EFFECTS OF SUPPLEMENTING BEEF COWS GRAZING FORAGES WITH WHEAT-BASED DRIED DISTILLERS' GRAINS WITH SOLUBLES ON ANIMAL PERFORMANCE, FORAGE INTAKE & RUMEN METABOLISM

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ABSTRACT

Three experiments were conducted to determine the effects of supplementing wheat-based dry distillers' grains with solubles (DDGS) on cow performance, forage utilization, and production costs. In the first two experiments, 48 dry, pregnant Black Angus cows (mean BW±SD; 598.2±4.2 kg) stratified by body weight (BW) and days pregnant were allocated randomly to one of three replicated (n=2) treatments. Cows were managed on stockpiled crested wheatgrass pasture (TDN=49.0, CP=7.3 (% DM)) in experiment one (EXP 1) and barley straw-chaff residue (TDN=45.4, CP=8.6 (% DM)) in experiment two (EXP 2). EXP 1 supplement treatments were (1) 100% DDGS (70:30 wheat:corn blend; DDGS); (2) 100% commercial supplement (COMM); or (3) control– no supplement (CONT). EXP 2 supplement treatments were (1) 100% DDGS (70:30 wheat:corn blend; DDGS); (2) 50% DDGS + 50% rolled barley (50:50); or (3) 100% rolled barley grain (control; BARL). Forage utilization was measured for both trials using the herbage weight disappearance method. Cow BW, body condition score (BCS), and rib and rump fat were measured at the start and end of trial and cow BW was corrected for conceptus gain based on calving data. There was no effect ($P > 0.05$) of treatment on forage utilization in either experiment. In EXP 1, cow performance was not affected ($P > 0.05$) by supplement strategy. In EXP 2, BW change was 11.3, 6.8, and -6.5 ($P < 0.01$) for DDGS, 50:50, and BARL, respectively. Because forage utilization was not affected, the difference in cow BW was the result of supplement type. Costs per cow per day in EXP 1 were \$0.66, \$0.68, and \$0.60 for DDGS, COMM, and CONT, respectively. In EXP 2, costs per cow per day were \$0.79, \$0.80, and \$0.80 for DDGS, 50:50, and BARL treatments, respectively.

In experiment three (EXP 3), four ruminally cannulated beef heifers were individually fed a basal ration of 75% ground barley straw and 25% ground grass hay (TDN=46.3, CP=7.5 (% DM)). Heifers were supplemented with either (1) DDGS (70:30 wheat:corn blend; DDGS); (2) commercial range pellet (COMM); (3) barley grain and canola meal (BAR+CM); or (4) control – no supplement (CONT). Forage intake, apparent total tract digestibility, and passage rate; rumen fermentation parameters; and the rate and extent of forage degradation were measured. Forage intake, passage rate, and apparent total tract digestibility of DM, NDF, and ADF were not affected ($P > 0.41$) by treatment. Apparent total tract digestibility of CP was increased ($P = 0.02$) by supplementation, but was not different between DDGS, COMM, and BAR+CM treatments. Ruminal pH was not affected ($P = 0.20$) by treatment diet, but rumen ammonia-N was increased ($P < 0.01$) by supplementation. The potentially degradable and undegradable forage fractions were affected ($P < 0.02$) by supplementation, reducing the extent of forage degradation. Also, there was a tendency ($P = 0.06$) for the rate of forage DM degradation to increase when supplements were fed.

The results of these experiments indicate that wheat-based DDGS can be used as a supplement for beef cows consuming forages with similar or greater effects compared to a commercial pellet and barley grain. DDGS had similar effects on rumen metabolism as the commercial range pellet or barley grain and canola meal, suggesting DDGS can be substituted on a unit basis with these supplements. As such, the inclusion of wheat-based DDGS as a supplement for beef cows will depend on the initial price of the supplement.

Key Words: wheat-based dried distillers’ grains with solubles, low quality forage, beef cows

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ADF	Acid detergent fibre
ADG	Average daily gain
ADL	Acid detergent lignin
ADIN	Acid detergent insoluble nitrogen
ADIP	Acid detergent insoluble protein
AIA	Acid insoluble ash
AOAC	Association of Official Analytical Chemists
BCS	Body condition score
BW	Body weight
Ca	Calcium
CDS	Condensed distillers' solubles
CGF	Corn gluten feed
CP	Crude protein
D	Potentially degradable fraction
d	Day
DDG(S)	Dried distillers' grains (with solubles)
DE	Digestible energy
DM	Dry matter
DMI	Dry matter intake
EDDM	Effective degradability of dry matter
EDNDF	Effective degradability of neutral detergent fibre
h	Hour
ha	Hectares
IVDMD	*In vitro* dry matter digestibility
IVOMD	*In vitro* organic matter digestibility
IU	International units
Kd	Rate of degradation
Kp	Rate of passage
ME	Metabolizable energy

mL	Milliliters
MP	Metabolizable protein
MWDG	Modified wet distillers’ grains
N	Nitrogen
NDF	Neutral detergent fibre
NDIN	Neutral detergent insoluble nitrogen
NDIP	Neutral detergent insoluble protein
NE_g	Net energy of gain
NE_m	Net energy of maintenance
NH_3-N	Ammonia nitrogen
NPN	Non-protein nitrogen
NSC	Non-structural carbohydrates
OM	Organic matter
P	Probability
RDP	Rumen degradable protein
RUP	Rumen undegradable protein
S	Immediately soluble fraction
SARA	Sub-acute ruminal acidosis
SAS	Statistical analysis systems
SD	Standard deviations
T0	Lag time
TDN	Total digestible nutritents
U	Undegradable fraction
WDG(S)	Wet disillers’ grains (with solubles)
Yb	Ytterbium
%	Percent

1. General Introduction

For beef producers in western Canada, meeting cow maintenance and gestation requirements economically is a challenge. Efforts to lower costs of production have led to the adoption of extended grazing and extensive management practises. This has subsequently led to increased use of low quality forages in beef cow diets. These types of forages, which are characterized by high fibre and low protein content (NRC 1996), require supplementation in order to meet cow requirements, especially during the second and third trimester of pregnancy (Willms et al. 1998; McCartney et al. 2006). Protein supplements are considered ideal for low quality forages, as the crude protein provides nitrogen for maintenance and growth of rumen microbial populations, optimizing rumen health and function and promoting fibre digestion (Chase and Hibberd 1987; Mathis et al. 1999).

With expansion in the North American ethanol industry, there is an increasing availability of wheat-based distillers' co-products. Dried distillers' grains with solubles (DDGS) is the most common co-product available to cow-calf producers as it is easiest to transport and store (Schingoethe 2006). Because corn is the most common substrate used for ethanol fermentation in the United States (Mustafa et al. 2000b; Nyachoti et al. 2005), there have been a number of evaluations focused on corn-based co-products in range cow diets (Smith et al. 2001; Morris et al. 2006; Stalker et al. 2006; Loy et al. 2007). In western Canada, however, wheat is more readily available as an ethanol feedstock (Lee et al. 1991). There is currently no information regarding the use of wheat-based DDGS in range cow diets.

In western Canada, over 500 million litres of ethanol are produced each year from over 1.3 million metric tonnes of wheat or wheat-corn blends (Canadian Renewable Fuels Association (CRFA) 2009; University of Saskatchewan 2009). The demand for feedstock has resulted in some of the highest cereal grain prices in decades – a serious concern for livestock producers where feed can be as much as 65% of total costs (Kaliel and Kotowich 2002). Furthermore, this level of ethanol production creates roughly 460 thousand metric tonnes of DDGS (University of Saskatchewan 2009). Ruminant diets are the most logical target for the displacement of the co-products – distillers' grains traditionally have been a valued protein supplement in dairy rations – however, more information is needed to facilitate their adoption by the beef cattle industry. As ethanol co-products become increasingly available to producers in western Canada, information on the efficacy of wheat-based DDGS as a supplement will be required to make economical management decisions.

The objectives of this literature review are (1) to provide an overview of the expanding biofuels industry in North America, more specifically the ethanol industry in western Canada; (2) to review the nutritional value of ethanol co-products for ruminant nutrition; (3) to review the use of low quality forages in beef cow diets as a cost reduction strategy; (4) to review the techniques used to evaluate feeding trials; and (5) to review the various types and sources of supplements for beef cow diets.

2. Literature Review

2.1. Overview of the biofuels industry in western Canada

Renewable fuel alternatives are a topic of considerable interest as economic and environmental concerns, such as increasing oil and gas prices and the reduction of greenhouse gas emissions, continue to escalate. Government polices supporting biofuel development and integration are motivated by efforts to minimize dependency on foreign petroleum products, meet environmental commitments, and stimulate rural economies (CRFA 2009Olar et al. 2004). North American ethanol and biodiesel production from cereal grains and oilseeds, respectively, has expanded exponentially as federal incentives and mandates for blended fuels pass legislation. In Canada, these incentives include Investing in Cleaner Fuels in the Federal Budget 2007, the Ethanol Expansion Program, and Canada’s Clean Air Act (CFRA 2009).

2.1.1. Co-product production

Ethanol is produced by the fermentation of starch or enzyme-treated cellulose in either a dry or wet process (Bothast and Schlicher 2005). An in-depth discussion of the fermentation process is beyond the scope of this review and can be found in the literature (Tibelius 1996; Stock et al. 2000; Dien et al. 2003; Jacques et al. 2003; Johnson and May 2003; Maisch 2003; Bothast and Schlicher 2005; Weigel et al. 2005). The final products of this process are ethanol, carbon dioxide, and wet stillage, the latter of which is further processed into thin stillage and distillers' grains. Several crops are used in North America for the production of ethanol, most notably corn in the United States and wheat in western Canada (Lee et al. 1991; Nyachoti et al. 2005). Because starch is removed from the initial feedstock during ethanol production, the remaining co-products have an approximate three-fold increase in nutrients when compared to the original grain (Mustafa et al. 2000a; Jacques 2003; Klopfenstein et al. 2008). The type and quality of end product generated depends on the initial feedstock and milling process employed, as well as the post-processing of the feedstock residue.

2.1.2. Types of distillers' co-products

Co-products from dry milling are generally categorized by the extent of their post-processing. The initial wet stillage is fractionated into solid and liquid parts: wet distillers' grains (WDG) and thin stillage, respectively (Ojowi et al. 1996). Thin stillage may undergo evaporation to produce condensed distillers' solubles or syrup (CDS), or may be made available to livestock directly (Ojowi et al. 1996; Fisher et al. 1999). Fisher et al. (1999) found beef cattle drinking thin stillage had improved feed:gain ratios when considering dry matter intake (DMI) from feed only. The authors attributed the decrease in apparent feed consumption to the increased DMI from drinking the thin stillage (6-8% dry matter (DM)).

Because a high proportion of the nutritional value is found in CDS, these are generally added back to distillers' grains (Spiehs et al. 2002). WDG or WDG with solubles (WDGS) may be incorporated into cattle rations if a consistent and local demand exists. However, to facilitate transportation and storage, distillers' grains are often dried, producing dried distillers' grains (DDG) or DDG with solubles (DDGS). More recently, due to high drying costs, many ethanol plants are producing modified wet distillers' grains (MWDG), which are distillers' grains dried to approximately 50% DM (Rich et al. 2009).

2.2. Nutritive value of ethanol co-products

With increased capacity for biofuel production, co-product generation also continues to rise. It was advertised that ethanol production could indirectly stimulate the livestock sector in western Canada by producing a valuable new feedstuff for the market (Greenprint 2002). Displacement of these co-products has been largely targeted at beef and dairy industries, but also poultry and swine (Rosentrater 2007). As previously stated, due to the removal of starch during fermentation, distillers' grains have an estimated three-fold increase in levels of chemical components such as protein, fibre, and fat when compared to the original grain (Mustafa et al. 2000a; Jacques 2003; Klopfenstein et al. 2008). Traditionally, distillers' grains have been viewed as a protein feed; however, in light of current production improvements, distillers' grains are also an excellent source of dietary energy due to an increase in digestible fibre and fat (Beliveau and McKinnon 2008; Klopfenstein et al. 2008; Nuez-Ortin and Yu 2009b).

2.2.1. Crude protein

Fermentation co-products have been used as protein supplements in dairy rations for decades (Loy and Wright 2003; Klopfenstein et al. 2008). Crude protein (CP) content of co-products range widely, product depending (Table 2.1). Generally, wheat-based co-products are higher in CP than corn-based co-products. Nuez-Ortin and Yu (2009b) reported 39.32% CP in wheat-based DDGS and 32.01% CP in corn-based DDGS. The level of nitrogen (N) necessary to maintain microbial populations and optimize rumen function is 6 to 9% CP (DM basis; Chase and Hibberd 1987; NRC 1996; Mathis et al. 1999). Although the level of CP serves as a benchmark, protein availability within the

Table 2.1 Nutritional profile of various ethanol co-products (Adapted from Beliveau 2008)

Feedstock	Co-product	Dry Matter (%)	Crude Protein (%)	ADIN[z] (% N)	Fat (%)
Corn	WDG	34.9	31	-	15.4
	TS	4.4	19	-	9.2
	DDGS	90.4	33.9	18.1	10.7
Wheat	WDG	-	27.5	6.2 (ADIP)[y]	4.4
	TS	-	36.6	6.1 (ADIP)	5.9
	DDGS	94.4	40.7	11.8	4.3
Barley	WDG	35.5	20.1	14.7 (ADIP)	5.1
	TS	-	30.8	14.3 (ADIP)	6
	DDGS	87.5	28.7	-	-

[z] ADIN = Acid detergent insoluble nitrogen

[y] Acid detergent insoluble protein (ADIP) values are reported as percent of crude protein

rumen is more critical in ruminant nutrition. Rumen degradable protein (RDP) is protein readily available to rumen microorganisms, while rumen undegradable protein (RUP) is available to the animal via digestion in the small intestine (NRC 1996).

DDGS is traditionally high in rumen undegradable protein. Protein degradability depends on the initial feedstock used and the fermentation process, as well as the amount and duration of heat applied when the product is dried (McKinnon et al. 1991; Boila and Ingalls 1994). When heat is applied, there is an increased fraction of acid detergent insoluble protein (ADIP; Mustafa et al. 2000b) and the remaining amount of potentially soluble CP has a slower rate of degradation (Ojowi et al. 1997). Reduced rates of CP degradability in the rumen have been found for both corn and wheat distillers' grains as a result of high levels of ADIP (Boila and Ingalls 1994; Ham et al. 1994). Also contributing to the RUP values of DDGS are heat damaged yeast cells present in distillers' solubles; ethanol distillation and concentration denatures yeast protein, making it unavailable to rumen microbes (Klopfenstein et al. 2008).

The type of grain used affects the fractionation of CP into soluble protein, neutral detergent insoluble protein (NDIP), non-protein nitrogen (NPN), and ADIP (Mustafa et al. 2000b). These properties ultimately determine the CP digestibility of a feed. Mustafa et al. (2000c) found the RUP value of wheat-, rye-, triticale-, and barley-based WDG was 46.1, 45.9, 48.8, and 50.8%, respectively. Literature values of RUP for corn DDGS range from 54 to 87% of CP (Firkins et al. 1985; Brouk 1994; Kleinschmit et al. 2007). Wheat DDGS has varied RUP levels from 51 to 55% of CP, while blended DDGS (70% wheat: 30% corn) have reported RUP values of 59 to 64% CP (Boila and Ingalls 1994; Nuez-Ortin 2010).

2.2.2. Energy

Although traditionally a source of protein, distillers' grains, both wet and dry, have been shown to have higher feeding values than the original grain when replacing corn or barley in feedlot rations (Larson et al. 1993; Ham et al. 1994). Ham et al. (1994) found corn WDGS and DDGS to have feeding values of 47 and 24% greater than corn, respectively, when replacing corn at 40% of diet DM. Similarly, Larson et al. (1993) reported corn WDGS to have a feeding value 35% greater than corn at the same inclusion level. Gibb et al. (2008) estimated the energy value of wheat DDGS to be 97 and 90% of the energy value of barley when included in a barley-based ration at 20 and 60% inclusion levels, respectively. The high energy value of distillers grains is attributed to the combination of highly digestible fibre and, particularly in corn DDGS, fat (Kononoff and Erickson 2006; Schingoethe 2006; Nuez-Ortin and Yu 2009b). Because corn DDGS has approximately twice the fat concentration of wheat (Gibb et al. 2008), corn DDGS has consistently higher energy values than wheat DDGS. Literature values for net energy of gain (NE_g) of DDGS range from 1.67 to 1.93 Mcal kg^{-1} for corn (Spiehs et al. 2002; Klopfenstein et al. 2007; Nuez-Ortin and Yu 2009b) and 1.26 to 1.41 Mcal kg^{-1} for wheat (Beliveau and McKinnon 2008; Gibb et al. 2008; Nuez-Ortin and Yu 2009b).

Generally, high inclusion rates of fibre are considered adverse due to low digestibility (Van Soest 1994; Mustafa et al. 2000b). However, the fibre found in distillers' grains is significantly more digestible than fibre in other feeds due to low levels of lignin (Schingoethe 2006) and highly digestible neutral detergent fibre (NDF; Nuez-Ortin and Yu 2009a). Ojowi et al. (1997) and Mustafa et al. (2000b) found wheat-based WDG to have high rumen degradability and high total tract digestibility, respectively. The drying process and type of grain used seems to have a lesser effect on the overall digestibility of NDF than CP, perhaps leaving the fibre content less variable than the protein content of this feedstuff. Also, a high amount of protein is associated with NDF, increasing the ruminal and total tract digestibility of NDF (Mustafa et al. 2000b).

That distillers' grains, despite the absence of starch, have more energy than the original grain has been a perplexing concept. Larson et al. (1993) hypothesized that the lack of starch reduced the incidence of sub-acute ruminal acidosis (SARA). However, research by Beliveau (2008) found incidence of SARA was not reduced when wheat-based DDGS replaced barley in feedlot rations. Current wet chemistry analytical techniques are unable to accurately predict the energy value of DDGS (Nuez-Ortin and Yu 2009a). For example, Gibb et al. (2008) found that the NE_g of wheat DDGS was higher than the value predicted by the DM digestibility of DDGS. As such, animal performance trials play an important role in determining the feeding value of distillers' grains.

2.2.3. Minerals

Along with other nutrients, minerals, namely phosphorus and sulfur, are also concentrated in distillers' grains. Phosphorous is often the third most limiting nutrient, after energy and protein (Holechek et al. 2004). High levels of phosphorus in the diet could offset the calcium to phosphorus ratio, which should be 1:1 to 7:1 for cattle (NRC Wise et al. 1963; 1996), potentially causing metabolic problems (Kincaid 1988). As such, calcium supplementation may be required when feeding distillers' grains (Iowa Beef Center 2008). More importantly, overfeeding phosphorus will increase fecal excretion, which could cause environmental contamination (McGechan and Topp 2004; Spiehs and Varel 2009). Likewise, high levels of sulfur in beef cattle rations can also cause problems by reducing DMI and average daily gain (ADG); reducing bioavailability of trace minerals in the rumen, thereby reducing copper reserves in the liver; and potentially causing thiamine- or sulfur-induced polioencephalomalacia (Loneragan et al. 2001; Crawford 2007).

2.2.4. Factors affecting the use of ethanol co-products in ruminant diets

2.2.4.1. Variability & quality limitations

The nutritional content of distillers' grains is affected by the quality and processing of raw feedstock, the fermentation process, input material such as yeasts and enzymes, as well as the post-processing of the whole stillage (Mustafa et al. 2000b; Kaiser 2005). As such, ethanol co-products are known to have a high level of physical and chemical variation, both between and within plants using the same initial feedstock (Cromwell et al. 1993; Loy and Wright 2003; Kononoff and Erickson 2006; Rosentrater 2007). High product variation negatively impacts the value of distillers' grains (Belyea et al. 2004).

