round bale hay. Therefore, these results may help explain the higher DMI of SPF cows compared to DMI of cows from the DL system. In summary, the greater DMI of cows in SPF paddocks was likely a result of the combined effect of environment temperature below the LCT during the study period and the higher potentially digestible fraction of neutral detergent fiber.

The total energy density (TDN, DE) was similar in both stockpiled perennial forage and round bale hay (Table 4.2). However, total TDN intake was greater ($P = 0.01$) for cows in SPF system compared to cows in DL system (Table 4.3), mainly due to the higher level of rolled barley supplementation (0.2% of BW) and forage DMI (2.5% of BW) of SPF cows. Similarly, there was 35% increase in CP intake for SPF cows compared to DL cows (Table 4.3) due to increased DMI and numerically higher CP content of stockpiled perennial forage compared to baled hay throughout the experimental period (Figure 4.3).

4.3.4 Animal performance

Previous studies have used changes in live BW (corrected for conceptus weight), body fat depth (rib and rump fat), body condition score and reproductive efficiency as indicators to evaluate the efficiency of different winter feeding systems (Lardner 2005; Kelln et al. 2011; Krause et al. 2013). In the current study initial BW (P = 0.08), final BW (P = 0.70) and BW change (P = 0.20) were not different between cows in SPF and DL treatments (Table 4.4). In addition, initial, final and body fat reserves change (rib and rump fat) which were quantified

Table 4.4. Effect of winter feeding system on beef cow performance

	Treatment[z]			
Item	SPF	DL	SEM	*P* value
Body weight (kg)[y]				
Initial	667	658	15.9	0.08
Final	695	698	6.1	0.70
Change	28	41	19.7	0.20
Rib fat (mm)				
Initial	3.5	3.5	0.25	0.82
Final	5.6	4.6	0.81	0.14
Change	1.9	1.3	0.68	0.16
Rump fat (mm)				
Initial	3.7	3.5	0.37	0.68
Final	5.0	4.4	0.86	0.13
Change	1.3	1.1	0.48	0.19
Average daily gain (kg d^{-1})	0.7	0.5	0.41	0.30

[z]SPF = stockpiled perennial forage grazing; DL = drylot feeding.
[y]Cow body weight was adjusted for conceptus gain.

using ultrasonography were not affected by wintering system (P > 0.05). However, cows managed in both SPF and DL treatment gained BW during the winter feeding period and no differences (P > 0.05) were observed for rib fat, rump fat or BCS among treatments (Table 4.5). At the end of each winter feeding period, the BCS of cows in both SPF and DL treatments were within the range of 2.5 to 4.0 (Table 4.5).

Table 4.5. Effect of winter feeding system on body condition score (BCS)

	Treatment[z]			
BCS	SPF	DL	SEM	*P* value
Start of trial (% of cows)				
2	4.3	5.6	0.30	0.77
2.5	83.0	79.6	0.55	0.68
3	12.8	14.8	0.49	0.77
3.5	0.0	0.0	0.00	1.00
4	0.0	0.0	0.00	1.00
End of trial (% of cows)				
2	0.0	0.0	0.00	1.00
2.5	53.2	68.5	0.68	0.15
3	36.2	24.1	0.64	0.22
3.5	10.6	5.6	0.39	0.38
4	0.0	1.9	0.13	0.98
BCS change (% of cows)				
-1	0.0	0.0	0.00	1.00
-0.5	2.1	3.8	0.24	0.65
0	53.2	66.0	0.69	0.22
0.5	38.3	26.4	0.65	0.23
1	6.4	3.8	o.31	0.57
1.5	0.0	0.0	0.00	1.00

[z]SPF = stockpiled perennial forage grazing; DL = drylot feeding.

The cow performance data is similar to results from previous studies where spring-calving cows wintered on extensive feeding systems were able to manage BW, body fat reserves and BCS at an adequate level (Allen et al. 1992; Hitz and Russell 1998; Schoonmaker et al. 2003; Meyer et al. 2009). In an extensive winter grazing system, cattle need to balance source of energy gain and source of energy loss to maintain their BW and BCS (Olson and Wallander 2002). As the season advances, the temperature drops dramatically (Figure 4.3) resulting in excessive use of endogenous energy or fat reserves by cows to meet their energy requirements which can decrease cow BW and body condition. Some extensive winter grazing studies reported lower forage intake of ruminants due to decreased nutritive value and low forage availability (Prescott et al. 1994; Houseal and Olson 1996; Willms et al. 1998).

In this study, cows had access to better quality stockpiled perennial forage (Table 4.2) which was similar to baled hay quality and the SPF cows consumed 2.5% of BW (Table 4.3) and availability of forage biomass was adequate for extensive winter grazing. Furthermore, the CP source and forage fiber was highly digestible when considering the rumen degradation characteristic observed in Experiment 1 (Chapter 2). Moreover, SPF cows were given adequate energy supplementation (Table 4.3) adjusted for cold temperatures during the field grazing study, resulting in maintenance and improvement of BW and body condition throughout the study. Hitz and Russel (1998) observed equal or greater BW and BCS in cows grazing stockpiled forage compared to cows in drylot and conclude that grazing cows can select more digestible forage than cows in drylot.

When cows were grazing in field paddocks they were exposed to cold ambient temperatures and wind more than cows housed in drylot. Wind breaks can minimize the convective heat losses and decrease the use of endogenous energy reserves of drylot cows (Olson and Wallander 2002). Olson et al. (2000) and Olson and Wallander (2002) experienced similar BW and BCS changes between groups of cattle with good protection from wind breaks and groups of cattle without windbreaks (control). When exposed to cold environment, cattle without windbreaks had increased feed intake to balance energy losses whereas cows with wind breaks conserved energy reserves. This strategy can explain the results of the current study where field grazing cows have increased feed intake (Table 4.3) to balance energy losses due to their unprotected cold environment. In contrast, the drylot cows have conserved their energy reserves using their wind protection structures, without a significant increase in feed intake leading to similar BW and BCS change and average daily gain (P = 0.30) of beef cows from both SPF and DL treatment (Table 4.4).

Maintaining good BCS and BW are associated with better reproductive performance of beef cows (Selk et al. 1988; Osoro and Wright 1992; Eversole et al. 2009). When BCS drops below 2.5 (Canadian scale) during the pre-calving and pre-breeding periods, there is a negative effect on cow reproduction efficiency (Selk et al. 1988). Reproductive performance data including calf birth date (P = 0.33), calf birth weight (P = 0.23), first calf born (P = 0.69), last calf born (P = 0.48), length of calving span (P = 0.50), calving interval (P = 0.85) and calving pattern (P > 0.05) were not different among treatments (Table 4.6).

Table 4.6. Effect of different winter feeding system on cow reproductive performance

	Treatment[z]			
Item	SPF	DL	SEM	*P* value
Calf birth date (Julian date)	104	106	1.98	0.33
Calf birth weight (kg)	42.7	41.4	0.70	0.23
First calf born (Julian date)	90	89	2.32	0.69
Last calf born (Julian date)	129	136	8.49	0.48
Length of calving span (d)	40	48	10.37	0.50
Calving interval (d)	364	363	2.45	0.85
Calving pattern (% of total)				
1 to 21 d	75.0	64.7	5.40	0.30
22 to 42 d	18.2	23.5	4.80	0.54
43 to 63 d	6.8	11.8	3.41	0.44

[z]SPF = stockpiled perennial forage grazing; DL = drylot feeding.

These results agree with previous studies where there was no effect of winter feeding method on cow reproductive performance (McCartney et al. 2004; Kelln et al. 2011; Krause et al. 2013).

Considering the forage quality (Table 4.2), forage and supplement intake (Table 4.3) and cow performance data (BCS, BW and rib and rump fat) (Table 4.4) we can conclude that cows in both winter feeding systems were allocated forage and supplement adequately to meet NRC (2000) beef cow maintenance requirements (no net loss or gain of body tissue beyond conceptus growth). There was lower forage utilization in SPF paddocks due to difficulty in accessibility to forage however; field cows consumed more forage than cows were in DL treatment. Spring calving dry pregnant beef cows in early to mid-gestation have low energy demand as most of the fetus growth occurs in the last trimester (NRC 1996; Olson and Wallander 2002). In the current study the beef cow maintenance energy requirements were met and resulting recommended BCS (2.5 to 3.5) throughout the winter feeding period as the reproductive efficiency of cows was not negatively affected (Krause et al. 2013) by the extensive winter feeding system (SPF treatment).