Feedstock and DDGS samples from three ethanol plants operating in Saskatchewan were analyzed at the University of Saskatchewan (Table 2.2; University of Saskatchewan 2009). From this data it was concluded that the leading contributors to nutrient variability of DDGS were 1) inconsistent production processes, especially with regards to drying; 2) type, quality, and blend (ie wheat and corn) of feedstock; 3) amount

Table 2.2 **Nutrient profile of feedstock and DDGS samples from three Saskatchewan ethanol plants (University of Saskatchewan 2009)**

	100% wheat feedstock		100% wheat DDGS		70% wheat feedstock		70% wheat DDGS		All DDGS	
Nutrient[z]	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev
Moisture (%)	12.1	1.0	9.1	2.5	12.9	0.5	11.5	0.8	9.7	2.2
CP (% DM)	14.6	1.2	37.7	3.4	12.3	0.5	34.6	0.9	35.9	4.1
Ash (% DM)	2.0	0.1	5.4	0.7	1.7	0.1	5.2	0.3	5.2	0.6
EE (% DM)	2.0	0.3	5.7	1.5	2.5	0.1	7.9	0.5	6.8	1.9
ADF (% DM)	4.2	0.5	15.2	3.8	4.7	0.6	12.6	0.7	14.4	2.9
NDF[y] (% DM)	16.2	1.8	49.9	2.9	15.0	1.8	55.4	1.3	51.6	4.0
NDF [x] with Na_2SO_3	14.4	1.9	32.0	3.7	11.9	0.9	32.6	1.6	32.8	3.2
Corr. NDF [w]	14.6	1.6	29.7	3.4	14.0	1.9	34.9	1.0	31.6	3.6
ADIP (% CP)	0.2	0.2	6.6	3.4	0.5	0.9	2.9	1.0	6.1	4.4
NDIP (% CP)	11.0	1.5	55.2	4.2	8.6	0.6	59.5	2.4	57.4	3.8
ADL (% DM)	0.6	0.3	5.3	2.4	0.4	0.1	5.8	1.0	5.3	1.8
Starch (% DM)	63.0	2.5	4.6	2.5	69.5	1.1	3.7	1.1	4.2	2.4
GE (cal/g)	4543.0	78.1	5197.0	140.3	4521.0	58.7	5273.0	92.8	5232.0	116.9
NPN (% CP)	25.4	2.0	19.2	4.0	24.2	2.5	12.8	3.7	17.3	4.7
SCP (% CP)	24.9	4.4	15.7	4.5	20.6	3.5	7.4	1.5	13.2	5.1
Calcium (% DM)	0.10	0.04	0.20	0.10	0.10	0.10	0.20	0.10	0.20	0.10
Phosphorus (% DM)	0.40	0.03	0.90	0.10	0.30	0.00	1.00	0.10	0.90	0.10

[z] Crude protein (CP); Ether extract (EE); Acid detergent fibre (ADF); Neutral detergent fibre (NDF); Acid detergent insoluble protein (ADIP); Neutral detergent insoluble protein (NDIP); Acid detergent lignin (ADL); Gross energy (GE); Non-protein nitrogen (NPN); Soluble crude protein (SCP)

[y] NDF analysis with α-amylase (Van Soest et al. 1991)

[x] Van Soest et al. (1991) method with sodium sulfite added

[w] NDF corrected for nitrogen: NDF - [NDICP x 0.01 x CP] (Sniffen et al. 1992)

and mixing of added solubles; 4) difficulty in obtaining a representative sample; and 5) laboratory methodology, particularly for NDF analysis.

In a review of ten new (operating five years or less) ethanol plants in South Dakota and Minnesota, Spieh et al. (2002) concluded that the amount of solubles added back to the distillers' grains was a major source of nutrient variation and that the ratio of grains to solubles strongly influences nutrient composition. In addition to nutrient concentrations, nutrient availability may also be variable (Kononoff and Erickson 2006). Furthermore, mycotoxin contamination, either concentrated from the original grain or accumulated during storage, can also negatively impact the feeding value of distillers' grains (Thaler 2002; Schaafsma et al. 2009).

2.2.4.2. Logistical limitations

Issues pertaining to the physical form of DDGS need to be addressed to facilitate sales, marketing, distribution, and utilization of co-products (Rosentrater 2007). Consolidation of fine particles during shipping and storage can reduce flowability and lead to clogged equipment and damaged rail cars and storage bins, contributing indirect costs of using co-products (Anonymous 2007; Rosentrater 2007). The final particle size of wheat DDGS after drying can resemble lightweight flakes (Terra Grains, Belle Plain, Saskatchewan, Canada) or variable sized marbles (Husky Energy, Lloydminster, Saskatchewan, Canada). These differences are a result of the drying process, which can vary from plant to plant (Dr. C. Christensen, University of Saskatchewan, personal communication). The physical form of supplements have logistical implications (DelCurto and Olson 2000; Mathis and Sawyer 2007). Flake-form DDGS is a high volume, low density feedstuff that can be costly to transport and troublesome to feed on range. The low density flake is readily lost due to wind, snow, or uneven or muddy ground. As a dry feed, pelleting DDGS may be a potential solution to increase the flowability and density of DDGS, thereby reducing transportation costs and feeding losses (Anonymous 2007).

2.2.4.3. Environmental concerns

Because manure excretion of nitrogen, phosphorus, and sulfur is a function of dietary levels (Ternouth 1989; Morse et al. 1992), there are a number of environmental concerns when feeding high levels of distillers' grains ($\geq$40% of the diet; Hao et al. 2009). Excess environmental nitrogen can contaminate water and air with nitrate or ammonia via leaching or nitrous oxide via denitrification, respectively (McGechan and Topp 2004). High levels of phosphorus in manure increases the amount of land necessary for manure application, and well as increasing the potential for run-off and eutrophication (McGechan and Topp 2004; Spiehs and Varel 2009). Likewise, high excretion of sulfur can increase hydrogen sulfide (H_2S) emissions from livestock operations, thereby negatively impacting air quality (Spiehs and Varel 2009). It has been indicated that high levels of DDGS in the diet can increase the concentration of isobutyric, valeric, and isovaleric acids, volatile fatty acids (VFA) linked to odour emissions (Hao et al. 2009). These factors need to be taken into consideration when formulating rations for beef cattle using high levels of distillers' grains.

2.3. Low quality roughages in beef cow diets

DelCurto et al. (1999) defines optimal production as "a function of the resources each ranching unit has available and how successfully the manager can match the type of cow and (or) production expectations to the available resources". Therefore, successful producers are those who are able to adapt to a changing industry using available resources and ingenuity to maintain economic viability. In western Canada, reducing production costs, particularly those associated with over-wintering, has become the goal of many beef producers. As the use of barley and other cereal grains in beef cattle diets continues to fluctuate as a result of variable market prices, producers in western Canada are using alternative or more economical feed ingredients, namely forages. For cow-calf producers, efforts to reduce costs have led to the implementation of extended grazing and wintering programs.

2.3.1. Extending the grazing season

In cow-calf operations, rangeland resources are often the most economical and readily available feed resource for producers (Vallentine 2001). Western Canada is dominated by cool season forages which typically cannot meet livestock demands during the summer and fall months (Figure 2.1; Barnes et al. 2003). The variation of forage quality and quantity in pasture settings is largely due to species composition, physical factors, and climatic variables; topography, soil type and depth, elevation, and canopy cover are examples of physical factors, while climatic variables include temperature and timing and amount of precipitation (Walburger 2007). As such, grazing systems and forage management plans have been developed to provide adequate forage to range animals throughout the grazing season. Stocking rates and grazing distribution directly impact beef cow performance and are important parameters for forage management (Vallentine 2001; Olson 2005). Proper forage management throughout the season will lend itself to an extended grazing season and subsequently decrease requirements for stored forage in the winter period (Gunter et al. 2002). Two commonly adopted strategies to extend the grazing season include stockpiling perennials and grazing annual cereals.

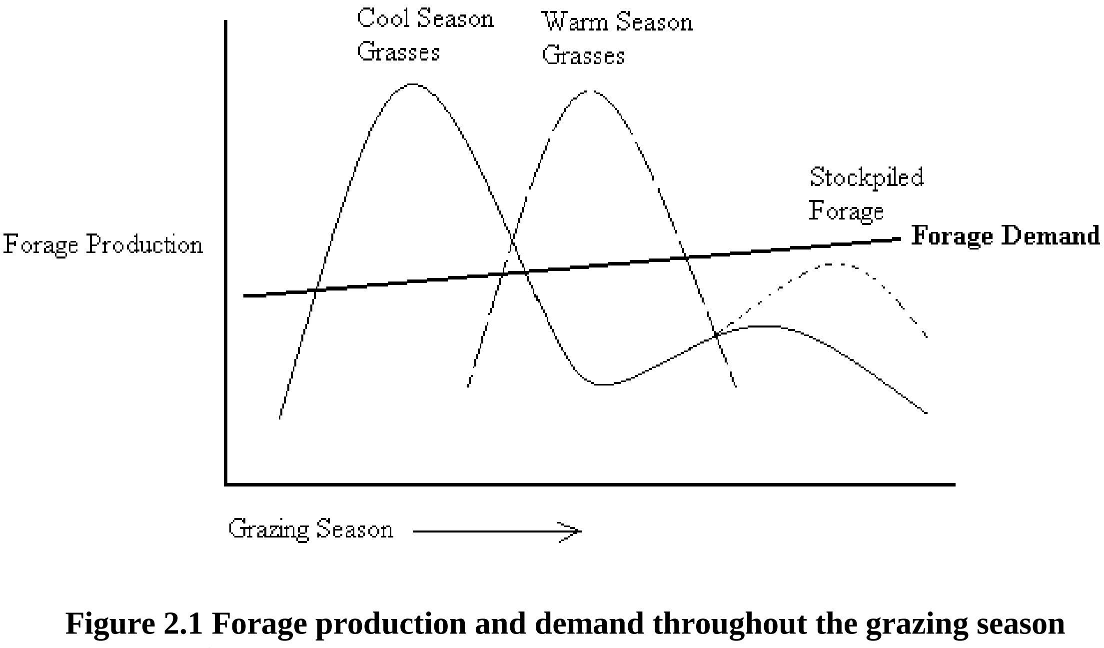

Figure 2.1 Forage production and demand throughout the grazing season (Adapted from Barnes et al. 2003)

2.3.1.1. Stockpiled perennials

Stockpiling pasture refers to the accumulation of forage for grazing after the growing season (Riesterer et al. 2000). The success of grazing stockpiled pasture depends on forage quality and yield as influenced by species selection and management practices (Matches and Burns 1995). Although nearly any forage species may be stockpiled (Johnson and Wand 1999), cool-season grasses adapted to lower temperatures are more capable of maintaining forage quality as the season progresses (Cherney and Kalenback 2003; Lacefield et al. 2006). Because stockpiling typically takes advantage of growing conditions in late summer and early fall – months which are generally already low in available forage – incorporating stockpiling regimes into grazing systems requires a great deal of managerial skill to optimize the timely use of all available resources (Riesterer et al. 2000; Scarbrough et al. 2004).

2.3.1.2. Annual crops for grazing

Annual crops can be used to defer grazing of perennial pastures later in the season, when perennial plant growth has slowed (McCartney et al. 2008). Spring annuals such as oats, barley and triticale are best used for early spring grazing or swath grazing as these crops are most productive around the same time as perennial forages (Aasen 2003). Peak production may be delayed by later seeding dates however yield is often compromised (McCartney et al. 2008). A series of studies by Abouguendia et al. (2001) comparing seeding dates in different soil zones for cool season annuals intended for swath grazing showed a 10% decrease in yield for every week seeding was delayed after May 25 or May 15 in drier regions. Winter annuals such as fall rye, winter triticale, and winter wheat seeded in the spring are ideal for summer and fall grazing, as they are most productive during these months (McCartney et al. 2008). Additionally, because they require vernalization for seed production, winter annuals remain vegetative and regrowth consists mainly of leaf material (Aasen 2003; McCartney et al. 2004b). Winter annuals may also be seeded in the fall to be used for fall grazing, as well as for early spring grazing the following year (McCartney et al. 2008).

2.3.2. Extensive wintering systems

Another strategy to reduce costs in cow-calf operations is the practice of extensive wintering systems. The term ‘extensive’ involves a large land base and minimal labour and expense; in cow-calf systems, this usually implies managing cows in a pasture or field instead of a traditional in-yard drylot system. Three important advantages of extensive winter grazing are (i) decreased stored feed requirements; (ii) direct deposition of nutrients from urine and manure onto the field; and (iii) reduced yardage costs. Labour and expense associated with harvesting, handling, and feeding baled forage can be significantly reduced when stored feed requirements are reduced (Baron et al. 2006). Furthermore, extensively managing cattle in the field eliminates yardage costs associated with traditional drylot wintering systems, where feed and bedding is hauled in and manure is hauled out (Johnson and Wand 1999). Examples of extensive wintering systems include swath grazing, bale grazing, and grazing cereal crop residue.

2.3.2.1. Swath grazing

In swath grazing systems, cereal crops are cut and left in windrows in the field for winter grazing purposes (Surber et al. 2001). Seeding and swathing dates have the greatest impact on forage quality, with earlier seeding dates having improved yields, while later seeding dates produce higher quality forages (McCartney et al. 2008). Because seeding for swath grazing is delayed until June compared to the traditional seeding date of April and early May for grain production, warm season annuals such as millet and corn may be advantageous due to their heat and moisture tolerance (Lardner and Froehlich 2006). A further advantage of swath grazing is the potential for regrowth after harvest, which can increase overall forage quality in the field (Volesky et al. 2002).

A major concern with swath grazing is feed wastage. Wastage may occur when the feed is frozen to the ground or buried under deep or crusted snow, trampled or otherwise contaminated (Nayigihugu et al. 2007). Wastage is more likely to occur under light stocking densities, therefore strip grazing should be practiced to decrease selective grazing and encourage uniform consumption of all parts of the swath (Hutton et al. 2004). Generally, swath grazing adequately meets the needs of beef cows in mid-gestation, however supplemental feeding may be required in adverse environmental conditions (Adams et al. 1986; Freeze et al. 1999).

2.3.2.2. Bale grazing

Bale grazing, where baled feed is strategically place on a winter grazing site, is another option for extensively wintering cattle. While this system does have costs associated with baling and hauling feed to the site and feeding and labour costs throughout the winter, it is still less expensive than drylot systems (McCartney et al. 2004a). Anderson and Mader (1985) estimated feed loss during baling and transporting to be 8%, but less feed waste is associated with bale graze systems compared to swath graze systems; this may be attributed to reduced trampling and greater accessibility of bales relative to windrow in deep or crusted snow conditions (Nayigihugu et al. 2007). Lardner (2005) found no difference in performance between beef cows fed in-field by bale grazing or processed hay compared to cows fed in drylot. As with swath grazing, supplementation is usually not required for cattle in bale graze systems (Manitoba Agriculture Food and Rural Initiatives (MAFRI) Klein 2006; 2008). Because excess residue material may cause problems for reseeding, spring grazing may be considered to clean up the remaining feed prior to seeding the following year (Kelln et al. 2007).

2.3.2.3. Cereal crop residue

The relative abundance of cereal crop residue in western Canada dictates its potential for use in beef cow winter feeding programs (Anderson 1978; McCartney et al. 2006). Straw-chaff is considered a low cost feed due to its low quality and highly variable nutrient composition. Assessment of straw-chaff as a feed for beef cattle is difficult due to the compounded nature of its variability; straw-chaff quality is affected by the relative proportions and nutritive value of each of its components. Varying amounts of leaf and stem affect the nutrient composition of the straw, while the inclusion of chaff will change the nutrient composition of the entire residue (McCartney et al. 2006). The characteristically low protein and high fibre content dictate the need for supplementation to meet the nutritional requirements of the cow and to prevent impaction when straw-chaff is used as the base forage in beef cow diets. Additionally, other factors, such as mineral composition and the presence of mold or mycotoxins, should also be considered (NRC 1996; McCartney et al. 2006). Kelln et al. (2007) found beef cows winter grazing barley straw-chaff, supplemented with a range pellet, had slightly lower body weight gains than cows grazing swathed and baled forage. However, body condition score, rib fat, and rump fat measurements were not affected by treatment.

2.3.3. Limitations of low quality forages

The majority of strategies for extending the grazing season can reduce costs by increasing the amount of forage in beef cow diets or by using mature forages with reduced quality, particularly in the case of stockpiled pasture and cereal crop residue. These forages are typically high in fibre and low in protein (NRC 1996; Males 1987). The fibre content of a feed is particularly important for determining quality within the parameter of digestibility. Fibre may be defined as the structural part of plants, namely components of the cell wall: soluble pectins, waxes, and proteins, and insoluble lignin, cellulose, and hemicellulose (Van Soest 1994). The presence of insoluble fibre, particularly lignin, lowers the overall digestibility of the feed by limiting nutrient availability (Van Soest 1994). Furthermore, the quality and digestibility of forages decline as the growing season progresses as a result of increasing plant maturity and the effects of weathering (Wilson 1982; Huston and Pinchak 1991). As plants age, photosynthetic leaf material decreases and structural stem material – namely lignin, cellulose, and hemicellulose – increases, thus reducing the overall digestibility of the plant (Jones and Wilson 1987; Van Soest 1994; Holechek et al. 2004). Therefore, these forage types have more fibre and less protein, and are characterized as low quality forages. Furthermore, leaf loss and weathering will also negatively affect forage yield (Baron et al. 2005).

To meet nutritional requirements when grazing low quality forages, animals must consume more feed. However, when digestibility is low and energy and protein are limiting, gastrointestinal capacity, or more importantly for ruminants, reticulorumen capacity, may limit feed intake (Horrocks and Vallentine 1999). As such, reticulorumen capacity may be reached before the energy requirements of the animal have been satisfied. Another limitation of low quality forages is the low protein content. Forages low in protein may not supply adequate nitrogen for optimal microbial health, compromising rumen function and animal nutrition (DelCurto et al. 1999).

Because voluntary forage intake is limited by the physical capabilities of the rumen and its microbes, supplementation may be required to meet nutritional requirements when using low quality forages to extend the grazing season (Waldron et al. 2006). Forages should be tested throughout the grazing period as forage quality will decline due to weathering, trampling, and the tendency of cattle to sort as they feed (Baron et al. 2006). Additionally, nitrates may accumulate due to stress from periods of drought, frost, or persistent cool, cloudy weather (Hutton et al. 2004) or if the field was previously exposed to heavy fertilizer or manure applications (Klein 2006). Monitoring forage quality is important for re-evaluating beef cow rations as the grazing season progresses and as requirements evolve according to environmental changes and cow maintenance and pregnancy demands.

2.4. Evaluating feeding trials

To accurately evaluate feeding trials, both forage and animal parameters must be quantified, including forage quality, intake, and animal performance. Several techniques exist for such evaluation; choosing the right technique is based on several factors, including but not limited to available resources, time constraints, and overall objectives.

2.4.1. Feed quality & chemical composition

The value of a feed is affected by both the level of nutrients within the feed and their availability (Van Soest 1994). Feed testing is important to ensure animal nutrient requirements are being met as economically as possible. Forages in particular have highly variable nutrient compositions due to species, soil type, precipitation, maturity, grazing or harvest management, and weathering. Care must be taken to obtain a representative sample; this is best achieved by subsampling a composite of random samples taken from many parts of the forage or feed of interest (Adesogan et al. 2000).

2.4.1.1. Wet chemistry

A variety of laboratory analyses have been developed to routinely evaluate the chemical constituents of forages and feed. Feed constituents of particular interest include CP and fibre, as well as fat and minerals. Ideally, procedures to quantify these constituents should be quick, cheap, and accurate, however, this is not always the case; evaluation techniques often have multiple stages and can require expensive chemical reagents and/or equipment (Weiss 1993).