4.3.5 Soil nutrient levels in winter feeding systems

Soil nutrient levels from paddocks in both winter feeding systems from two depths (0 - 30 cm and 30 - 60 cm) are shown in Table 4.7. When compared to a traditional drylot feeding system, in-field-wintering systems can recycle most of the nutrients consumed by animals and improve soil fertility (Lardner 2005; Jungnitsch et al. 2011). Jungnitsch et al. (2011) reported a 3 to 3.7 times increase in soil inorganic nitrogen at the 0 - 15 cm depth in extensive feeding paddocks compared to sites where manure or compost was mechanically spread in a research field in Saskatchewan. In addition, 30 to 40% of N and 20 to 30% of P from the original feed was recovered in soil in the extensive winter feeding paddocks. Soil NO_3-N level in SPF paddocks was higher (11.8 kg ha^{-1}) (P = 0.07) than soil NO_3-N in round bale hay paddocks (9.3 kg ha^{-1})

Table 4.7. Soil nutrients levels at the 0 - 30 and 30 - 60 cm depth from stockpile grazed and baled hay paddocks in spring.

	Treatment[z]			
Soil nutrient	SPF	DL	SEM	*P* value[y]
	---------------------------- 0 – 30 cm --------------------------			
NO_3-N (kg ha^{-1})	11.8	9.3	0.87	0.07
NH_4-N (kg ha^{-1})	8.1	8.6	0.75	0.62
NO_3+NH_4 (kg ha^{-1})	19.9	17.9	1.21	0.28
Potassium (kg ha^{-1})	720.2	692.9	37.0	0.61
Phosphorus (kg ha^{-1})	32.2	40.3	4.29	0.21
Organic carbon (%)	2.7	2.9	0.30	0.35
	---------------------------- 0 – 60 cm --------------------------			
NO_3-N (kg ha^{-1})	1.5	1.9	0.34	0.34
NH_4-N (kg ha^{-1})	5.1	6.1	0.99	0.50
NO_3+NH_4 (kg ha^{-1})	6.6	8.0	1.29	0.44
Potassium (kg ha^{-1})	213.1	290.8	37.18	0.11
Phosphorus (kg ha^{-1})	12.5	16.3	2.16	0.25

[z]SPF = stockpiled perennial forage grazing; DL = drylot feeding.
[y]Significance were declared when $P < 0.10$.

(Table 4.7). However, at the 0 - 30 cm soil depth NH_4-N, total N, potassium (K), P and organic carbon and NO_3-N, NH_4-N, total N, K and P at the 30 - 60 cm depth were not different (P > 0.10) between soil samples from SPF and DL paddocks (Table 4.7).

The whole field was used for summer grazing previously, which could explain by high amount of pre-treatment availability of soil nutrients in DL paddocks. Possible reasons for manure nutrient losses in extensive wintering sites are volatilization and denitrification, leaching, runoff, eutrophication and plant capture (Jarvis et al. 1989; Shipitalo and Owens 2006; Kelln et al. 2012). Nutrient levels in soil samples collected in spring each year may have been affected by the thick layer of snow which melted, causing runoff and diluting the manure and urine patches' nutrients (Jarvis et al. 1989; Shipitalo and Owens 2006; Kelln et al. 2012). Urine contains urea

$(CO\ (NH_2)_2)$ which can be converted to ammonia by urease enzyme activity in the soil and then NH_3 is lost through volatilization (Muck and Steenhuis 1981).

Cattle excrete more than 96% of diet P in fecal manure and very little amounts of P in the urine (Barrow 1987; Eghball and Power 1994). Like N, dissolved P in soil can be lost due to high precipitation and runoff with water (Barrow 1987; Eghball and Power 1994; Gburek and Sharpley 1998). An experiment was conducted by Smith et al. (2011) in east-central Saskatchewan to evaluate nutrient deposition in soil and losses in runoff water and ground water following extensive winter feeding systems. Ponded water and soil samples were collected from both a controlled area (ungrazed) and a winter bale grazed area. The results suggest that more orthophosphate-P and NH_4-N was in runoff from the bale grazing site than from the control site. However, NO_3-N levels in runoff from bale grazing and control areas were not different ($P > 0.05$). Smith et al. (2011) concluded that conversion of organic N, urea and NH_4^+ in excreta to NO_3 needs sufficient time and temperature and therefore runoff NO_3-N losses are less compared to NH_4-N and phosphorus. This may explain the observed greater NO_3-N level in soil samples from the 0 - 30 cm from the SPF paddocks than the round bale paddocks.

Cattle manure contains different proportion of N fractions. However, high proportion of N in cattle manure is in the organic form and mineralization of organic N and release as inorganic N is a very slow process (Jungnitsch et al. 2011). According to another study conducted in east of Lanigan, Saskatchewan concluded that high C : N ratio of manure can lead to immobilization of N and less availability of inorganic form of N in field grazing paddocks at the time of sampling (Kelln et al. 2012). Further, an observation in the current study was that most of the manure and urine patches were concentrated around the wind breaks, on bedding sites and near water troughs. Manure nutrients may be lost or not used efficiently because of the heterogeneity of manure distribution and concentration in a small area (Barrow 1987) and low stocking densities (2.5 – 2 Animal Units ha^{-1}) of field paddocks in both years may explain the reason for not observing greater difference in most of the soil nutrients from both SPF and DL paddocks.

4.3.6 Winter feeding system costs

Feed cost, direct cost, yardage cost and total production costs associated with the winter feeding systems over two years (2011 and 2012) are outlined in Table 4.8. In 2011, all costs were estimated for the 71 d winter feeding period, whereas in 2012 costs were estimated for the 54 d winter feeding period. In 2011, total feed costs were 38.4% lower for the stockpiled perennial forage system than drylot feeding system. Similarly, in 2012, total feed costs were 60.3% lower in SPF than DL system. These differences resulted from higher price for round baled hay (\$0.71 $head^{-1}$ d^{-1}) compared to stockpiled forage cost (\$0.25 $head^{-1}$ d^{-1}).

The supplement cost in the SPF system was 81 and 100% greater than the DL system in 2011 and 2012, respectively. Bedding cost was similar for both systems as the same amount of bedding was used in both treatments. The total yardage cost was \$0.94 and \$0.58 for 71 d of winter feeding for SPF and DL, respectively in 2011. Yardage cost was \$0.85 and \$0.53 for 54 d SPF and DL winter feeding, respectively. The higher yardage cost for SPF system reflects the 2X greater machinery and labour cost for cows managed in SPF system compared to DL system. Field grazing cows were supplemented 20 to 27 times more than drylot housed cows during the experiment. Moving fences and windbreaks and watering the SPF grazing cows on a regular basis increased the machinery (including fuel) and labour cost in both years. The stockpiled

Table 4.8. Economic analysis of winter feeding systems				
	SPF[z]		DL[z]	
Item	2011	2012	2011	2012
	……………………… $ cow^{-1} d^{-1}……………………			
Feed costs				
Supplement	0.44	0.13	0.08	0.00
Mineral	0.12	0.08	0.12	0.07
Salt	0.01	0.02	0.01	0.01
Stockpiled pasture	0.25	0.25	.	.
Baled hay	.	.	1.12	1.13
Total feed costs	0.82	0.48	1.33	1.21
Other direct costs				
Bedding	0.03	0.03	0.03	0.02
Yardage cost				
Machinery cost (including fuel)	0.63	0.55	0.29	0.28
Building repair	0.01	0.01	0.02	0.01
Depreciation	0.01	0.01	0.03	0.04
Manure removal	.	.	0.03	0.04
Labour	0.29	0.28	0.21	0.16
Total yardage cost	0.94	0.85	0.58	0.53
Total Production costs	1.79	1.36	1.95	1.76

[z]SPF = stockpiled perennial forage grazing; DL = drylot feeding.

perennial forage in this study was swathed for the purpose of estimating biomass, residue and intake more accurately. However, producers may prefer to graze the standing forage would decrease the machinery and labour cost listed in Table 4.8.