Crude protein analysis is estimated from the quantity of N in the feed, as determined via the Kjeldahl or LECO procedure, using a conversion factor of 6.25 (Adesogan et al. 2000). Results are referred to as 'crude' protein because N from both true protein and NPN, such as ammonia, peptides, and free amino acids, are detected. Techniques to measure true protein, such as the liquid chromatography, ninhydrin assays, and colorimetric techniques, are expensive and/or complex (Adesogan et al. 2000). In ruminant nutrition, crude protein is less important than determining protein degradability within the rumen (RDP and RUP), which dictates the availability of N for rumen microbes. Meeting microbial N requirements is crucial for normal rumen function and fibre digestion (Broderick 1994; Van Soest 1994).

Fibre, particularly in regard to forages, refers to plant components which are slowly or only partially degraded by ruminants. Comprised of the cell wall components cellulose, hemicellulose, and lignin, fibre is important for healthy rumen functions such as rumination and saliva stimulation (Moore and Hatfield 1994). Neutral detergent fibre (NDF) contains all three cell wall components and has been negatively correlated to forage intake (Mertens 1983, 1987). Acid detergent fibre (ADF) contains only cellulose and lignin and is negatively correlated to digestibility (Van Soest 1994). The Van Soest detergent system (1967) allows rapid analysis of NDF and ADF in feeds.

2.4.1.2. Near infrared reflectance spectroscopy

An alternative to wet chemistry laboratory analysis is the use of near infrared reflectance spectroscopy (NIRS). Chemical constituents within feed have been correlated to the absorption of different wavelengths of light (Adesogan et al. 2000). The reflectance spectrum of a feed sample of unknown composition is scanned, then statistically correlated to samples of known composition, thereby calculating the chemical composition of the unknown sample based on standards (Van Soest 1994). NIRS offers a rapid, non-destructive method to analyze large numbers of feed samples; however, calibration with the appropriate standard is critical for accurate results (Van Soest 1994; Adesogan et al. 2000).

2.4.2. Digestibility

Digestibility, as simply defined by Cochran and Galyean (1994), is “the fraction of a feedstuff or dietary constituent that is lost on passage through the digestive tract”. There are three main techniques to estimate digestibility: *in vivo*, *in situ*, and *in vitro* digestibility trials. *In vivo* and *in situ* methods, while laborious, expensive, and requiring fistulated animals, provide detailed information on the dynamics of forage digestion. *In vitro* techniques are designed to simulate rumen fermentation to inexpensively and accurately analyze large numbers of samples (Adesogan et al. 2000).

2.4.2.1. In vivo

Apparent total tract digestibility is the difference between feed consumed and feces voided (Minson 1990). If animal intake is known, total fecal collections may be used to determine digestibility by the equation:

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

where I is the intake of feed or nutrient component of the feed and F is the total fecal output or corresponding nutrient component in the feces (Corbett 1978; Coates and Penning 2000). While total fecal collection is the best technique to determine apparent digestibility, it may not be feasible in range research, where animal intake is difficult to assess and total collection of feces is challenging (Cochran and Galyean 1994). Instead, inert markers may be used to determine digestibility.

Using markers to determine apparent total tract digestibility is based on the relationship between the relative concentration of marker ingested and marker excreted (Cochran and Galyean 1994; Van Soest 1994):

$$Digestibility\ (\%) = 100 - 100 * \left[\left(\frac{marker\ in\ feed}{marker\ in\ feces} \right) * \left(\frac{nutrient\ in\ feces}{nutrient\ in\ feed} \right) \right]$$

Therefore, an ideal marker is not absorbed or likewise affected by processes of microbial fermentation or intestinal digestion, mimics the flow of digesta through the gastrointestinal tract, and is easily analyzed (Owens and Hanson 1992). Complete recovery of markers is necessary, otherwise digestibility will be underestimated (Van Soest 1994). Markers may be added to the feed (external) or intrinsically present as indigestible plant parts (internal).

External markers can be dosed continually or frequently to reach steady state equilibrium within the animal or, alternatively, administered as a one time pulse dose (Owens and Hanson 1992). When dosed continuously or frequently, external markers can be used to estimate flow rates at particular points in the digestive system (ie abomasal or duodenal) or to determine fecal output for digestibility determination. Pulse dosing is used to determine passage rate, fluid and particulate pool sizes, and dilution rates (Owens and Hanson 1992). External markers can be added to the feed, infused or dosed into the rumen, or attached to feed particles (ie labelled forage). Examples of external markers include metal oxides, such as chromic oxide (Cr_2O_3); rare earths, like ytterbium chloride ($YbCl_3$); and isotopes, including ^{14}C, ^{35}S, or ^{15}N. Other examples of external markers include metal chelates, stains or dyes, and synthetic materials (Van Soest 1994).

Internal markers are more commonly used for digestibility determination in grazing trials, as continuous dosing with external markers is not always feasible (Sunvold and Cochran 1991). Moreover, internal markers can be used to determine digestibility when intake is not known (Cochran and Galyean 1994). Silica, chromogen, and potentially indigestible cellulose have been evaluated as potential internal markers, but have limited success (Streeter 1969; Minson 1990). Lignin and acid insoluble ash (AIA) have been used more successfully. However, in a review, Fahey and Jung (1983) reported that lignin may be digested, degraded, or form complexes with carbohydrates within the ruminant digestive tract. Alternatively, Van Keulen and Young (1977) found AIA to give similar estimates of digestibility as total fecal collections. Reviews comparing AIA and lignin have found AIA to be more accurate as a digestibility indicator in cattle rations than lignin (Wilson et al. 1971; Thonney et al. 1979; Sunvold and Cochran 1991).

Alkanes present in plant waxes have also been used for digestibility and intake determination (Mayes et al. 1986; Dove and Mayes 1996). Internal and external markers can be used in concert to determine intake, digestibility, passage rate, and so forth (Dove and Mayes 1996; Ferreira et al. 2004; Undi et al. 2008).

2.4.2.2. In situ

The dynamics of ruminal digestion is commonly determined using the *in situ* incubation technique (Mehrez and Orskov 1977; Orskov and McDonald 1979; Orskov et al. 1980). Also known as *in sacco* or the nylon bag technique, the rate and extent of feed degradation is evaluated by ruminally incubating a small amount of feed sample contained in porous nylon bags for various time intervals (Huntington and Givens 1995; Nozière and Michalet-Doreau 1996). Disappearance data is then either fitted to a nonlinear or logarithmic-linear mathematical model to estimate degradation parameters including immediately soluble, intermediately soluble, and insoluble fractions (Blümmel and Ørskov 1993; Heendeniya 2008). Several factors can affect the results of *in situ* incubations, most importantly sample preparation, washing and drying procedures, animal effects, bag type and porosity, and bag to sample ratio (Orskov et al. 1980; Huntington and Givens 1995; Vanzant et al. 1998). Despite these sources of variation, information obtained from *in situ* incubation trials are highly useful in estimating the digestibility of different feedstuffs (Aerts et al. 1977; Vanzant et al. 1996; von Keyserlingk et al. 1996).

2.4.2.3. In vitro

Because considerable time, labour, and expense are associated with *in vivo* and *in situ* trials, *in vitro* laboratory techniques have been developed to estimate digestibility (De Boever et al. 1988; Iantcheva et al. 1999; Gosselink et al. 2004). The two-stage method of Tilley and Terry (1963) and variations thereof have been widely accepted to produce realistic estimates of digestibility (Johnson and Dehority 1968; Meyer et al. 1971; Scales et al. 1974; Aerts et al. 1977; Goldman et al. 1987; Van Soest 1994). Because the technique requires rumen fluid for inoculation, variability is expected and reproducibility is reduced as a result of the physiological state, diet, and intake of the animal from which the fluid is harvested (De Boever et al. 1988; Iantcheva et al. 1999; Adesogan et al. 2000). To avoid this variability, enzyme-based *in vitro* techniques have been developed (Jones and Hayward 1975; Kellner and Kirchgessner 1976; McLeod and Minson 1978). Although enzymatic digestion, typically using cellulase enzymes, offers a simple and highly reproducible estimate of digestibility, high cost and reduced accuracy may limit its use (Wainman et al. 1981; De Boever et al. 1988). Furthermore, enzymatic digestion is not sensitive to toxins and associative effects which may impede microbial digestion (Getachew et al. 1998). A third *in vitro* technique measures the quantity of gaseous fermentation products instead of dry matter residue (Menke and Steingass 1988; Pell and Schofield 1993). Gaseous *in vitro* measurements are highly correlated to organic matter digestibility and metabolizable energy (ME; Blümmel and Ørskov 1993; Getachew et al. 1998), however interactions between end products and the buffer solution may occur, indirectly producing gas that may not be accounted for (Adesogan et al. 2000). Ultimately, the success of any *in vitro* system depends on how accurately it can reproduce the events of digestion within the ruminant digestive system (Van Soest 1994).

When comparing the *in vivo* digestibility of forages in sheep, Gosslink et al. (2004) found *in situ* estimations to be more accurate in predicting digestibility when compared to gaseous measurements, the Tilley and Terry (1963) method, and enzyme digestion techniques. Conversely, Rinnes et al. (2006) found enzyme digestion to be the most accurate of the four techniques. Dewhurst et al. (1995) compared the Tilley and Terry (1963) method to *in situ* incubation and found the nylon bag technique overestimated fermentation. In a comparison of seven laboratory techniques including the Tilley and Terry (1963) method to estimate organic matter digestibility, Aerts et al. (1977) found the nylon bag technique to be the most accurate when compared to *in vivo* results. These comparative studies illustrate the complex nature of digestibility estimation. As such, multiple factors must be considered in order to choose the appropriate technique.

2.4.3. Voluntary intake

Voluntary intake is the most important factor affecting dry mater digestibility and animal performance and is a critical aspect for assessing forage quality (Mertens 1994).

Accurate prediction of intake is also important for economic production (Fawcett et al. 2005). Predicting voluntary intake is necessary in order to formulate rations which will meet animal requirements at *ad libitum* levels of intake and optimize diet utilization (Bourne 2007; Forbes 2007). The intake of grazing animals is affected by multiple plant, animal, and environmental factors, which have been described in detail in the literature (Minson 1990; Vanzant et al. 1991; Mertens 1994; Van Soest 1994; Redmon et al. 1995; Allen 1996; Aroeira et al. 1999). As such, accurately quantifying intake in grazing animals is challenging. Various direct and indirect methods have been developed.

2.4.3.1. Direct measurement

The only direct way to measure the intake of free ranging animals is by (1) weighing animals or (2) monitoring grazing behaviour (Burns et al. 1994). When weighing animals, adjustments must be made for respiratory, fecal, and urinary losses, as well as for water, supplement, and other non-forage intake. Furthermore, correcting the intake of fresh herbage for dry matter intake requires moisture determination from plucked forage resembling that which was ingested, increasing associative error (Minson 1990). Determining intake by monitoring grazing behaviour requires estimates of time spent grazing and intake rate (bite mass x biting rate). Equipment such as grazing and GPS collars make obtaining these estimates more accurate, however, adjustments are required if grazing is to be monitored for long periods of time (Minson 1990; Ungar et al. 2005). Furthermore, observations may be complicated by diverse plant species and stage of plant growth, which will elicit a selective grazing response (Holechek et al. 1982). Considerable time, labour, and equipment costs are associated with direct measurement of forage intake. As such, indirect measurements are more commonly used.

2.4.3.2. Indirect measurement

The most commonly used indirect methods of measuring forage intake are the use of fecal indices, estimating via forage utilization, and prediction equations. Indirect methods of measuring intake are best used to compare treatments within an experiment, as quantitative assessment of intake tends to be inaccurate (Burns et al. 1994).

2.4.3.2.1. Fecal indices

The intake of grazing animals is commonly estimated using the relationship between fecal output and digestibility (fecal indices; Coates and Penning 2000):

$$Intake = \frac{FecalOutput}{(1 - Digestibility)}$$

Fecal output and digestibility can be determined via total fecal collections or the use of external markers, as discussed above. Estimates of forage digestibility in grazing scenarios are generally determined using *in vitro* or *in situ* analysis on hand plucked samples or samples collected from esophageal fistulated animals (Van Dyne and Torrell 1964; Cordova et al. 1978).

2.4.3.2.2. Forage utilization

Forage utilization is defined as “the degree to which animals have removed the current growth of herbage” and is expressed as a percent (Cook and Stubbendieck 1986). There are several methods to measure percent utilization of rangeland and choosing the right technique depends on study objectives, available resources, and forage type. The most common techniques to determine percent utilization include (1) ocular estimates, where small plots are visually appraised by a trained individual; (2) weight measurement, where differences in herbage weight between grazed and ungrazed plots are compared; (3) height measurements, based on the assumption that percent utilization is proportional to the reduction in average leaf height; and (4) percent of grazed plants, which relates the percent of plants grazed to the weight of forage utilized (Jasmer and Holechek 1984). All techniques have limitations as range heterogeneity, regrowth, decomposition, selective grazing, trampling, and contamination can reduce the precision to which utilization can be measured. The ideal method should be rapid, accurate, precise, and simple ('t Mannetje 2000). Estimating utilization of harvested forage, such as windrows, bales, or straw-chaff piles, can be done more directly by weighing the forage pre- and post-grazing, assuming the difference is that which was consumed by the animals (Volesky et al. 2002). However, similar limitations apply.

2.4.3.2.3. Prediction equations

Several equations have been developed to predict feed intake based on information concerning the animal, diet, and/or environmental conditions. For example, Mertens (1983; 1987) developed a relatively simple equation estimating the intake of long stemmed forages based on NDF content. The NRC (1996) equation to predict voluntary DMI in pregnant beef cows is based on shrunk body weight and the energy density of the diet. The Cornell Net Carbohydrate and Protein System (CNCPS) is a series of mathematical models derived from ruminant physiology, microbial population dynamics, and nutrient utilization to predict intake (Fox et al. 2004). Rumen fermentation, microbial protein production, post-ruminal absorption, and total ME and protein supplied to the animal are estimated according to carbohydrate and protein degradation and passage rates. As such, CNCPS focuses on nutrient supply to the animal in its intake calculations (Fox et al. 2004). Using inputs based on animal requirements as affected by breed, age, sex, and physiological status; environment; forage quality and digestion; and nutrient metabolism, intake predictions can be adjusted for specific production systems. However complex the model, it can only be as accurate as the inputs from which intake is derived (Fox et al. 2004).

2.4.4. Animal performance

To evaluate feeding programs, animal performance parameters are often assessed. Milk production, wool growth, and reproductive performance can be measured (Corbett 1978), however, in beef trials, body weight and body condition are commonly evaluated. For all parameters, measurements are most useful when comparing similar animals in simultaneously evaluated treatment groups (Cook and Stubbendieck 1986).

2.4.4.1. Body weight

Body weight (BW) changes have been used to evaluate beef cow performance in numerous trials (Koster et al. 1996; Huston et al. 1999; Bohnert et al. 2002a; Stalker et al. 2006; Engel et al. 2008; Hall et al. 2008; McGee and Drennan 2008). However, variation in BW measurements may occur without corresponding changes to body energy reserves as a result of gut fill and body water volume variation as affected by grazing and water consumption patterns, environment, and physiological state of both animals and plants (Coates and Penning 2000; Martin et al. 2007b). Such disparity may be minimized by using consistent routines when weighing animals, minimizing stress during weighing, withholding feed and water for a set period of time to achieve shrunk BW, and/or averaging weights taken on multiple days (Cook and Stubbendieck 1986; Coates and Penning 2000). Because during pregnancy females gain more weight than that which is associated with retained energy, adjustments must be made to BW changes measured in pregnant animals to account for conceptus weight and the weight of associated fluids and membranes (Silvey and Haydock 1978).

2.4.4.2. Body condition

Although BW change is a useful parameter for evaluating animal performance, it is not possible to decipher body composition from BW measurements (Corbett 1978). Body composition is an important economic parameter in beef production. In cow-calf operations, for example, adequate cow condition in the fall will reduce feed costs throughout the winter (Lowman et al. 1976). Body composition can be easily assessed in live animals either by palpation, known as body condition scoring (BCS), or ultrasonography. When manually scoring body composition, the lumbar processes and tail head region are typically palpated. Scores are given based on qualitative assessment of fat thickness, with thin cows represented by lower scores (Domecq et al. 1995). Ultrasonic measurements are generally taken in at the mid-rib (11th, 12th, or 13th rib) and the thurl or rump regions (located between the hooks and pins). Fat thickness is quantitatively measured to the nearest 0.1 cm according to on-screen tissue images (Schroder and Staufenbiel 2006). Several studies have shown high correlation between palliative body condition score (BCS) and ultrasonic fat depth measurements (Anderson et al. 1995; Domecq et al. 1995; MacDonald et al. 1999; Zulu et al. 2001; Ayres et al. 2009).

2.5. Supplementing beef cow rations

While intensively managed livestock are delivered diets carefully calculated to provide all nutrients required to maximize production, diets of free ranging animals are subject to wide variation as affected by environmental conditions, management practises, and economic constraints (Holechek et al. 2004). When considering beef cow diets, supplementation may be required to meet production goals due to yearly and seasonal variation in forage quality and quantity and animal requirements (Hart 1991).

Supplementation may serve to substitute forage or to enhance forage utilization, depending on forage availability or quality, respectively. These different scenarios require different supplement types and strategies to meet production goals. Typically, energy supplements are used if forage availability is low; conversely, protein supplements are used to enhance intake and digestibility of low quality forages (Olson 2005). When incorporated with effective forage management, supplementation can have additive effects on reproductive status, the main criteria for beef cow production (Farmer et al. 2001). While energy supplementation should be delivered no less often than alternate days, reduced protein supplementation frequency does not negatively affect animal performance (Bohnert et al. 2002a; Schauer et al. 2005; Mathis and Sawyer 2007). This allows flexibility for producers considering supplementation in response to labour and supplement availability and cost (Mathis and Sawyer 2007). Supplementation strategies are determined by animal performance, grazing behaviour, and forage value, as affected by the supplement (Chase and Hibberd 1987; Mathis et al. 1999).

2.5.1. Protein versus energy supplements

Protein supplements, such as soybean meal and canola meal, are considered ideal for medium- to low-quality forages; the crude protein provides nitrogen for maintenance and growth of rumen microbial populations, optimizing rumen health and function and promoting fibre digestion (Petersen 1987; DelCurto et al. 1990b; DelCurto et al. 1999; Mathis et al. 1999). Energy supplements, particularly those high in nonstructural carbohydrates (NSC), such as cereal grains, have been shown to decrease forage intake and digestibility compared to protein supplements (Sanson et al. 1990; Olson et al. 1999; Martin et al. 2001; Bodine and Purvis 2003; Bowman et al. 2004). This is known as a substitution effect (Bowman and Sanson 2000). Several mechanisms are involved, including reduced ruminal pH (Hiltner and Dehority 1983; Tamminga and Van Vuuren 1988), impaired bacterial attachment to fibrous material in the rumen (Hoover 1986;

Firkins et al. 1991), and reduced cellulytic populations due to nutrient competition in the rumen (Mackie et al. 1978; Bodine et al. 2001). These negative associative effects may be mitigated if a source of ruminally degradable protein is available with the carbohydrate supplement (DelCurto et al. 1999; Mathis et al. 1999; Vallentine 2001). Common energy supplements for beef cattle include corn, barley, and tallow, as well as by-products such as corn gluten feed, wheat middlings, and potato waste (Mathis and Sawyer 2007).