Total cow cost per day was 9% lower in 2011 and 29% lower in 2012 for beef cows wintered on stockpiled perennial forages in field paddocks compared to beef cows wintered in drylot pens. Therefore, on average the extensive winter feeding system had 19% lower total system cost compared with drylot system which was similar to previous study results (Kaliel and Kotowich 2002; Kelln et al. 2011). The rolled barley grain price was $0.24 kg^{-1} and as the season advanced, field grazing cows needed more supplementation (0.2% of BW) resulting in a significant increase in supplementation cost (Table 4.8). Therefore, the economic analysis shows that a stockpiled perennial forage grazing system is less costly than a drylot feeding system. However, extending stockpiled forage grazing into late December, and the months of January and February may increase supplementation cost and reduce any saving of production cost in the system.

4.4 Summary and Conclusions

Stockpiled perennial forage quality was adequate to meet the NRC (2000) dry beef cow nutrient requirements and beef cows maintained BW, body fat reserves, BCS and reproductive performances. Forage utilization in SPF system (83.5%) was lower than DL system (94.4%). However, stockpiled forage grazing cows have increased both forage and supplement intake compared to drylot cows. Soil nutrients were not different between winter feeding systems except soil NO3-N level at the 0 – 30 cm soil depth which was greater in SPF paddocks than DL paddocks. Total production cost was 19% less in stockpiled forage grazing system compared to drylot system.

In conclusion the results of this 2-yr study indicate that SPF grazing can be an economically effective management alternative for extending the grazing season during the winter in western Canada.

5.0 GENERAL DISCUSSION

Experiment I (Chapter 3) evaluated forage quality and rumen digestibility of stockpiled perennial forage and baled hay. According to the results, swathed stockpiled forage was similar or greater in nutritive value and digestibility of DM, CP, ADF and NDF compared to baled hay. Therefore, the greater DMI of cows in SPF treatments compared to cows in DL treatment was likely a result of the combined effect of environment temperature below the LCT and a highly potentially digestible fraction of NDF. However, digestibility of stockpiled forage declined with time due to weathering, leaf loss and leaf senescence. As the season advances, field grazing cows exposed to low temperature as -30 to -40 ºC more than DL cows and required provision of extra energy for body thermoregulation, grazing and walking. Therefore when extending the grazing season further into winter, adequate energy supplementations is required to manage beef cow performance at an optimum level. Protein was not a limiting nutrient in the SPF system as stockpiled forage contained adequate levels of CP to meet the protein requirement of dry cow in early to mid-gestation.

In current study forages were allowed to accumulate throughout the year in order to available sufficient amount of forages to maintain cows in both winter feeding systems. Forages were harvested at the same time in all 6 paddocks to have similar quality forages in both treatments. Stockpiled forages were swathed to consolidate the biomass and make it more accessible and easy to estimate DMI and utilization. Furthermore, swathing can improve grazing efficiency than grazing standing forage by increasing the utilization of each part of forages due less selection and facilitate dry matter and energy intake. Nevertheless, swathing is more expensive than grazing standing stockpiled forage because of increased labour and machinery cost. Forage utilization was lower in the SPF grazing system likely due to decreased accessibility of forage due to snow cover. However, there was a calculated 9% harvesting (baling) loss of hay in DL system compared to SPF system. This calculated harvesting loss was not considered in determining utilization as the estimated utilization was based on total forage allocated and total forage intake values. Considering a round bale (615 kg) valued at $32.16 ($0.0523/kg), the estimated cost of 9% hay loss would be $42.41 from each DL paddock in each year. Therefore, this harvesting loss can possibly increase the total production cost and decrease hay quality and utilization in a DL system. Forage quality of stockpiled perennial forage was sufficient to meet maintenance requirements of beef cows in early to mid-gestation without observed loss of BW, BCS and body fat reserves and no negative effect on reproductive performance. Further, the total cost of managing beef cows during the winter feeding period by stockpiled forage grazing was less than drylot feeding. There was an average 49% reduction in winter feed cost in the SPF system compared to drylot system as hay is more expensive than stockpiled forage. Total production cost decreased by 19% when cows were managed in stockpiled forage grazing system compared to traditional drylot system. Nevertheless, the average supplement cost was 91% greater in SPF system than for drylot cows, because, field cows consumed more supplement as a result of exposure to cold environmental temperatures, wind and snow. Therefore, further extending stockpiled forage grazing during the months of December, January and February may increase supplementation cost and reduce any savings in this system relative to the drylot system. In SPF systems manure nutrients need to be managed properly to prevent runoff nutrient losses.