Protein supplements, on the other hand, have been shown to proportionally increase forage intake and digestibility to the extent of which forages are deficient (DelCurto et al. 1990b). Therefore, response to protein supplementation on rangeland will vary depending on forage quality and quantity, as well as environmental conditions (Campling 1970; Kartchner 1980). Generally, greater responses to supplementation are seen with low quality forages that have less than 6% CP (Rittenhouse et al. 1970). Other factors that may influence the impact of protein supplementation include forage availability (Rittenhouse et al. 1970), forage digestibility (Allden 1981), sulfur:nitrogen ratios (Hunter 1991), and the animals' stage of production (DelCurto et al. 1999). Common protein supplements for beef cattle include oilseed meals such as soybean meal, canola meal, and cottonseed meal, as well as by-products such as corn gluten meal, brewers' grains, and distillers' grains (Stalker et al. 2006).

2.5.2. Supplementing beef cows with wheat-based distillers' grains

Currently, little is known about the value of wheat-based distillers' grains in beef cow rations. More research on the use of corn-based distillers' grains in cow-calf production systems has been conducted. Stalker et al. (2006) found that supplementing beef cows wintering on native range with a corn DDG-based supplement improved heifer BW and BCS compared to a corn gluten feed (CGF)-based supplement. Furthermore, calf weight and weaning weight were greater for the DDG treatment group. Similarly, Martin et al. (2007b) found corn DDG-based supplements promoted weight gains over CGF-based supplements in replacement heifers, resulting in improved artificial insemination (AI) conceptions and pregnancy rates. Conversely, Harris et al. (2008) found diet had no influence on AI conception rates or pregnancy rates when heifers were supplemented with different diet inclusion levels of raw soybeans, wet CGF, or corn-based DDG.

While grazing corn stalks in their last trimester, Hall et al. (2008) found that cows gained more weight and condition when supplemented with a distillers'-based cube compared to unsupplemented cows. However, calf birth weight and adjusted weaning weight were not different between treatment groups. In the same study, a greater percentage of supplemented cows were cyclic prior to the breeding season. Likewise, Engel et al. (2008) found heifers had greater positive BW changes when fed hay, supplement, and corn-based DDGS compared to hay, supplement, and soybean hulls. Also, while there were no differences in initiated estrous cycles between treatments, the DDGS fed heifers had a greater ($p<0.058$) pregnancy rate than those fed soybean hulls (94 and 84%, respectively).

It has been suggested that using distillers' grains as a supplement in cow-calf operations may be useful to enhance the nutritive value of forage based diets, as well as supplying metabolizable protein in the form of RUP (Klopfenstein and Adams 2005). While corn-based distillers' grains are estimated to contain 110-125% of the energy value of corn when fed to beef cow herds (Iowa Beef Center 2008), wheat-based DDGS tend to have similar energy values to both wheat and corn grain. Nuez-Ortin and Yu (2009b) found predicted net energy for maintenance (NE_m) based on NRC (1996) equations were 2.06 Mcal kg^{-1} for 100% wheat grain, 2.08 Mcal kg^{-1} for 100% wheat DDGS, and 2.16 Mcal kg^{-1} for corn grain.

As a result of the ethanol industry expansion in Canada, wheat-based distillers' co-products will become increasingly more prevalent in western Canadian feed markets. Currently, there is no research on the use of wheat-based distillers' grains in beef cow rations. As this product becomes increasingly available to cow-calf producers in western Canada, information will be needed to make informed management decisions. As such, the overall objectives of this study were to 1) evaluate the impacts of supplementing wheat-based DDGS in forage-based diets on cow performance and forage intake and 2) determine the economic feasibility of feeding wheat-based DDGS. Additionally, voluntary dry matter intake, particulate matter passage rate, and apparent total tract digestibility as well as rumen fermentation parameters and rate and extent of forage degradation will be determined.

3. Effect of supplementing beef cows grazing stockpiled perennial forages with wheat-based dried distillers' grains with solubles on animal performance and intake

3.1. Introduction

Because winter feeding costs account for 60 to 65% of total production costs for cow-calf producers in western Canada (Kaliel and Kotowich 2002), strategies to extend the grazing season and reduce costs have become increasingly important. Johnson and Wand (1999) estimated that total annual feed costs could be reduced approximately 1% for each week of extended grazing. This is largely due to reduced stored feed requirements, thereby reducing costs and losses associated with harvesting and feeding stored feed (Johnson and Wand 1999; Riesterer et al. 2000). Cool season forages are adapted to lower temperatures and have greater fall regrowth potential, as they can take advantage of the growing conditions in the late summer and fall (Baron et al. 2004). Furthermore, cool-season grasses are more capable of maintaining forage quality as the season progresses (Cherney and Kalenback 2003). Several studies have evaluated the use of various stockpiled cool-season forages for fall and winter grazing (Johnson and Wand 1999; Riesterer et al. 2000; Jensen et al. 2002; Baron et al. 2004; McCartney et al. 2004a; Meyer et al. 2009).

Although crested wheatgrass (*Agropyron cristatum* L.) is most often utilized in early spring, fall grazing pastures can increase grazing days without impairing forage production (Currie 1970). The likelihood of a second grazing of crested wheatgrass is dependent on location and environmental conditions (Bruynooghe 1997; Baron et al. 2004). In Oregon, Miller et al. (1990) found adequate forage regrowth was present by mid-August, providing the initial grazing occurred before the elevation of the apical meristem. In Lacombe, Alberta, Baron et al. (2004) found forage yield of crested wheatgrass was maximized in mid-October. These authors concluded that, while crested wheatgrass had advantageous forage mass production in years of adequate rainfall, protein requirements of beef cows in midgestation may not be met by forage alone. This agrees with the results of others (Cochran et al. 1986; Krysl and Hess 1993; Willms et al. 1993; Adams et al. 1994; Villalobos et al. 1997; Freeze et al. 1999; Jensen et al. 2002). As such, protein supplementation may be necessary to maintain beef cow condition when grazing stockpiled cool-season forages. Protein supplementation has been shown to have positive associative effects when supplied to animals consuming low quality forages. By supplying rumen microbes with N for growth and maintenance, rumen health and function are optimized, increasing the intake and digestibility of low quality forages (Petersen 1987; DelCurto et al. 1990b; Koster et al. 1996; Huston et al. 1999; Mathis et al. 1999; Bandyk et al. 2001).

With the expansion of the ethanol industry in western Canada, wheat-based DDGS may become more available to cattle producers. The product has great potential as a supplement as it is high in crude protein, digestible fibre, and minerals (Mustafa et al. 2000a; Klopfenstein et al. 2008). Research on corn-based DDGS has resulted in cow performance equal to or greater than traditional supplements (Stalker et al. 2006; Martin et al. 2007a; Engel et al. 2008; Hall et al. 2008). Currently, no information is available regarding the use of wheat-based DDGS as a supplement for beef cows grazing stockpiled forage. Therefore, the objectives of this study were to 1) compare the performance of dry pregnant beef cows grazing stockpiled crested wheatgrass pasture as affected by supplement strategy; 2) estimate forage intake and displacement as a result of supplementation; and 3) conduct an economic analysis.

3.2. Materials & Methods

3.2.1. Study site

A two year grazing trial was conducted on stockpiled crested wheatgrass (*Agropyron cristatum* L.) pastures at the Western Beef Development Centre’s Termuende Research Ranch near Lanigan, Saskatchewan, Canada (51°51 'N, 105°02 'W). Stockpiling of perennial forage was initiated on 15 July in 2007 and 2008. Chemical composition of stockpiled pasture forage is presented in Table 3.1. Six pastures with gently rolling topography were subdivided using high tensile electric fencing into four 1.8 ha paddocks for the grazing study. Soils at the study site were a mixture of Oxbow Orthic Black and carbonated Oxbow with a loam texture.

3.2.2. Grazing animal management

Forty-eight dry, pregnant (83±22 d) multiparous Black Angus cows (BW±SD; 609±11 kg) grazed stockpiled crested wheatgrass pastures for 34 days (3 October to 6 November) in 2007 and 42 days (19 September to 31 October) in 2008. Cows were stratified by BW and days pregnant to maintain homogeneity between groups and assigned randomly to 1 of 3 replicated (n=2) supplementation strategies: (1) wheat-based dried distillers' grains with solubles (DDGS); (2) commercial range pellet (COMM); or (3) control (no supplement; CONT). The DDGS was a 70% wheat, 30% corn blend obtained from Husky Energy (Lloydminster, Saskatchewan, Canada). The commercial range pellet was custom formulated by FeedRite Ltd. (Humboldt, Saskatchewan, Canada) to be nutritionally similar to the DDGS supplement (Table 3.1 and Appendix Table A.1). Groups were moved to the next paddock when crested wheatgrass residue reached an approximate height of 4 cm.

Table 3.1 Chemical composition of pasture forage and supplements

Nutrient	Pasture[z]	DDGS[y]	Commercial Pellet[x]
DM (%)	87.5	90.0	91.0
CP (% DM)	7.3	38.5	38.6
NDF (% DM)	74.6	50.8	34.5
ADF (% DM)	46.9	19.8	16.0
ADL (% DM)	11.5	-	-
Phosphorus (% DM)	-	0.8	0.8
Sulfur (% DM)	-	0.8	0.9
NDIN (% N)	-	4.1	1.8
ADIN (% N)	14.2	-	-
IVDMD (% DM)	56.4	88.8	90.8
IVOMD (% DM)	55.6	91.7	93.9
TDN[w] (% DM)	49.0	80.0	84.3
DE[w] (Mcal kg^{-1} DM)	2.1	3.3	3.4

[z] Stockpiled crested wheatgrass pasture

[y] DDGS = wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend)

[x] Ingredient composition presented in Appendix Table A.1

[w] Calculated using the Penn State Equations based on ADF content (Adams 1995)

Cows receiving supplement were fed the equivalent of 1.2 kg per head per day (9.6% of total dry matter intake) (Table 3.2) or 0.2% of BW daily, fed three times per week between 0800 and 0900. Cows had *ad libitum* access to 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) and cobalt-iodized salt (99.0% NaCl (min), 39.0% Na, 150 ppm I, 100 ppm Co; FeedRite Ltd., Humboldt, Saskatchewan, Canada) over the course of the trial. Water was supplied to each paddock in troughs fed via underground pipe system.

Parameters measured to evaluate cow performance included BW, BCS, and subcutaneous body fat thickness. Body weights were taken over 2 consecutive days at the

Table 3.2 Feed ingredients and nutrition composition of ration[z]

	Treatments[y]		
	DDGS	COMM	CONT
Predicted intake (kg DM/hd/d)	13.0	12.9	12.8
Feed		% of ration	
Pasture[x]	89.5	89.8	99.3
DDGS	9.7	-	-
Commercial Supp	-	9.5	-
2:1 Mineral	0.5	0.4	0.4
Salt	0.4	0.4	0.4
Chemical composition[w]			
CP (% DM)	10.3	10.2	7.3
NDF (% DM)	71.7	70.2	74.0
TDN (% DM)	51.7	52.0	48.7
DE (Mcal kg^{-1} DM)	2.2	2.2	2.1

[z] Rations formulated using CowBytes Beef Ration Balancer Program. Version 4. (Alberta Agriculture Food and Rural Development 1999)

[y] DDGS = cows supplemented with wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); COMM = cows supplemented with commercial range pellet; CONT = cows received no supplement

[x] Stockpiled crested wheatgrass pasture

[w] Calculated from average nutrient composition of ingredients.

start and end of trial and every 14 d throughout the course of the trial. Cow BW was corrected for conceptus gain using the equation from NRC (1996):

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

Body condition score was determined by the same experienced technician at the beginning and end of the trial using the Scottish scale where 1=emaciated and 5=grossly fat (Lowman et al. 1976; Wildman et al. 1982). Ultrasound measurements of subcutaneous body fat thickness were determined between the 12th and 13th rib and at the thurl location using an Aloka SSD-500V ultrasound machine and Aloka UST-5044 probe (3.5 MHz). Guidelines for animal care (Canadian Council on Animal Care 1993) were followed at all times for all animals used in this experiment.

3.2.3. Estimation of forage utilization

Ten randomly distributed plots (0.25 m^2) were clipped to a 3 cm stubble height as cows entered and exited each paddock to estimate available and residual forage, respectively. Previously clipped areas were not re-harvested. The difference between the weight of the available and residual forage samples after drying at 55°C for 72 hours was used to estimate forage utilization by the cows as per the Herbage Disappearance (Weight Estimate) Method (Jasmer and Holechek 1984):

$$Pasture\ utilization\ (\%) = \frac{(g\ DM\ per\ 0.25\,m^2\ available - g\ DM\ per\ 0.25\,m^2\,residual)}{g\ DM\ per\ 0.25\,m^2\,available}$$

Grams per 0.25 m^2 were extrapolated to determine kg per ha and forage intake was estimated using the following equation:

$$DMI\,(kg) = \frac{(kg\,DM\ p^{-1} allocated - kg\,DM\ p^{-1} residual)}{n^{-1}/p}$$

where p = the number of days the paddock was grazed and n = the number of cows per experimental unit.

3.2.4. Environmental data

Daily minimum and maximum temperatures, as well as precipitation, were obtained from Agri-Environment Services Branch, Agriculture and Agri-Food Canada, Termuende Research Ranch Benchmark Site meteorological station, approximately 1 km east of the study site (Appendix Table A.2 to A.12). Precipitation in the form of snow was obtained from Environment Canada's Climate Data Online (www.climate.weatheroffice.ec.gc.ca) for Esk, Saskatchewan, approximately 5 km southeast of the study site (51°48 'N, 104°51 'W). Snow precipitation data was unavailable for December 2007.

3.2.5. Laboratory analysis

Forage DM was determined by drying clipped samples at 55°C for 72 h in a forced air oven. Prior to chemical analysis, forage samples were ground through a 1-mm screen (Thomas-Wiley Laboratory Mill Model 4; Thomas Scientific, Swedesboro, NJ, USA). Representative supplement samples were also ground to pass through a 1-mm screen using a Retsch ZM-1 grinder (Haan, Germany). All feed samples were analyzed for moisture, CP, acid detergent fibre (ADF), neutral detergent fibre (NDF), in-vitro dry matter digestibility (IVDMD), and in-vitro organic matter digestibility (IVOMD) and forages were analyzed for acid detergent lignin (ADL) and acid detergent insoluble nitrogen (ADIN). Additionally, supplements were analyzed for phosphorus, sulfur, and neutral detergent insoluble nitrogen (NDIN). Total digestible nutrients (TDN; % DM) and digestible energy (DE; Mcal kg^{-1} DM) were calculated for forage samples using the grass-legume Penn State equation based on ADF and for supplement samples using the cereal grains Penn State equation (Appendix Equations A.1 and A.2; Adams 1995).

Moisture was determined according to the procedure outlined by the Association of Official Analytical Chemists (method #930.15; AOAC 2000). Crude protein (N x 6.25), NDIN, and ADIN concentrations were determined using the Kjeldahl procedure (method #984.13; AOAC 2000) using the 2400 Kjeltec Analyzer Unit (FOSS Tecator, Hoganas, Sweden). NDF and ADF were analyzed using an ANKOM 200 Fiber Analyzer (ANKOM Technology, Fairport, NY). NDF was analyzed without sodium sulfite in order to further determine NDIN content of the samples (Hertz and Mertens 1996). Lignin content was evaluated using the beaker method outlined by ANKOM Technology.

In vitro dry matter digestibility and IVOMD were estimated using the filter bag technique (Daisy^{II}, ANKOM Technology Corporation, Fairport, NY). Artificial saliva was inoculated with rumen fluid strained through four layers of cheese cloth. Rumen fluid was collected from a ruminally-fistulated Holstein cow fed 70% silage and 30% concentrate (custom pellet; DM basis). Phosphorus and sulfur were analyzed according to the procedures outlined by Qian et al. (1994) and Kowalenko (1993), respectively.

3.2.6. Data analysis

The Proc Mixed Model procedure of SAS (2005) was used for all statistical analysis except body condition score. Differences were considered significant when $P < 0.05$; means were separated using Tukey's multi-treatment comparison method (Saxton 1998). Cow BW, rib and rump fat, forage utilization, and dry matter intake estimations were analyzed as fixed effects in a randomized complete block design with year considered as a random effect. The experimental model was:

$$Y_{ij} = \mu + \rho_i + \alpha_j + e_{ij}$$

where μ is the overall mean, ρ_i is the block or random effect to the *i*th year, α_j is the fixed effect of the *j*th treatment, and e_{ij} is the error term specific to the experimental unit (cow group) assigned to the *j*th treatment within the *i*th year.

Because cow body condition score data are discrete values with no unit, cow body condition score data was analyzed using the Proc Glimmix procedure of SAS (2005). Proc Glimmix is used to fit statistical models to data with correlations or non-constant variability and where the response is not necessarily normally distributed (SAS Institute Inc. 2005).

3.3. Results & Discussion

3.3.1. Pasture quality

Chemical composition of stockpiled crested wheatgrass pasture forage and supplements are presented in Table 3.1. Average forage quality of the pasture was higher than anticipated. Total digestible nutritents, calculated using the Penn State equations based on ADF content (Appendix Equation A.1; Adams 1995), was 49.0% and IVDMD was 56.4%. As such, pasture forage could provide adequate energy for the grazing beef cows (NRC 1996). Average CP was 7.3%, which is greater than the 6-7% CP recommended for beef cows (NRC 1996; Mathis et al. 2000). However, during the study, CP content decreased 1.9% (Figure 3.1), indicating the potential for CP to be deficient.

Forage quality spiked in the third graze period. Precipitation in the second week of October in both years (Appendix Table A.3 and A.9) may have caused a flush of regrowth, increasing forage quality and availability in the third graze period. However, over the course of the trial, forage quality declined. Crude protein decreased from 7.6% to 5.7% while NDF increased from 73.2% to 77.5% and ADF levels increased from 45.3% to 50.1% (Figure 3.1). It is well documented that forage digestibility decreases as plants mature, weather, and senesce due to decreased photosynthetic leaf material and increased structural stem components, including cellulose, hemicellulose, and lignin (Wilson 1982; Jones and Wilson 1987; Huston and Pinchak 1991; Van Soest 1994; Vallentine 2001). Reduced dietary intake in response to seasonal advancement has been observed in other studies (McCollum and Galyean 1985a; McCollum et al. 1985; Johnson et al. 1998). Beck et al. (2006) found the extent of *in situ* organic matter (OM) disappearance in the rumen decreased as the ADF content in stockpiled forage increased. Cline et al. (2009) found that total tract and apparent ruminal organic matter digestibility decreased as the grazing season progressed, as did organic matter intake. In the current study, IVOMD was estimated to decline 10.2% in the pasture forage during the trial (Figure 3.2). This decline in IVOMD is similar to that reported by Baron et al. (2004) for crested wheatgrass pasture.

3.3.2. Forage utilization

Available and residual forage levels were not different (P = 0.43 and 0.89, respectively) between treatments (Table 3.3). However, during the trial, available forage was significantly greater (P = 0.02) during the third graze period, which occurred during mid-October for both years of the study. Baron et al. (2004) also found DM yield of crested wheatgrass pasture (*Agropyron cristatum* L.) was greatest at the mid-October time period. In this study, a high standard error of the mean (SEM; Table 3.3) may be reflective of the low number of quadrat samples taken and the variability associated with the estimation technique.

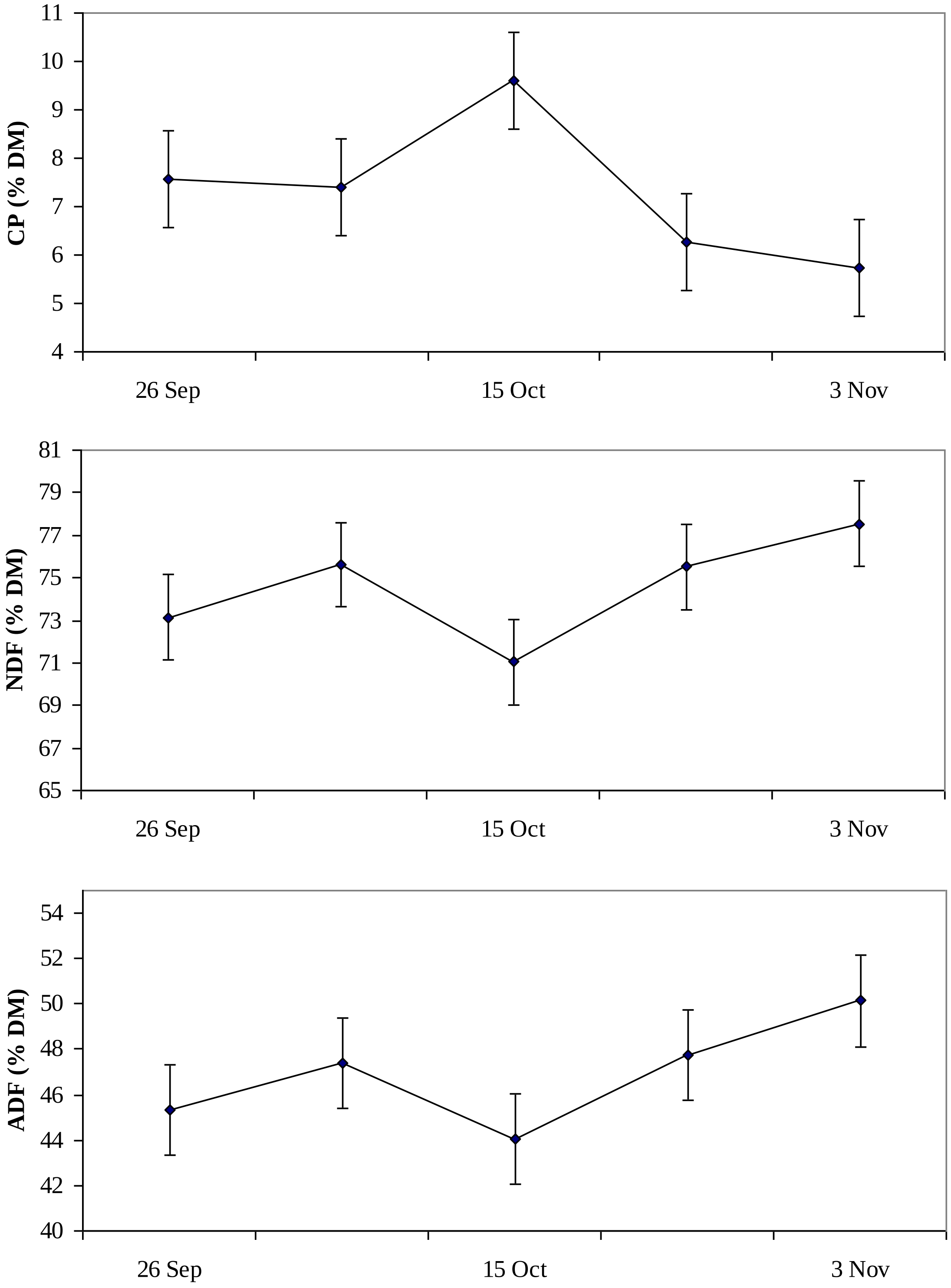

Figure 3.1 Forage quality of stockpiled crested wheatgrass pasture (CP = crude protein; NDF = neutral detergent fibre; ADF = acid detergent fibre)

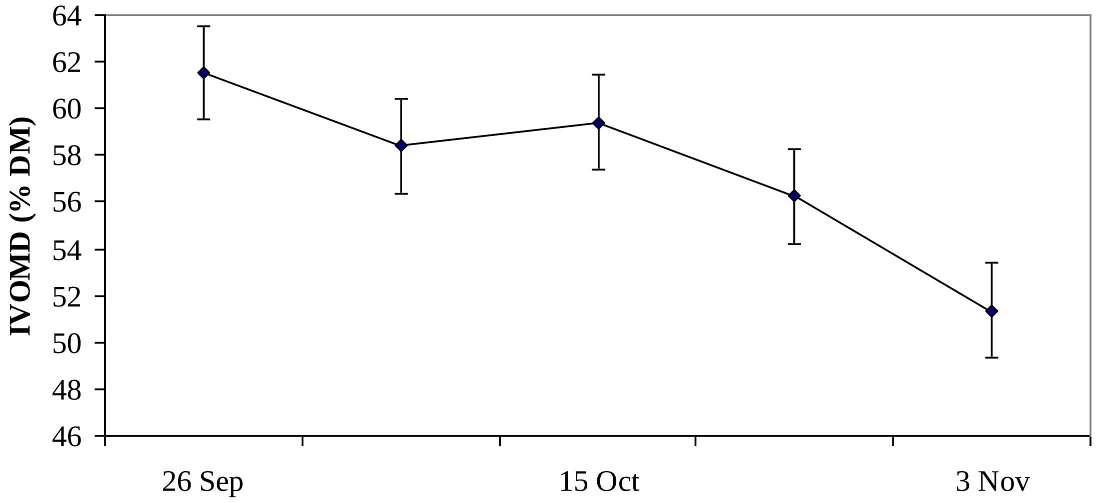

Figure 3.2 ***In vitro*** **organic matter digestibility (IVOMD) of stockpiled crested wheatgrass pasture**

Estimated forage utilization did not differ (P = 0.79) between treatment groups. This agrees with results reported by Poore et al. (2006), who observed no difference (P > 0.20) in forage use as affected by whole cottonseed meal plus corn grain supplementation on stockpiled fescue pasture. However, in the current study, cows receiving supplement numerically utilized 6% more forage than the unsupplemented control cows (Table 3.3), while heifers in the study by Poore et al. (2006) utilized 3.4% less forage when supplemented. Forage utilization was not different (P > 0.05) during the course of the study.

Forage utilization data was used to estimate forage intake on a per head per day basis (Table 3.4). Dry matter intake of pasture forage was not affected (P = 0.37) by supplementation strategy. This is in contrast with other studies (Chase and Hibberd 1987; Koster et al. 1996; DelCurto et al. 1999; Mathis et al. 1999; Bandyk et al. 2001) which have reported increased forage intake as a result of protein supplementation and may have been a result of low experimental power. In an extensive review, Moore et al. (1999) reported that forage intake was often increased with supplementation if forage intake alone was less than 1.75% of BW and the forage TDN to CP ration was less than 7. In the current trial, the forage intake of control cows was 1.48% of BW. Based on this data, forage intake was expected to increase with protein supplementation. However, it is

Table 3.3 Effects of supplementation on pasture utilization

	Treatment^z				Graze Period					P values^x		
	DDGS	COMM	CONT	SEM^y	1	2	3	4	SEM	trt	gp	trt*gp
Available forage (kg ha^{-1})	1943.8	2042.4	1769.9	571.54	1730.7b	1830.4b	2407.6a	1706.2b	577.91	0.43	0.02	0.7
Residual forage (kg ha^{-1})	1073.4	1120.3	1110.7	482.19	1126.5	1102.6	1060.4	1116.3	483.93	0.89	0.94	0.83
Percent utilization	39.9	40	34.3	0.09	31.1	41.8	49.3	30.1	0.1	0.79	0.25	0.58

[z] DDGS = cows supplemented with wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); COMM = cows supplemented with commercial range pellet; CONT = cows received no supplement

[y] Means separated using Tukey's multi-treatment comparison method. SEM = standard error of mean

[x] trt = treatment effects; gp = graze period effects; trt*gp = treatment by graze period interaction

Table 3.4 Estimated DM intake of dry, pregnant beef cows grazing stockpiled crested wheatgrass pasture

	Treatment^z				Graze period^y					P value^x		
Item	DDGS	COMM	CONT	SEM	1	2	3	4	SEM	trt	gp	trt*gp
Dry matter intake, kg d^{-1}												
Supplement	1.2	1.2	0.0	N/A	0.7	0.7	0.8	0.8	N/A	N/A	N/A	N/A
Pasture	11.7	12.6	9.1	1.81	6.3b	10.3b	18.3a	9.7b	2.09	0.37	<0.01	0.66
Total	12.9	13.8	9.1	1.81	7.0b	11.1b	19.2a	10.5b	2.09	0.16	<0.01	0.66
Dry matter intake, % BW												
Supplement	0.19	0.19	0.00	N/A	0.12	0.12	0.13	0.3	N/A	N/A	N/A	N/A
Pasture	1.86	2.01	1.47	0.291	1.02b	1.67ab	2.86a	1.57b	0.335	0.40	<0.01	0.67
Total	2.05	2.21	1.47	0.290	1.15b	1.79ab	2.99a	1.71b	0.335	0.18	<0.01	0.68

[z] DDGS = cows supplemented with wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); COMM = cows supplemented with commercial range pellet; CONT = cows received no supplement

[y] Graze period: period 1 = 11 d; period 2 = 10 d; period 3 = 10 d; period 4 = 7 d

[x] trt = treatment effects; gp = graze period effects; trt*gp = treatment by graze period interaction

[a-b] Means with different letters in the same row are significantly different ($P < 0.05$) using Tukey's multi-treatment comparison method.
SEM = standard error of mean

known that supplementation effects are influenced by forage quality and supplement composition (Huston et al. 1993). Average TDN:CP ratio of the pasture forage was 6.7, however due to selective grazing, it is likely that the forage consumed by the cows had a higher TDN:CP ratio (Vallentine 2001). Furthermore, Kartchner (1980) found no effect of protein supplementation when forage DM digestibility (DMD) was 55 percent. Average IVDMD of stockpiled crested wheatgrass pasture in this study was 56.4 percent (Table 3.1).

Unsupplemented or control cows were estimated to consume 9.1 kg of pasture per day. This is similar to the estimated forage intake of 9.98 kg per day for a 620 kg cow based on the observations of Mertens (1987; 1994) and Ferrell et al. (1999), where predicted dry matter intake of long stem forage is 1.2% of BW as NDF. Supplemented cows did not ($P = 0.37$) consume more pasture forage than the control cows. This contrasts with the results of Morris et al. (2005), who found supplementation of graded levels of corn-based DDGS linearly decreased DMI of both high (65% TDN) and low (53% TDN) quality forages. Similar results were observed by MacDonald et al. (2007) when corn-based DDGS was supplemented at different levels to beef heifers grazing smooth bromegrass pastures with average TDN values of 58.2 percent. The energy level of the pasture forage in the current study was lower (49.0% TDN; Table 3.1) than the forages in these studies, perhaps eliminating the substitution effects observed by Morris et al. (2005) and MacDonald et al. (2007).

3.3.3. Cow performance

Supplementing cows with either DDGS or commercial range pellet had no effect ($P > 0.05$) on cow BW, body fat, or body condition (Tables 3.5 and 3.6). These results do not agree with other studies that reported significant effects on BW and condition with protein supplementation (Clanton and Zimmerman 1970; Huston et al. 1999; Bohnert et al. 2002a). Cows supplemented with DDGS or COMM gained 10.0 and 6.8 kg respectively, while cows receiving no supplement gained only 1.8 kg BW. Rib and rump fat depth of supplemented cows increased 1.1 and 1.5 mm for DDGS and COMM treatments, respectively, while unsupplemented cows lost 0.8 mm.

Table 3.5 Effect of supplementation on performance of beef cows grazing stockpiled pasture

	Treatment^z				
	DDGS	COMM	CONT	SEM^y	P value
Body weight^x, kg					
Initial	608.1	607.3	610.3	10.44	0.58
Final	618.0	614.1	612.1	6.17	0.34
Change	10.0	6.8	1.8	5.24	0.24
Rib fat, mm					
Initial	3.8	4.2	3.7	0.25	0.33
Final	4.9	5.4	4.6	0.23	0.09
Change	1.1	1.5	0.8	0.21	0.12
Rump fat, mm					
Initial	4.5	4.9	3.9	0.37	0.21
Final	5.4	6.1	4.8	0.65	0.31
Change	1.1	1.5	0.8	0.81	0.37

^{z}DDGS = cows supplemented with wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); COMM = cows supplemented with commercial range pellet; CONT = cows received no supplement

^{y}SEM = standard error of the mean

^{x}Cow BW was adjusted for conceptus gain

Effect of supplementation on body condition score (BCS) is presented in Table 3.6. The majority of the cows (72.4% supplemented, 86.7% unsupplemented) maintained (0 score change) or gained 0.5 BCS. During the trial, 24.1% of cows supplemented with DDGS gained one BCS compared to only 6.7% of the unsupplemented (control) cows. For cows supplemented with a commercial range pellet, 17.2% gained one BCS. Very few animals (3.4% supplemented, 6.7% unsupplemented) lost (negative change) body condition.

Because the energy levels of the pasture forage met maintenance requirements of gestating beef cows, DDGS and commercial range pellet served as protein supplements. There have been variable results reported on the effects of protein supplementation on beef cow performance. Bohnert et al. (2002a) reported positive cow BW and body condition score changes when soybean meal-based protein supplements were fed to pregnant beef cows consuming low quality meadow hay (5.2% CP; 60.1% NDF). Similarly, Huston et al. (1999)

Table 3.6 Effects of supplementation on body condition score (BSC) of beef cows grazing stockpiled pasture

	Treatment[z]				
BCS	DDGS	COMM	control	SEM[y]	P value
Start of trial (% of cows)					
2	31.0	20.7	20.0	0.23	0.57
2.5	41.4	51.7	50.0	0.28	0.71
3	24.1	24.1	23.3	0.23	1.00
3.5	3.4	3.4	6.7	0.11	0.80
4	0.0	0.0	0.0	0.00	1.00
End of trial (% of cows)					
2	6.2	0.0	6.2	0.09	1.00
2.5	28.1	37.5	46.9	0.25	0.35
3	43.8	43.8	40.6	0.26	0.96
3.5	18.8	28.0	6.3	0.22	0.38
4	3.1	6.2	0.0	0.07	0.85
Change (% of cows)					
-1	0.0	3.4	0.0	0.03	1.00
-0.5	3.4	0.0	6.7	0.08	0.86
0	31.0	24.1	46.7	0.26	0.23
0.5	41.4	48.3	40.0	0.27	0.80
1	24.1	17.2	6.7	0.20	0.27
1.5	0.0	6.9	0.0	0.05	1.00

[z] DDGS = cows supplemented with wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); COMM = cows supplemented with commercial range pellet; CONT = cows received no supplement

[y] SEM = pooled standard error of the mean

found feeding cottonseed meal to beef cows grazing native range in western Texas reduced losses in BW and BCS. Clanton and Zimmerman (1970) also reported increased cow BW and body condition when soybean meal was supplemented to cows consuming bromegrass hay (8.1% CP). Conversely, Smith et al. (2001) found beef cows grazing native winter range in eastern Colorado lost BW and condition ($P < 0.05$) when supplemented with corn-based DDG. These authors concluded that degradable intake protein requirements were not met by the high RUP value of the DDG.

A two year study by Kartchner (1980) found the effect of supplementation dependent on a number of factors, such as environmental conditions and forage quality and availability. Protein supplementation positively impacted cow performance when forage DMD was less than 50% and environmental conditions were less favourable (-2 to -38°C, heavy snow), limiting forage availability. When forage DMD was greater than 50% and environment was mild, there were no observed effects of protein or energy supplementation on cow performance. Average IVDMD of the stockpiled crested wheatgrass pasture was 56.4 percent in the current study and average temperature was 5.0°C (range -1.8 to 12.2°C). Greater differences in cow performance may have been observed if pasture forage quality had been lower or if environmental conditions had been more adverse.

3.3.4. Economic analysis

Study economic analysis included feed and yardage costs associated with supplement strategy, pasture establishment costs, equipment use, fuel, and labour. Sufficient quantities of DDGS and commercial range pellet were secured for both years of the study in September 2007. The wheat-based DDGS (70:30 wheat:corn blend) was obtained from Husky Energy (Lloydminster, Saskatchewan, Canada) and quoted by Wilbur Ellis to be priced at $140 per tonne (September 2007). The commercial range pellet was custom blended by FeedRite Ltd (Humboldt, Saskatchewan, Canada) and cost $8.25 per 25 kg bag ($330 per tonne). Mineral and salt were purchased from FeedRite Ltd. (Humboldt, Saskatchewan, Canada) and priced at $24.47 per 25 kg and $4.75 per block in 2007 and $31.80 per 25 kg and $5.48 per block in 2008, respectively. A rate of $0.25 per head per day was used for the cost of stockpiled crested wheatgrass pasture for both years of the study; this rate includes pasture repairs and depreciation (Saskatchewan Ministry of Agriculture (SMA) 2006). Labour was valued at $15.00 per hour. Equipment rates were obtained from SMA (2006).

Because expenses are magnified in small research trials due to increased costs associated with data collection and managing multiple groups of animals, trial costs are also presented to more accurately represent industry costs by extrapolating actual research costs to a model herd size of 200 head. To account for increased time, labour, and equipment use required to manage a larger herd, yardage costs were adjusted $0.50 per cow per day. Supplementation strategy costs are presented in Tables 3.7.

Table 3.7 Economics of managing beef cows on stockpiled crested wheatgrass pastures

	DDGS		COMM		CONT	
Item	2007	2008	2007	2008	2007	2008
			$\$$ hd^{-1} d^{-1}			
Feed costs						
Supplement^{z}	0.01	0.01	0.04	0.03	-	-
Mineral	0.01	0.03	0.01	0.03	0.01	0.03
Salt	-	-	-	-	-	-
Pasture	0.02	0.02	0.02	0.02	0.02	0.02
Total feed costs	0.05	0.06	0.07	0.08	0.04	0.05
Yardage costs						
Machinery cost (incl. fuel)	0.06	0.06	0.06	0.06	0.02	0.02
Labour	0.03	0.02	0.03	0.02	0.03	0.01
Total yardage costs	0.58	0.58	0.58	0.58	0.54	0.53
Total production costs	0.63	0.64	0.65	0.66	0.58	0.58

^{z}Feed prices are reported in Appendix Table A.13

Average total costs were $0.64, $0.66, and $0.58 per head per day for DDGS, COMM, and CONT, respectively ($0.63, $0.65, and $0.58 per head per day in 2007 and $0.64, $0.66, and $0.58 per head per day in 2008 for DDGS, COMM, and CONT, respectively). Assuming daily pasture cost to graze cattle is equivalent to control cost, supplementing with either DDGS or commercial range pellet cost 10% or 13% more, respectively. Total cost differences between the two supplement strategies is reflective of the cost of the supplement. Because no difference ($P > 0.05$) in animal performance was observed between cows supplemented with either wheat-based dried distillers' grains with solubles or a commercial range pellet, producers may decide to supply wheat-based DDGS to their cows based solely on the current market cost of the supplement.

3.4. Conclusion

No significant differences were found in pasture forage utilization, forage intake, or beef cow performance between treatments. The lack of supplement effect on animal performance in this experiment may be attributed to the low experimental power, reducing the detection of significant differences. Furthermore, pasture quality in this trial was likely able to meet pregnant beef cow requirements, particularly if selective grazing was occurring.

Providing supplement increased costs of production over the non supplemented groups as a result of increased feed costs, as well as yardage associated with delivering supplement. Supplementing beef cows with wheat-based DDGS resulted in no negative effects on cow performance in this study. Therefore, using DDGS as a supplement, based on these results will depend on the current market price of the potential supplements.

4. Effect of supplementing beef cows grazing barley crop residue with wheat-based dried distillers' grains with solubles on animal performance and intake

4.1. Introduction

For beef producers in western Canada, significant feed costs are incurred during the winter feeding period, when harsh environmental conditions can challenge animal performance. Kaliel and Kotowich (2002) estimate 60-65% of total production costs for western Canadian cow-calf operations can be attributed to winter feeding and management. As such, producers are increasingly interested in extensive management systems including swath grazing, bale grazing, and grazing cereal crop residue in order to lower winter feed costs.