In summary, according to the results from these two experiments it can be concluded that stockpiled perennial forage grazing can be a cost effective alternative system for producers in western Canada to manage beef cows without having any negative effect on cow performance and reproductive efficiency. Nevertheless, climatic conditions can affect the outcome of an extensive feeding system and therefore when managing cows in SPF systems, producers need to adjust the management systems according to winter conditions in western Canada.

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7. APPENDICES

APPENDIX A

Table A.1. Forage cut and baling dates of treatment paddocks

	Treatment[z]					
Item	DL			SPF		
Paddock no	1	4	6	2	3	5
2011						
Swath date	Sept 14	Sept 14	Sept 12	Sept 15	Sept 15	Sept 16
Baled date	Sept 21	Sept 21	Sept 16	.	.	.
2012						
Swath date	Sept 13	Sept 13	Sept 10	Sept 15	Sept 15	Sept 14
Baled date	Sept 14	Sept 14	Sept 14	.	.	.

[z]SPF= Stockpiled forage; DL = Drylot feeding of round hay bales.

APPENDIX B

Table B.1. Chemical composition of stockpiled perennial forage and hay at the time of harvesting in September (% DM)

Nutrient	Forage	
	Stockpile forage	Baled hay
Crude protein (% DM)	8.5	8.4
Ash (% DM)	7.5	8.6
Acid detergent fiber (% DM)	39.1	37.2
Neutral detergent fiber (% DM)	65.1	59.3
Net energy maintenance (Mcal kg^{-1})[z]	1.3	1.2
Net energy gain (Mcal kg^{-1})[z]	0.7	0.7
Total digestible nutrients[y] (% DM)	58.9	57.9
Calcium (% DM)	0.2	0.5
Phosphorus (% DM)	0.2	0.2
Magnesium (% DM)	0.2	0.2
Potassium (% DM)	1.9	1.8

[z]Calculated using the equations from the NRC (1996).
[y]Calculated using Adams (1995).

Table B.2. Chemical composition of supplementation (rolled barley)

Item	Chemical composition
Dry matter (%)	87.2
Total digestible nutrients (g kg^{-1})	864
Net Energy Maintenance (Mcal kg^{-1})	2.1
Net Energy Gain (Mcal kg^{-1})	1.5
Crude protein (g kg^{-1})	124
Ash (g kg-1)	27
Neutral detergent fiber (g kg^{-1})	161
Acid detergent fiber (g kg^{-1})	52
Calcium (g kg^{-1})	1
Phosphorus (g kg^{-1})	4
Magnesium (g kg^{-1})	1
Potassium (g kg^{-1})	6

APPENDIX C

Table C.1. Average monthly temperature (^{O}C) and total precipitation (mm) for Termuende Research Ranch[z]