The relative abundance of cereal crop residue in Western Canada dictates its use in beef cow feeding programs (Anderson 1978; McCartney et al. 2006). Crop residue is a mixture of botanical fractions including chaff, grain, leaf blade, leaf sheath, internode, and node. These fractions are variable in their palatability, rumen degradability, and digestibility depending on crop variety and maturity at harvest, harvest method, and weathering of the residue (Capper et al. 1989; McCartney et al. 2006). Not only does the quality of the components cause variation in the total residue, but also the relative amounts of each fraction, which are also affected by variety, maturity, harvest, and weathering (Capper et al. 1989; Colucci et al. 1992; Mathison et al. 1999). An in-depth review of the composition and availability of cereal straw-chaff in western Canada is available in the literature (McCartney et al. 2006).

Cereal crop residue is considered a low quality forage due to its low protein, high fibre content (NRC Males 1987; 1996). Straw in particular is high in lignin as a result of selective breeding for grain production and lodging resistance (McCartney et al. 2006). Fibre adds bulk to the feed, physically limiting total feed intake by volume and slow rates of digestion, potentially causing impaction within the gastrointestinal tract (Van Soest 1994; Allen 1996). Energy supply to the animal is dictated by feed intake (Capper et al. 1989). Typically, protein supplementation of low quality forages increases forage intake and digestibility sufficiently to meet energy requirements (Church and Santos 1981; Chase and Hibberd 1987). However, despite protein supplementation, pregnant beef cows are unable to consume enough straw-chaff to meet energy requirements based on the low energy and high bulk density of the feed (NRC 1996). Furthermore, straw diets require an appropriate energy source to utilize nitrogen (N) supplementation (Zorrilla-Rios et al. 1989). Sultan and Loerch (1992) reported N digestibility was increased by cornstarch supplementation when lambs were fed wheat straw. Therefore, both energy and protein supplements are required when straw constitutes the main forage in beef cow rations.

The carbohydrate composition of a supplement has significant impacts on the utilization of low quality forage (Bowman and Sanson 2000). Energy supplements containing high levels of non-structural carbohydrates (NSC), such as cereal grains, have been shown to decrease the DMI and digestion of low quality forages (Sanson and Clanton 1989; DelCurto et al. 1990b; Sanson et al. 1990; Koster et al. 1996; Mathis et al. 1999). Depressed fibre digestion is the result of the negative associative effects which occur in the rumen when NSC are fed. Rapid fermentation of starch by amylolytic bacteria increases the concentration of VFA, decreasing ruminal pH below the level which cellulolytic bacteria are able to thrive, (Hiltner and Dehority 1983; Tamminga and Van Vuuren 1988; Bowman and Sanson 2000). This causes a shift in the microbial populations within the rumen, reducing the number of cellulolytic bacteria, thereby reducing fibre digestion. Depressed fibre digestion may lead to reduced passage rates and forage DMI (Robinson et al. 1987; Uden 1988). Alternatively, protein supplements tend to have positive associative effects by supplying N to the rumen microbes to facilitate population growth. This optimizes rumen function and fibre digestion, improving forage DMI and passage rate (McCollum and Galyean 1985b; DelCurto et al. 1990a; Mathis et al. 2000). The extent to which forage intake is affected by supplementation is known as the substitution effect (Bowman and Sanson 2000).

Barley grain is commonly used to supplement beef cow diets in the winter due to its high energy content (2.06 Mcal NE_m kg^{-1}; 1.40 Mcal NE_g kg^{-1}; NRC 1996). However, barley, like most cereal grains, has a high starch content (> 60% DM; Sanford et al. 2003) and at least 90% of the starch in processed barley is readily degraded within the rumen (Orskov 1986; Beliveau 2008), potentially depressing fibre digestion due to negative associative effects. Nuez-Ortin and Yu (2009b) reported the energy value of 100% wheat DDGS and 70% wheat, 30% corn DDGS to be 2.08 and 2.17 Mcal NE_m kg^{-1}, respectively. This agrees with Gibb et al. (2008) who found the energy level of wheat-based DDGS (1.21 to 1.36 Mcal NE_g kg^{-1}) was comparable to the energy of barley grain. The energy value of DDGS is likely due to the high digestibility of the neutral detergent fibre (Nuez-Ortin and Yu 2009a) and concentrated fat content (Kononoff and Erickson 2006; Schingoethe 2006). While DDGS is not expected to have negative associative effects on the rumen due to the lack of starch, Beliveau (2008) reported the incidence of SARA was not reduced by replacing barley grain with graded levels of 100% wheat DDGS in feedlot rations. Currently, there is no information on the effects of wheat-based DDGS on the rumen metabolism of cattle consuming low quality forages.

The characteristically low protein and high fibre content dictate the need for both synergistic energy and protein supplementation when straw-chaff is used as the base forage in beef cow diets in order to meet the nutritional requirements of the cow and to prevent impaction (Beck et al. 1992; Bowman and Sanson 1996; NRC 1996; McCartney et al. 2006). With the increasing availability of wheat-based dried distillers' grains with solubles (DDGS) from ethanol production in western Canada, animal performance information is needed for wheat-based DDGS as a supplement for beef cows diets. Therefore, the objectives of this study were to 1) evaluate the performance of dry pregnant beef cows grazing barley straw-chaff crop residue and supplemented with either wheat-based DDGS, barley grain, or a 50:50 blend of DDGS and barley grain; 2) determine estimated intake of straw-chaff as affected by supplementation strategy; and 3) compare the economics of the different supplement programs.

4.2. Materials & Methods

4.2.1. Study site

A 2 year winter grazing study was conducted at the Western Beef Development Centre's Termuende Research Ranch near Lanigan, Saskatchewan, Canada (51°51 'N, 105°02 'W). In late spring of each year (1 June 2007 and 29 May 2008) 25 hectares of forage barley (cv. Ranger) was seeded at a rate of 107.6 kg per ha with 56.1 kg per ha of actual nitrogen fertilizer. Crop weed control was managed using Round Up and Estaprop applied on 2 June and 11 June, respectively, in 2007 and Round Up and Buctril M were applied on 26 May and 25 June, respectively, in 2008. The barley was swathed 10 September 2007 and 8 September 2008 and combined to collect straw-chaff crop residue. Barley straw-chaff residue was collected in piles using a whole-buncher (AJ Manufacturing, Calgary, Alberta, Canada) unit attached to the combine. Average pile weight was 12.7 kg (dry matter basis). Chemical composition of the straw-chaff residue is presented in Table 4.1. Barley straw-chaff piles were divided into six 4 ha paddocks using high tensile electric fence.

4.2.2. Grazing animal management

Forty-eight dry, pregnant (125±22 d) Black Angus cows (BW±SD; 629±8 kg) were managed on barley straw-chaff piles for 47 days (17 November 2007 to 2 January 2008) in 2007-08 and 46 days (14 November to 31 December) in 2008-09. Cows were allocated straw-chaff residue based on BW and feed nutrient density in accordance with the NRC (1996) beef model as predicted by CowBytes ration balancing program (Alberta Agriculture Food and Rural Development 1999). However, the amount of crop residue allotted varied depending on utilization and environmental conditions. Cow access to straw-chaff piles was controlled using temporary electric fence on a 3 d basis. Back-grazing was allowed, but not observed.

Each year, the same 48 Black Angus cows were used for Experiment I and Experiment II. After Experiment I, animals were stratified according to BW and days pregnant and re-allocated into 6 homogenous groups of 8. Cow groups were randomly allocated to 1 of 3 replicated (n=2) supplement strategies: (1) 100% wheat-based dried distillers’ grains with solubles (DDGS); (2) 50% DDGS and 50% rolled barley grain (50:50); or (3) 100% rolled barley grain (control; BARL). The DDGS was a 70% wheat, 30% corn blend provided by Husky Energy Ltd. (Lloydminster, Saskatchewan, Canada). In addition, medium quality hay (47.7% TDN; 7.1% CP; Table 4.1) was supplied to all cow groups during extreme winter conditions (> -25°C; 16 km wind) to minimize body condition loss. Chemical composition of the feedstuffs used in this trial is presented in Table 4.1.

During the trial, cows received an average of 4.4 kg of supplement per day (28.5% of total dry matter intake (DMI); Table 4.2) or 0.7% of BW daily. The control diet (rolled barley grain) was formulated to meet beef cow maintenance requirements using CowBytes Ration Balancer Program (Version 4. Alberta Agriculture Food and Rural Development 1999). Wheat-based DDGS was then substituted 1:1 for barley grain for the DDGS and 50:50 diets. Supplements were fed daily between 0800 and 0900. During the trial, 68 g per cow per day of 2:1 mineral supplement (20.0% Ca, 10.0% P, 60 ppm Se, 70 ppm Co, 200 ppm I, 3000

Table 4.1 Chemical composition of forages and supplements

	Forage		Supplements	
Nutrient	Barley straw-chaff	Grass hay	DDGS[z]	Barley
DM (%)	83.9	76.5	90.0	89.1
CP (% DM)	8.6	7.1	38.5	13.8
NDF (% DM)	76.5	68.5	50.8	21.2
ADF (% DM)	50.1	48.1	19.8	8.1
ADL (% DM)	8.5	10.1	-	-
Phosphorus (% DM)	-	-	0.7	0.4
Sulfur (% DM)	-	-	0.8	0.3
NDIN (% N)	-	-	4.1	1.9
ADIN (% N)	16.1	14.4	-	-
IVDMD (% DM)	58.0	64.1	88.8	89.1
IVOMD (% DM)	59.7	66.5	91.7	94.1
TDN[y] (% DM)	45.4	47.7	80.0	93.3
DE[y] (Mcal kg^{-1} DM)	2.0	2.1	3.3	3.6

[z]DDGS = wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend)
[y]Calculated using the Penn State equations based on ADF (Adams 1995)

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) and 78 g per cow per day of limestone (calcium carbonate, 38.0% Ca (actual); FeedRite Ltd., Humboldt, Saskatchewan, Canada) were top dressed on the supplements and cows had *ad libitum* access to cobalt-iodized salt (99.0% NaCl (min), 39.0% Na, 150 ppm I, 100 ppm Co). Water was supplied in troughs and portable windbreaks (10 x 16 m) were supplied for each group of cows.

Parameters measured to evaluate cow performance included BW, BCS, and subcutaneous body fat thickness. Body weights were taken over 2 consecutive days at the start and end of trial and every 14 d throughout the course of the trial. Cow BW was corrected for conceptus gain using the equation from NRC (1996):

$$\text{Conceptus weight (kg)} = (\text{calf birth weight} \times 0.01828) \times e^{[(0.02xt) - (0.0000143xtxt)]}$$

Body condition score was determined by the same experienced technician at the beginning and end of the trial using the Scottish scale where 1=emaciated and 5=grossly fat (Lowman et al. 1976; Wildman et al. 1982). Ultrasound measurements of subcutaneous body fat thickness were determined between the 12th and 13th rib and at the thurl location using an

Table 4.2 Feed ingredient and nutrient composition of rations[z]

Item	Treatments[y] DDGS	50:50	BARL
Predicted intake (kg DM/hd/d)	14.7	14.9	14.9
Feed		% of ration	
Barley Straw-Chaff	43.2	43.6	42.9
Hay	55.0	46.3	48.2
DDGS	28.1	14.4	-
Barley Grain	-	14.4	28.6
2:1 Mineral	0.5	0.4	0.4
Limestone	0.5	0.5	0.3
Salt	0.3	0.3	0.3
Chemical composition[x]			
CP (% DM)	19.8	15.8	11.4
NDF (% DM)	83.6	78.8	69.2
TDN (% DM)	68.4	70.6	69.4
DE (Mcal kg^{-1} DM)	2.9	3.0	2.9

[z] Rations formulated using CowBytes Beef Ration Balancer Program. Version 4. (Alberta Agriculture Food and Rural Development 1999)

[y] DDGS = cows supplemented with 100% wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); 50:50 = cows supplemented with 50% DDGS and 50% barley grain; BARL = cows supplemented with 100% barley grain

[x] Calculated from average nutrient composition of ingredients.

Aloka SSD-500V ultrasound machine and Aloka UST-5044 probe (3.5 MHz). Guidelines for animal care (Canadian Council on Animal Care 1993) were followed at all times for all animals used in this experiment.

4.2.3. Estimation of forage utilization

Prior to the start of the winter grazing trial, 40 straw-chaff piles in each paddock were weighed. To determine forage utilization by the cows, straw-chaff residue from areas grazed at the start, middle, and end of the trial were weighed the following spring. The difference between the pre- and post-graze weight of straw-chaff piles was used to estimate daily forage intake by the cows (Volesky et al. 2002) using the following equation:

$$DMI\,(kg) = \frac{\left(kg\,DM\;\;p^{-1}allocated - kg\,DM\;\;p^{-1}residual\right)}{n^{-1}\,/\,p}$$

where p = the number of days per graze period and n = the number of cows per experimental unit.

4.2.4. Environmental data

Daily minimum and maximum temperatures, as well as precipitation, were obtained from Agri-Environment Services Branch, Agriculture and Agri-Food Canada, Termuende Research Ranch Benchmark Site meteorological station, approximately 1 km east of the study site (Appendix Table A.2 to A.12). Precipitation in the form of snow was obtained from Environment Canada’s Climate Data Online (www.climate.weatheroffice.ec.gc.ca) for Esk, Saskatchewan, approximately 5 km southeast of the study site (51°48 'N, 104°51 'W). Snow precipitation data was unavailable for December 2007.

4.2.5. Laboratory analysis

Straw-chaff samples were collected at the start, middle, and end of the grazing trial. Hay samples were collected when hay supplementation started, and at the end of the trial. Forage DM was determined by drying the samples at 55°C for 72 h in a forced air oven. Prior to laboratory analysis, all forage samples were ground to pass through a 1-mm screen (Thomas-Wiley Laboratory Mill Model 4; Thomas Scientific, Swedesboro, NJ, USA). Representative supplement samples were also ground through a 1-mm screen using a Retsch ZM-1 grinder (Haan, Germany). All feed samples were analyzed for moisture, CP, ADF, NDF, IVDMD, and IVOMD and forages were analyzed for ADL and ADIN. Additionally, supplements were analyzed for phosphorus, sulfur, and NDIN. TDN (% DM) and DE (Mcal kg^{-1} DM) were calculated for forage samples using the grass-legume Penn State equation based on ADF and for supplement samples using the cereal grains Penn State equation (Appendix Equations A.1 and A.2; Adams 1995).

Moisture was determined according to the procedure outlined by the AOAC (method #930.15; AOAC 2000). Crude protein (N x 6.25), NDIN, and ADIN concentrations were determined using the Kjeldahl procedure (method #984.13; AOAC 2000) using the 2400

Kjeltec Analyzer Unit (FOSS Tecator, Hoganas, Sweden). NDF and ADF were analyzed using an ANKOM 200 Fiber Analyzer (ANKOM Technology, Fairport, NY). NDF was analyzed without sodium sulfite in order to further determine NDIN content of the samples (Hertz and Mertens 1996). Lignin content was evaluated using the beaker method outlined by ANKOM Technology.

In vitro dry matter digestibility and IVOMD was estimated using the filter bag technique (Daisy^{II}, ANKOM Technology Corporation, Fairport, NY). Artificial saliva was inoculated with rumen fluid strained through four layers of cheese cloth. Rumen fluid was collected from a ruminally-fistulated Holstein cow fed 70% silage and 30% concentrate (custom pellet; DM basis). Phosphorus and sulfur were analyzed according to the procedures outlined by Qian et al. (1994) and Kowalenko (1993), respectively.

4.2.6. Data analysis

The Proc Mixed Model procedure of SAS (2005) was used for all statistical analysis except body condition score. Differences were considered significant when $P < 0.05$; means were separated using Tukey's multi-treatment comparison method (Saxton 1998). Cow BW and rib and rump fat were analyzed as fixed effects in a randomized complete block design with year considered as a random effect. The experimental model was:

$$Y_{ij} = \mu + \rho_i + \alpha_j + e_{ij}$$

where μ is the overall mean, ρ_i is the block or random effect to the *i*th year, α_j is the fixed effect of the *j*th treatment, and e_{ij} is the error term specific to the experimental unit (cow group) assigned to the *j*th treatment within the *i*th year.

Because cow body condition score data are discrete values with no unit cow body condition score data was analyzed using the Proc Glimmix procedure of SAS (2005). Proc Glimmix is used to fit statistical models to data with correlations or non-constant variability and where the response is not necessarily normally distributed (SAS Institute Inc. 2005).

Forage intake estimations were analyzed as a completely randomized design using the Proc Mixed procedure with data collected in 2008 only:

$$Y_{ij} = \mu + t_i + e_{ij}$$

where *i* is the treatment (supplementation), μ is the overall mean, t_i is the fixed effect to the *i*th treatment, and e_{ij} is the error term specific to the experimental unit (cow group) assigned to the *j*th treatment.

4.3. Results & Discussion

4.3.1. Forage utilization[1]

Estimated daily DM intake of barley straw-chaff residue was not affected ($P > 0.05$) by supplement program (Table 4.3). Average barley straw-chaff intake was 7.2, 6.9, and 7.5 kg per day ($P = 0.80$), or 1.14, 1.12, and 1.18% BW per day ($P = 0.92$) for DDGS, 50:50, and BARL supplemented cows, respectively. This level of intake is slightly lower than that predicted using NRC (1996) beef model in CowBytes, which estimated beef cows in the second trimester of pregnancy can consume 1.2% of BW as straw daily. Similarly, Males et al. (1982) reported beef cows consuming wheat straw, supplemented with barley grain and urea, consumed 1.2% BW as wheat straw. Forage intake can be affected by supplementation type, environment, and physiological status of the beef cow (Kartchner 1980; NRC 1996). In the current study, based on the calculated DE of the straw-chaff, cows would need to consume 11.8 to 12.9 kg of barley straw-chaff to meet calculated maintenance requirements of 8.87 to 9.72 Mcal of NE_m per day (NRC 1996). Because maximum intake of crop residue is approximately 1.2% BW (NRC 1996), or 7.6 kg for a 630 kg beef cow, an additional 3.18 to 4.03 Mcal of NE_m needs to be supplied to the animal daily. This additional energy was supplied as barley grain, DDGS, or both, thus meeting requirements but not affecting straw-chaff intake ($P > 0.05$).

The extent to which supplementation can influence forage DMI is known as substitution rate (Bowman and Sanson 2000). The substitution rate of a supplement is affected by forage characteristics and availability, level and type of supplement, and physiological state of the animal (Allden 1981; Broster and Thomas 1981). Bowman and Sanson (2000) found a strong relationship between substitution rate and crude protein content of forage. Greater substitution rates have been observed for supplements with greater

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[1] Forage utilization data for 2008 only

Table 4.3 Estimated forage intake of beef cows grazing barley straw-chaff^{z}

	Treatment^{y}				Graze Period^{x}				P value^{w}		
Item	DDGS	50:50	BARL	SEM	1	2	3	SEM	trt	gp	trt*gp
Dry matter intake, kg d^{-1}											
Supplement	4.3	4.3	4.3	N/A	4.0	4.0	5.0	N/A	N/A	N/A	N/A
Hay	2.3	2.3	2.3	N/A	0.0	0.0	7.0	N/A	N/A	N/A	N/A
Straw-chaff	7.2	6.9	7.5	0.56	7.4	7.6	6.6	0.56	0.80	0.44	0.74
Total	13.8	13.5	14.0	0.54	10.9b	11.8b	18.5a	0.54	0.84	<0.01	0.66
Dry matter intake, %BW											
Supplement	0.69	0.70	0.67	N/A	0.57	0.67	0.82	N/A	N/A	N/A	N/A
Hay	0.35	0.38	0.36	0.011	0.00b	0.00b	1.09a	0.011	0.29	<0.01	0.31
Straw-chaff	1.14	1.21	1.06	0.105	1.17	1.21	1.06	0.105	0.92	0.61	0.73
Total	2.18	2.20	2.21	0.121	1.73b	1.88b	3.00a	0.121	0.98	<0.01	0.64

[z] Dry matter intake data analyzed by CRD for 2008 data only

[y] DDGS = cows supplemented with 100% wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); 50:50 cows supplemented with 50% DDGS and 50% rolled barley grain; BARL = cows supplemented with 100% rolled barley grain

[x] Graze period: period 1 = 14 days; period 2 = 16 days; period 3 = 16 days

[w] trt = treatment effects; gp = graze period effects; trt*gp = treatment by graze period interaction

[a-b] Means with different letters in the same row are significantly different ($P < 0.05$) using Tukey's multi-treatment comparison method.

SEM = standard error of mean

concentrations of NSC and forages with low CP content (Meijs 1986; Faverdin et al. 1991; Bowman and Sanson 2000). Cereal grain supplementation is recognized to depress forage intake (Chase and Hibberd 1987; Zorrilla-Rios et al. 1991; Bodine and Purvis 2003; Bowman et al. 2004), however substitution as a result of barley grain supplementation was not observed in the current trial. In a review, Zorrilla-Rios et al. (1991) reported cereal supplementation greater than 20% of the diet had negative impacts on straw intake (Lamb and Eadie 1979; Gibb and Baker 1988), but if fed at less than 20% of the diet, straw intake was not affected or stimulated (Crabtree and Williams 1971; Fick et al. 1973; Mulholland et al. 1976; Leibholz and Kellaway 1984; Zorrilla-Rios et al. 1989). Average supplementation in 2008 was 32.5% (28.6% for both years) of the ration, based on CowBytes formulation program (1999), which could explain why estimated DMI was slightly lower than NRC (1996) predicted intake. However, similar forage intakes ($P = 0.80$) were observed for all treatment groups, indicating that barley grain and DDGS had comparable effects on forage intake.

While protein supplements are known to increase DMI of low quality forages (DelCurto et al. 1990b; Koster et al. 1996; Mathis et al. 1999; Olson et al. 1999), the high level of protein supplied by wheat-based DDGS in the current study had no effect ($P > 0.80$) on barley straw-chaff consumption. DelCurto et al. (1990b), Church and Santos (1981), and Beaty et al. (1994) have reported protein supplementation of low quality forages had a quadratic effect on forage dry matter intake. DelCurto et al. (1990b) supplemented pregnant cows grazing dormant tallgrass range with soybean meal-sorghum grain mixtures with increasing CP content at 0.5% BW daily. Church and Santos (1981) individually fed Holstein heifers chopped wheat straw and provided soybean meal daily to provide 0, 1, 2, 3, or 4 g CP per kg metabolic weight. Beaty et al. (1994) also fed wheat straw to ruminally fistulated steers while providing soybean meal-sorghum grain supplements with increasing CP concentration. All supplement strategies in the current trial supplied protein well in excess of CP requirements for mid-gestation beef cows. As such, protein supplementation may have exceeded the level where forage DMI would be improved. Total diet crude protein content was 19.6, 15.6, and 11.4% for DDGS, 50:50, and BARL treatments, respectively.

Forage intake response to energy and protein supplementation has been shown to be variable. Zorrilla-Rios et al. (1991) reported that increasing supplemental corn linearly decreased ($P < 0.01$) intake of ammoniated wheat straw while supplemental corn gluten meal (CGM) had no effect on straw dry matter intake. DelCurto et al. (1990b) observed a positive quadratic intake response of dormant tall-grass forage to increasing levels of protein when supplemental energy was maintained. However, Beck et al. (1992) reported only a tendency ($P = 0.09$) for increasing supplemental crude protein levels to increase intake of ammoniated wheat straw when supplements were isocaloric. Church and Santos (1981) observed a quadratic increase of wheat straw consumption from soybean meal supplementation, however energy supplied by the supplement was also increased. The lack of supplement effect on straw-chaff DMI in the current study agrees with Winterholler et al. (2009), who reported forage intake was not different ($P = 0.10$) between late-gestation beef cows supplemented with wheat middlings and cottonseed meal, cottonseed meal-based supplement, or extruded, expelled cottonseed meal-based supplements while grazing low quality tall-grass prairie hay. However, supplements in that experiment were isonitrogenous but had different energy values (70%, 80%, and 55% TDN, respectively). Dixon et al. (1981) reported barley straw intake was greater for steers supplemented with untreated canola meal than formaldehyde treated canola meal or fish meal, indicating an influence of the rumen degradability of the supplemental protein.

Estimated DMI of barley straw-chaff was not affected ($P > 0.05$) by grazing period (Table 4.3). Straw-chaff intake was anticipated to decrease when cows were supplemented with grass hay for 12 days during the final third of the trial in 2008. Hay supplementation began when straw-chaff intake was compromised by adverse weather and severe windchill factor (> 16 km h^{-1}; mean temperature -26.5°C). Grazing behaviour, as assessed by the herd person, was altered as the temperature decreased and wind chill factors came into effect. These observations agree with Adams et al. (1986) who reported daily grazing time decreased as mean temperature dropped. However, Prescott et al. (1994) did not observe significant fluctuations in grazing time with short term temperature stress in Montana, USA. Differences in grazing time may be affected by forage and shelter availability (Leaver 1985; Prescott et al. 1994), degree of acclimatization (Beverlin et al. 1989), photoperiod, or physiological state (NRC 1996). In this trial, a 1.0 kg per day decrease in straw-chaff intake was noted during the last 21 days of the trial.

The minimal decrease in straw-chaff intake when supplemental grass hay was fed indicates either a lack of sensitivity of the forage intake estimation technique or an inability to differentiate between forage consumed and forage lost due to trampling or dispersal. The observed behaviour when the cows were first allowed access to straw-chaff piles was to sort through the piles and consume mainly chaff and grain residue. After the most palatable material had been consumed, cows would use the remaining straw for bedding. This activity caused great dispersal of material, plausibly causing loss that may have been mistakenly considered intake. This lack of sensitivity in the estimation technique may have compromised the detection of intake differences as affected by supplementation strategy.

4.3.2. Cow performance

Cows supplemented with 100% DDGS or 50:50 DDGS:barley grain had greater ($P < 0.01$) positive BW change than cows supplemented with 100% rolled barley grain (Table 4.4). Cows supplemented with 100% DDGS, 50% DDGS: 50% rolled barley grain, or 100% rolled barley grain gained or lost an average of 11.3, 6.8, or -6.5 kg per head, respectively. These results agree with Beck et al. (1992), who reported cows supplemented with sorghum grain plus soybean meal had higher gains than those supplemented with equal levels of energy or protein as sorghum grain while consuming ammoniated wheat straw. Sanson et al. (1990) reported protein (0.72 kg TDN per day; 290 g protein per day) supplemented cows lost less weight than those receiving ear corn and protein (1.16 kg TDN per day; 290 g protein per day) or just ear corn (1.16 kg TDN per day; 127 g protein per day) while grazing native Sandhills winter range in Nebraska.

Zorrilla-Rios et al. (1991) reported the improvement in ADG for steers supplemented with CGM was greater than that calculated from the energy supplied by the CGM supplement. The authors contributed the difference in ADG was attributed to the RUP content of the supplement which increased the total flow of protein to the small intestine (Egan 1981) and supplied limiting amino acids to the animal (Tamminga 1980; Oldham 1982). Nuez-Ortin (2010) reported the RUP content of 70% wheat, 30% corn

Table 4.4 Effect of supplementation on beef cow performance

	Treatment[z]				
Item	DDGS	50:50	BARL	SEM	P value
Body weight[y], kg					
Initial	629.1	628.7	629.1	6.93	0.99
Final	640.4a	635.4ab	622.6b	5.85	0.04
Change	11.3a	6.8a	-6.5b	3.05	<0.01
Rib fat, mm					
Initial	4.8	4.8	5.3	0.23	0.29
Final	5.2	5.2	5.3	0.64	0.91
Change	0.4	0.5	0.0	0.78	0.62
Rump fat, mm					
Initial	5.0	5.6	5.7	0.77	0.77
Final	6.4	6.5	5.7	1.70	0.10
Change	1.5	1.0	0.1	1.16	0.10

[z] DDGS = cows supplemented with 100% wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); 50:50 cows supplemented with 50% DDGS and 50% rolled barley grain; BARL = cows supplemented with 100% rolled barley grain

[y] Cow BW was adjusted for conceptus gain

[a-c] Means with different letters in the same row are significantly different ($P < 0.05$) using Tukey's multi-treatment comparison method. SEM = standard error of the mean

blend DDGS was 63.8% of total crude protein. The digestibility of RUP in the small intestine could also affect cow performance. Although NRC (1996) assumes all RUP to be 80% digestible, MacDonald et al. (2007) found the digestibility of corn DDGS varied from 31 to 94 percent. Deficiencies in metabolizable protein (MP) are more likely to be met by more digestible RUP and animal performance is improved when MP requirements are met (MacDonald et al. 2007). Therefore, the greater ($P < 0.01$) positive BW change observed for cows supplemented with 100% or 50% DDGS may be due to the effects of RUP.

Males et al. (1982) reported BW change was directly related to daily intake of digestible dry matter. In the current study, there was no difference ($P > 0.05$) detected in total dry matter intake between treatment groups, yet DDGS supplemented cows gained more weight. Differences in cow BW gains may be the result of forage intake differences that were undetected by the DMI estimation technique. Alternatively, these results may indicate a difference in the calculated verses actual energy value of the supplements. The TDN value used by CowBytes Ration Formulation program for barley and DDGS were 90% (NRC 1996) and 88% (ALS Central Testing, Saskatoon, SK), respectively. Therefore, supplements fed on a unit to unit basis were considered to have similar energy levels (Table 4.2). However, according to the wet chemistry analysis, barley grain has a higher DE content (3.97 Mcal kg^{-1}) than DDGS (3.42 Mcal kg^{-1}; Table 4.1) as calculated by the Penn State equations for cereal grains (Adams 1995). Therefore, greater performance would be expected from cows supplemented with barley grain. However, the opposite result was observed, suggesting a greater energy value for DDGS than calculated from laboratory analysis. Similarly, Gibb et al. (2008) reported that the NE_g of wheat DDGS was higher than the value predicted by the DM digestibility of DDGS. Other studies (Firkins et al. 1985; Larson et al. 1993; Ham et al. 1994; Trenkle 1997) have reported the energy content of corn-based distillers' products greater than the energy value of corn grain, resulting in greater animal performance.

While protein is considered the most limiting nutrient of low quality forages (Kartchner 1980; DelCurto et al. 1990a; Freeman et al. 1992), studies have shown that gestating beef cows consuming low quality forages continue to lose BW and body condition in the winter feeding period even when protein requirements are met with concentrated protein supplements (Lusby et al. 1991; Marston et al. 1995; Banta et al. 2006; Steele et al. 2007). Conversely, Beck et al. (1992) reported that animal performance was improved when natural protein was supplemented despite protein requirements being met. The positive weight gain observed in the current study for cows supplemented with 100% or 50:50 DDSG:barley grain compared to cows supplemented with 100% barley grain further validates the value of DDGS as an energy supplement and protein supplement, regardless of which nutrient improves animal condition.

Despite the change in cow BW, there were no differences ($P > 0.05$) in body fat between treatment groups, although there was a tendency ($P = 0.10$) for DDGS and 50:50 supplemented cows to gain more condition in the rump location compared to barley supplemented cows (Table 4.4). MacDonald et al. (1999) reported hip fat depth to be more variable than rib fat depth over time. Furthermore, ultrasound measurements taken at the hip location were a more accurate predictor of body condition than measurements taken at the rib location (MacDonald et al. 1999).

There were no differences (P > 0.05) in BCS as a result of supplementation program (Table 4.5). This is not unexpected, as a BW change of 50 kg is required to detect a BCS change of 0.5 (Lowman et al. 1976). Winterholler et al. (2009) also reported no difference in BCS change as a result of variable energy and equal protein supplementation of beef cows consuming tall grass prairie hay in late gestation and early

Table 4.5 Effects of supplementation on body condition score (BSC) of beef cows grazing barley straw-chaff piles

	Treatment[z]				
BCS	DDGS	50:50	BARL	SEM[y]	P value
Start of trial (% of cows)					
2	6.2	3.1	9.4	0.13	0.62
2.5	59.4	75.0	50.0	0.25	0.18
3	34.4	18.8	21.9	0.23	0.36
3.5	0.0	3.1	18.8	0.10	0.26
4	0.0	0.0	0.0	0.00	1.00
End of trial (% of cows)					
2	3.1	6.5	3.1	0.11	0.77
2.5	50.0	54.8	59.4	0.26	0.76
3	46.9	35.5	31.2	0.26	0.45
3.5	0.0	3.2	6.2	0.07	0.86
4	0.0	0.0	0.0	0.00	1.00
Change (% of cows)					
-1	0.0	0.0	0.0	0.00	1.00
-0.5	9.4	12.9	23.3	0.04	0.34
0	65.6	58.1	50.0	0.05	0.49
0.5	25.0	29.0	23.3	0.05	0.87
1	0.0	0.0	3.3	0.01	1.00
1.5	0.0	0.0	0.0	0.00	1.00

[z] DDGS = cows supplemented with 100% wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); 50:50 cows supplemented with 50% DDGS and 50% rolled barley grain; BARL = cows supplemented with 100% rolled barley grain

[y] SEM = pooled standard error of the mean

lactation. Similarly, Males et al. (1982) did not find differences in BSC change between cows grazing 100% alfalfa, combinations of alfalfa and wheat straw, or wheat straw supplemented with barley-urea.

4.3.3. Economic analysis

Economic analysis of supplement strategies included feed and yardage costs associated with supplement strategy, infrastructure establishment and removal costs, equipment use, fuel, and labour. The DDGS (70:30 wheat:corn blend) was obtained from Husky Energy (Lloydminster, Saskatchewan, Canada) in September 2007. Wilbur Ellis priced the DDGS at $140 per tonne in September 2007 and $175 per tonne in September 2008. Rolled barley grain was priced at $194.27 per tonne in November 2007 and $236.52 per tonne in November 2008. Mineral and salt were purchased from FeedRite Ltd. (Humboldt, Saskatchewan, Canada) and priced at $24.47 per 25 kg and $4.75 per block in 2007 and $31.80 per 25 kg and $5.48 per block in 2008, respectively. Barley straw chaff was valued at $0.048 per kg of DM for both years. Labour was valued at $15.00 per hour (Saskatchewan Ministry of Agriculture (SMA) 2006). Equipment rates were obtained from the SMA (2006).

Because expenses are magnified in small research trials due to increased costs associated with data collection and managing multiple groups of animals, trial costs are also presented to more accurately represent industry costs by extrapolating actual research costs to a model herd size of 200 head. To account for increased time, labour, and equipment use required to manage a larger herd, yardage costs were adjusted $0.50 per cow per day. Supplementation strategy costs are presented in Table 4.6.

Average total costs were $0.77, $0.77, and $0.78 per head per day for DDGS, 50:50, and BARL, respectively ($0.81, $0.82, and $0.83 per head per day in 2007 and $0.72, $0.72, and $0.73 per head per day in 2008 for DDGS, 50:50, and BARL, respectively). The difference between the total costs between the two supplemented treatments is reflective of the price of the supplement. Therefore, producers may choose affordable supplements based on the current market value. However, because cows supplemented with DDGS had positive BW change ($P < 0.01$) compared to cows supplemented with barley grain, producers may consider using wheat-based DDGS as a

Table 4.6 Economics of wintering beef cows on barley straw-chaff

	DDGS		50:50		BARL	
Item	2007	2008	2007	2008	2007	2008
Feed costs[z]			$ hd^{-1} d^{-1}			
DDGS[y] supplement	0.05	0.06	0.02	0.03	-	-
Barley grain supplement	-	-	0.03	0.04	0.07	0.08
Grass hay	0.03	0.01	0.03	0.01	0.03	0.01
Mineral	0.01	0.01	0.01	0.01	0.00	0.01
Limestone	-	-	-	-	-	-
Salt	-	-	-	-	-	-
Barley straw-chaff	0.02	0.02	0.02	0.02	0.03	0.02
Total feed costs	0.11	0.11	0.12	0.11	0.13	0.12
Yardage costs						
Machinery cost (incl. fuel)	0.15	0.09	0.15	0.08	0.15	0.08
Labour	0.05	0.03	0.05	0.03	0.05	0.03
Total yardage costs	0.70	0.61	0.70	0.61	0.70	0.61
Total production costs	0.81	0.72	0.82	0.72	0.83	0.73

[z] Feed prices are presented in Appendix Table A.13

[y] DDGS = wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend)

supplement strategy for cows grazing cereal crop residue based on improved performance, as well as its cost benefits.

4.4. Conclusion

When pregnant beef cows graze cereal crop residue in the winter, supplementation is necessary to meet daily nutrient requirements. No supplement effect ($P > 0.05$) was seen on forage DMI, possibly because differences were not detected by the estimation technique used. However, if forage intake was not altered by supplement strategy, straw-chaff consumption may have been equally depressed by the energy supplied by each supplement or protein may have been overfed in all treatments such that forage intake improvements were not detected.

Cow BW change was greater ($P < 0.01$) for cows supplemented with 100% or 50% DDGS compared to cows supplemented with 100% barley grain. These improvements in cow BW suggest a greater energy content of DDGS than that estimated by laboratory wet chemistry techniques. This would suggest that DDGS supplied more energy than barley grain when fed on a 1:1 unit to unit basis. There are discrepancies in the literature as to whether improved animal performance can be attributed to energy or protein supplementation while cattle consume low quality forages. Regardless, DDGS is high in both protein and energy, and therefore has great potential as a supplement for beef cows grazing barley straw-chaff residue. A slight economic advantage was noted when DDGS was included in supplement program. Considering the improved performance of beef cows supplemented with DDGS as well as the price advantage on the initial commodity, wheat-based DDGS may prove advantageous for producers managing dry, pregnant beef cows on barley straw-chaff.

5. Effect of supplement on forage intake and digestibility, passage rate, rumen metabolism, and rate and extent of forage degradation

5.1. Introduction

Supplementation is often required to maximize the use of low quality forages in ruminant diets. In a review, McCollum and Horn (1990) reported that improvements in animal performance as a result of supplementation are generally a result of increased forage intake. Several studies have documented the positive effects of protein supplementation on forage intake (Chase and Hibberd 1987; Stokes et al. 1988; DelCurto et al. 1990b; DelCurto et al. 1990a; Bandyk et al. 2001; Arroquy et al. 2004). Increased forage intake is often associated with improved forage digestion and increased particulate passage rate (McCollum and Galyean 1985b; Guthrie and Wagner 1988; McCollum and Horn 1990; Beaty et al. 1994; Koster et al. 1996; Mathis et al. 1999). It is widely accepted that protein supplementation relieves N deficiencies within the rumen, supporting microbial growth, thereby optimizing rumen fermentation and facilitating forage digestion.

Cellulolytic bacteria are the main organisms responsible for forage digestion. As such, maintaining favourable rumen conditions for cellulolytic bacteria is crucial for maximizing the utilization of low quality forages. Ideal rumen pH is between 6.3 and 6.8 (Hiltner and Dehority 1983; Hoover 1986), while the threshold pH below which cellulolysis is inhibited is 6.0 to 6.1 (Mould and Ørskov 1983; Mould et al. 1983). Ruminal ammonia-N (NH_3-N), the main source of N for microbial protein synthesis, results from microbial degradation of RDP (Heldt et al. 1999; Mathis et al. 2000; Reed et al. 2007). Satter and Slyter (1974) suggested 2 to 5 mg/dL of ruminal NH_3-N is required for maximal bacterial synthesis *in vitro*, while Mehrez et al. (1977) concluded 19 to 23 mg/dL would result in maximal forage digestion.