	Temperature (^{O}C)			Precipitation (mm)		
Month	Max	Min	Mean	Rain	Snow	Total
May 2011	19.7	2.0	9.0	18.4	0.0	18.4
June 2011	22.9	9.6	15.7	68.4	0.0	68.4
July 2011	20.8	14.9	17.8	109	0.0	109
August 2011	20.8	10.1	16.4	21.8	0.0	21.8
September 2011	22.8	4.0	13.4	14.6	0.0	14.6
October 2011	12.7	0.6	6.1	25.6	0.0	25.6
November 2011	-1.1	-10.9	-5.9	0.0	22.0	22.0
December 2011	-3	-6.5	-4.7	0.0	4.6	4.6
January 2012	-6.5	-17.1	-11.1	0.0	14.0	17.4
May 2012	18.1	4.1	10.4	103.8	0.0	103.8
June 2012	22.1	4.3	14.8	98.8	0.0	98.8
July 2012	23.7	14.3	17.8	41.2	0.0	41.2
August 2012	22.3	13.4	17.1	43.4	0.0	43.4
September 2012	20.5	3.2	11.7	9.8	0.0	9.8
October 2012	6.3	-4.0	1.3	8.6	10.6	19.2
November 2012	-4.6	-12.5	-8.5	0.0	29	29.0
December 2012	-13.	-23.2	-17.5	0.0	17.2	17.2
January 2013	-5.1	-10.6	-8.6	0.0	14.2	14.2

[z]Meteorological data from Environment Canada's Climate data online (www.climate.weatheroffice.ec.gc.ca) for ESK, Saskatchewan.

APPENDIX D

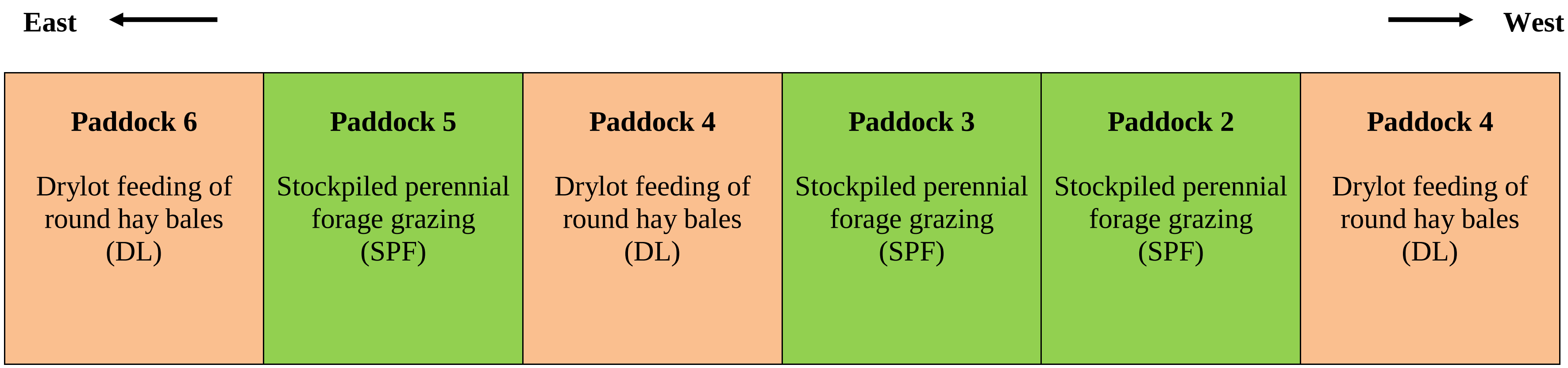
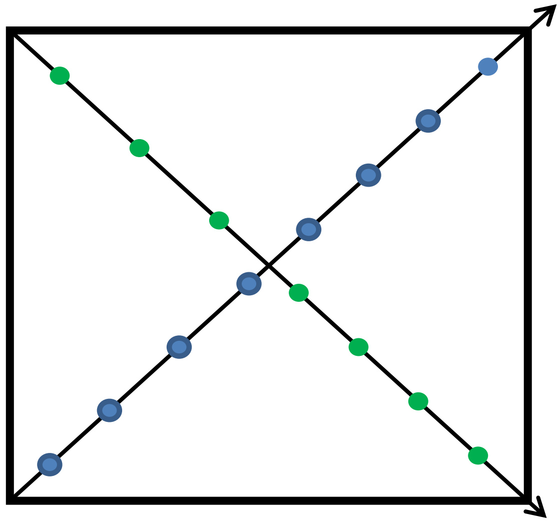


Fig. D.1. A schematic layout of the study field.

(a)



(b)

Fig. D.2. Random pasture sampling method from a paddock (www.livestocklogic.com.au) (a) and a quadrat pasture clip (0.25 m^2) (b).