The rate and extent of forage degradation refers to how quickly and completely forage is broken down by rumen bacteria. Forages are fractionated into three degrees of degradation: 1) immediately soluble (S); 2) potentially degradable (D); and 3) undegradable (U) (Orskov and McDonald 1979; Robinson et al. 1986). The rate of degradation (Kd) describes how much feed can be digested in a unit of time (Van Soest 1994). Alternatively, the extent of degradation considers how much forage would be degraded by the microbes if it was left in the rumen indefinitely and is the sum of the soluble and potentially degradable fractions. Effective degradability (ED) is the amount of forage that would be actually degraded in the rumen accounting for passage rate (Kp) and Kd (Orskov et al. 1980). Rumen environment, forage solubility, and microbial activity can impact forage degradation within the rumen (Van Soest 1994). Therefore, supplementation can influence the rate and extent of forage degradation as well as the rate at which feedstuff leaves the rumen.

As ethanol production continues to increase in western Canada, wheat DDGS and wheat-corn DDGS blends will continue to become more available to beef producers. Due to their nutritional density, there is potential to use DDGS as a supplement for beef cows consuming low quality forages. As such, the objectives of this experiment were to determine the effects of different supplements including wheat-based DDGS on the voluntary dry matter intake, digestibility, and passage rate of low quality forages. The effect of supplement on rumen pH and ammonia-N concentrations, as well as the rate and extent of forage degradation were also investigated.

5.2. Materials & Methods

5.2.1. Animals, housing, & experimental design

Four ruminally fistulated Hereford cross heifers (BW±SD; 630±39 kg) were housed in individual pens (3.6 m x 3.6 m) with rubber mats for footing in the Department of Animal and Poultry Science’s Livestock Research Barn on the University of Saskatchewan campus (Saskatoon, Saskatchewan, Canada). The average temperature in the barn was 17.6°C, 18.8°C, 14.4°C, and 12.6°C for periods 1 through 4, respectively. Each heifer received an intramuscular injection of Vitamin AD-500 Injection (Vetoquinol Canada, Inc) prior to the start of the trial. Guidelines for animal care (Canadian Council on Animal Care 1993) were followed at all times for all animals in this experiment.

A 4X4 Latin Square design was used to determine the voluntary intake, digestibility, rumen fermentation parameters, and passage rate of four diets. Each period was 24 d long and consisted of a 10 d dietary adaptation period, 7 d voluntary intake period, and 7 d collection period. Heifers were adjusted to the barn environment and the basal forage ration for 15 d prior to the start of the trial. The basal forage ration consisted of 75% ground barley straw and 25% ground grass hay. Forages were ground using a tub grinder (Haybuster H-1000) fitted with a 7.6 cm and 10.2 cm screen. Each heifer randomly received each diet for one 24 d period. Heifers were fed twice daily at 0800 and 1600 hours. The animals were fed to voluntary intake levels throughout the trial, with the exception of three days of restricted feeding at the beginning of the collection period. Water was available *ad libitum* via automated watering bowls throughout the trial.

5.2.2. Treatment diets

Four treatment diets consisted of the basal forage (75:25 straw:hay) supplemented with 1) dried distillers' grains with solubles (DDGS); 2) commercial range pellet (COMM); 3) rolled barley grain and canola meal (BAR+CM); or 4) control – no supplement (CONT). Chemical composition of all ingredients is shown in Table 5.1. Diets with supplements were formulated to be isocaloric and isonitrogenous. Due to the nature of the forage, the CONT diet was deficient in both energy and CP (Table 5.2). Supplements were fed at 0745 each morning and were topdressed with 28 g of cobalt-iodized salt (97.0% salt (min), 38.5% Na, 150 ppm I, 100 ppm Co; Federated Co- operatives Ltd, Saskatoon, Saskatchewan, Canada) and 57 g of mineral (16.0% Ca, 8.0% P, 4.0% Na, 5.0% Mg, 30 ppm Se, 10 100 ppm Zn, 70 ppm I, 5500 ppm Fe, 4650 ppm Mn, 3050 ppm Cu, 35 ppm Co, 3000 ppm Fl (max), 500 000 IU/kg Vitamin A (min), 50 000 IU/kg Vitamin D_3 (min), 1500 IU/kg Vitamin E (min); Federated Co-operatives Ltd, Saskatoon, Saskatchewan, Canada). Mineral supplementation was withheld on day 17 – 24, as digestibility was determined using acid insoluble ash as an internal marker. Forages were fed after supplements had been consumed at 0800. Supplements were typically consumed completely before forage was fed.

5.2.3. Data collection

Following a 10 d dietary adjustment period, voluntary intake was determined over 7 d (d 11-17) by weighing all feed and orts. Orts were collected daily and composited by heifer within period. Once voluntary intake was determined, heifers were restrictived to 90% of *ad libitum* intake for 3 d (d 18 to 20) to estimate digestibility using acid insoluble ash (AIA) as an internal marker. Any orts remaining were deposited directly into the

Table 5.1 Chemical composition of forages and supplements fed to heifers

Nutrient	Forage		Supplements			
	Barley straw	Grass Hay	DDGS	Commercial range pellet	Barley grain	Canola meal
DM (%)	96.6	96.4	92.4	92.8	91.4	92.7
CP (% DM)	6.3	11.7	39.0	38.7	12.2	43.5
NDF (% DM)	77.9	67.1	52.0	26.9	14.5	30.2
ADF (% DM)	50.7	43.5	21.4	12.8	5.0	20.6
ADL (% DM)	8.1	9.5	-	-	-	-
Phosphorus (% DM)	-	-	0.83	0.77	0.29	1.03
Sulfur (% DM)	-	-	0.72	0.84	0.23	1.32
NDIN (% N)	-	-	3.8	1.0	0.1	0.9
ADIN (% N)	7.6	17.0	-	-	-	-
IVOMD (% DM)	55.5	62.5	86.7	90.1	91.7	86.6
DE (Mcal kg^{-1} DM)	2.0	2.3	3.2	3.5	3.7	3.2

Table 5.2 Ingredient and chemical composition of treatment rations[z]

	Treatment[y]			
	DDGS	COMM	BAR+CM	CONT
Ingredients	% of ration DM			
Straw	67.8	67.8	65.2	75.5
Hay	22.6	22.6	21.7	23.6
DDGS	8.5	-	-	-
Commercial range pellet	-	8.5	-	-
Rolled Barley	-	-	4.8	-
Canola Meal	-	-	7.2	-
2:1 Mineral	0.5	0.5	0.5	0.5
Salt	0.5	0.5	0.5	0.5
Chemical Composition[x]				
CP (% DM)	10.2	10.2	10.4	7.5
NDF (% DM)	72.4	70.3	68.2	74.7
ADF (% DM)	46.0	45.3	44.2	48.5
Lignin (% DM)	7.6	7.6	7.3	8.3
TDN (% DM)	48.9	49.8	51.0	46.3
DE (Mcal kg^{-1} DM)	2.1	2.2	2.2	2.0

[z] Rations formulated using CowBytes Beef Ration Balancer Program. Version 4. (Alberta Agriculture Food and Rural Development 1999)

[y] DDGS = heifers supplemented with wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); COMM = heifers supplemented with commercial range pellet; BAR+CM = heifers supplemented with rolled barley grain and canola meal; CONT = heifers received no supplement

[x] Calculated from average nutrient composition of ingredients.

rumen prior to feeding the next day. Fecal samples were collected at 0800, 1200, 1600, and 2000 hours on d 19 to 22 and immediately dried at 55°C for 48 h, ground through a 1mm screen (Retsch ZM-1 grinder, Haan, Germany) and composited by heifer within each period.

On the first day of restricted feeding (d 18), 200 g of ytterbium (Yb) labeled forage prepared by immersion (Mader et al. 1984) was dosed directly into the rumen to measure total tract passage rate. Fecal samples were collected at 0, 4, 8, 12, 16, 20, 24, 28, 32, 36, 48, 52, 56, 60, 72, 76, 80, 84, 96, 100, 104, and 108 h post dosing (Vogel et al. 1989). The fecal samples were immediately dried at 55°C for 48 h and ground through a 1 mm screen (Retsch ZM-1 grinder, Haan, Germany).

On d 21 of each period, rumen fluid was sampled every 2 h for 12 h beginning at 0800 h, prior to supplement feeding. The samples were collected from three locations of the rumen (cranial-ventral, ventral, and caudal ventral) as well as a sample from the rumen mat. All four samples in combination were strained through four layers of cheesecloth and the fluid was pH tested (Model 265A portable pH meter; Orion Research Inc., Beverly, MA, USA) in duplicate and sub-sampled (10 ml) into test tubes. Fluid samples were acidified with 2 ml of 50% H_2SO_4 and frozen for future rumen ammonia-N analysis.

Also on d 21, beginning at 2000 h, forage ground through a 2 mm screen (Christie-Norris Laboratory Mill, Christie-Norris Ltd. Chelmsford, UK) was incubated *in situ* for 72 h to determine the rate and extent of forage degradability for each diet. Nylon bags (40 μm pore size) containing 5.25 (75%) and 1.75 (25%) g of ground straw and hay, respectively, were incubated for 0, 2, 4, 8, 12, 24, 48 and 72 h in each heifer's rumen using the gradual in, all out procedure (Yu 2005). All bags were removed at 2000 h on d 24. After removal, the sample bags were immediately submerged in cold water to stop digestion. Bags were rinsed 6 times in cold water (McKinnon et al. 1991) and dried at 55°C for 48 h. Forage residue was weighed and composited by incubation time for a total of 8 samples per heifer per period. Prior to laboratory analysis, *in situ* residue material was re-ground through a 1 mm screen (Retsch ZM-1 grinder, Haan, Germany).

Forage samples were collected weekly and supplement samples were collected every 2 weeks throughout the trial. Forage samples were dried at 55°C for 72 h to determine DM content and ground through a 1 mm screen (Christie-Norris Laboratory Mill, Christie-Norris Ltd. Chelmsford, UK). Supplement samples were also ground through a 1 mm screen using a Retsch ZM-1 grinder (Haan, Germany). Straw, hay, and supplement samples were composited by period prior to laboratory analysis.

5.2.4. Laboratory analysis

Feed, ort, *in situ*, and fecal samples were analyzed for moisture, CP, NDF, ADF, IVDMD, and IVOMD. Forage and *in situ* samples were also analyzed for ADL and ADIN, while the supplements were analyzed for NDIN, phosphorus, and sulfur. Analyses were completed as outlined in Experiment I with the exception of CP, which was analyzed for N content using a combustion N analyzer (Leco FP-528, Leco Corporation, St. Joseph MI).

Yb-labeled forage and fecal samples collected at 0, 4, 8, 12, 16, 20, 24, 28, 32, 36, 48, 56, 72, and 80 h post-dosing were analyzed for Yb according to the procedure of Lopez Molinero et al. (1988) as modified by Vicente et al. (2004). The natural logarithm of the Yb concentration was regressed against time for fecal samples collected post dosing (Titgemeyer et al. 2004). Natural logarithms were used to normalize the data and remove variations that were outside the laws of statistics and to create a linear line for regression analysis. The negative slope of the natural logarithm is the estimated total tract passage rate (% hr^{-1}).

Composited feed samples from each period as well as composited fecal samples collected on d 18 to 22 were analyzed for acid insoluble ash to determine digestibility (Van Keulen and Young 1977). Digestibility was calculated using the following equation (Cochran and Galyean 1994):

$$Digestibility\ (\%) = 100 - 100 * \left[\left(\frac{marker\ in\ feed}{marker\ in\ feces} \right) * \left(\frac{nutrient\ in\ feces}{nutrient\ in\ feed} \right) \right]$$

Rumen fluid samples were thawed and centrifuged (Beckman Centrifuge; Model TJ-6; Palo Alto, CA, USA) at 10 000 rpm for 10 m prior to ammonia nitrogen (NH_3-N) analysis. The phenol-hypochlorite method was used (Broderick and Kang 1980).

5.2.5. Data analysis

In situ data were fitted to the modified first order kinetics equation with lag time to determine rate and extent of forage degradation (Orskov and McDonald 1979; Robinson et al. 1986):

$$R(t) = U + D^{(-Kd*(t-T0))}$$

where R (*t*) = residue of the incubated material after *t* hours of rumen incubation (g/kg); U = undegradable fraction (%); D = potentially degradable fraction (%); T0 = lag time (h); and Kd = degradation rate (% h^{-1}).

Effective degradability (ED; g kg^{-1}) of DM, CP, NDF, and ADF was determined using the nonlinear (NLIN) parameters calculated by the above equation (U, D, and Kd):

$$ED = S + D * \left[\frac{Kd}{(Kp + Kd)} \right]$$

where S = soluble fraction (%) as determined by the samples incubated for 0 h and KP = rate of passage (4.0% h^{-1}; Yu et al. 2004).

Intake, total tract digestibility, rumen fermentation parameters (pH and NH_3-N), and passage rate were analyzed using Latin square design with period and heifer as random effects. The Proc Mixed Model procedure of SAS was used to complete statistical analysis (SAS Institute Inc. 2003). Means were separated using Tukey’s multi-treatment comparison method (Saxton 1998) and differences were considered significant when $P < 0.05$. The experimental model was:

$$Y_{ijk} = \mu + \rho_i + \delta_j + \alpha_k + e_{ijk}$$

where μ is the overall mean, ρ_i is the fixed effect of the *i*th period, δ_j is the random effect of the *j*th cow, α_k is the fixed effect of the *k*th treatment, and y_{ijk} is the observation for the experimental unit in the *i*th period, *j*th cow, and the *k*th treatment effect. Calculated values for Kd, T0, S, D, U, and ED of DM and NDF were analyzed in a similar fashion.

5.3. Results & Discussion

5.3.1. Voluntary dry matter intake

Total intake was greater ($P = 0.02$) for heifers fed supplemented diets compared to the heifers fed the unsupplemented control diet however forage intake did not differ ($P > 0.05$) across treatments (Table 5.3). Because there was no difference in forage intake, total intake differences are reflective of supplement amount fed.

Despite supplementation, DMI of forage was not different ($P > 0.05$) across treatments. Similar to the barley grain and canola meal supplement in this study, Winterholler et al. (2009) fed a greater quantity of wheat middlings-cottonseed meal supplement compared to cottonseed meal and found no resulting difference ($P = 0.10$) in forage intake. These results are comparable to those of Ferrell et al. (1999), who reported intake of bromegrass hay (4.3% CP; 73.9% NDF) was not affected by supplementation of energy (cornstarch, molasses, and soybean oil), energy plus urea, energy plus soybean meal (SBM), or energy plus ruminally undegraded protein (RUP; 50:50 mixture of blood and feather meals). The authors suggested intake response to supplementation may only

Table 5.3 Effect of supplement on voluntary dry matter intake, apparent total tract digestibility, and particulate matter passage rate

	Treatment[z]					
Item	DDGS	COMM	BAR+CM	CONT	SEM	P value
Forage intake (DM)						
kg d^{-1}	7.4	7.5	7.4	7.0	0.25	0.42
% BW	1.16	1.18	1.19	1.13	0.034	0.50
Supplement intake						
kg d^{-1}	0.75	0.75	1.08	0.00	N/A	N/A
% BW	0.11	0.12	0.17	0.00	N/A	N/A
Total intake						
kg d^{-1}	8.2a	8.2a	8.4a	7.0b	0.32	0.02
% BW	1.29a	1.30a	1.34a	1.13b	0.044	0.02
Apparent total tract digestibility						
DM (%)	63.4	61.1	61.6	56.0	2.9	0.41
CP (% DM)	63.9a	61.8a	62.5a	46.4b	3.2	0.02
NDF (% DM)	65.0	61.8	62.6	59.0	2.9	0.56
ADF (% DM)	58.9	56.2	56.6	52.0	3.1	0.51
Particulate passage rate (% h^{-1})	4.2	3.8	4.1	3.2	0.58	0.29

[z] DDGS = heifers supplemented with wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); COMM = heifers supplemented with commercial range pellet; BAR+CM = heifers supplemented with 4.8% rolled barley grain and 7.3% canola meal; CONT = heifers received no supplement

[a-c] Means with different letters in the same row are significantly different ($P < 0.05$) using Tukey's multi-treatment comparison method. SEM = standard error of mean

be observed if forage intake is low before supplementation. Similarly, Bohnert et al. (2002b) concluded the lack of supplementation effect on forage intake was due to an already high NDF intake in the unsupplemented control steers consuming low quality meadow hay (5% CP; 61% NDF; 31% ADF). Reed et al. (2007) reported intake of forage OM was not different when steers were supplemented with low, medium, or high levels of RUP and equal levels of energy and RDP compared to steers receiving no supplement. These authors hypothesized that prairie grass hay (6% CP; 69.1% NDF) provided adequate RDP or, alternatively, that sufficient N recycling occurred to prevent forage intake reductions. In the current study, average straw quality was higher than expected, thus the basal forage diet was higher quality than anticipated. Initial formulation of diets using CowBytes diet formulation software indicated the basal ration (no supplement) was 6.0% CP and 77.5% NDF. However, based on the average nutrient composition of straw and hay collected throughout the trial, the basal ration was 7.5 % CP and 74.7% NDF (Table 5.2). Based on these data, crude protein levels supplied on average were adequate to meet the requirements of non-pregnant, non-lactating beef heifers (NRC 1996). Therefore, forage quality was not likely to limit forage intake, thus reducing supplemental effects on forage intake (Ferrell et al. 1999; Reed et al. 2007).

When supplemented with DDGS, commercial range pellet, or barley grain and canola meal, forage intake of heifers was 7.4, 7.5, and 7.4 kg per day, respectively. Without any supplement, heifers ate 7.0 kg of forage per day. Beck et al. (1992) also found forage intake increased numerically (P = 0.09) when natural protein was supplemented beyond nutritional requirement in an isocaloric supplemented diet of ammoniated wheat straw. Conversely, other studies have reported protein supplementation of low quality forages typically increases forage intake (Guthrie and Wagner 1988; Stokes et al. 1988; DelCurto et al. 1990b; Beaty et al. 1994; Koster et al. 1996; Arroquy et al. 2004). McCollum and Gaylean (1985b) speculated that protein supplementation supplied N to rumen microbes, facilitating fibre digestion. Results from their study supported Ellis (1978), who suggested N supplementation increased forage digestion and particulate passage rate, resulting in increased intake. Other authors (Egan 1965; Redmon et al. 1980; Ketelaars and Tolkamp 1992; Kempton et al. 1997) have speculated about the metabolic effects of protein supplementation on forage intake, including alterations in rumen fermentation, increased N flow to the intestines, and changes to host nutrient status.

5.3.2. Apparent total tract digestibility

The apparent total tract digestibility of CP was greater (P = 0.02) for supplemented treatments than the control diet (Table 5.3). Bhatti et al. (2008) found apparent total tract CP digestibility was increased when orchardgrass was fed with alfalfa in a 3:1 ratio. Similarly, protein supplementation increased apparent total tract N disappearance as a result of increased intestinal digestion in a study by Bohnert et al. (2002b). Increased CP digestibility for the supplemented diets is likely a function of the increased CP content in the diets and the greater digestibility of CP from the supplement compared to CP from forage (Stern et al. 1983). Some studies (Church and Santos 1981; Hannah et al. 1991; Koster et al. 1996) have found a negative apparent CP digestibility in unsupplemented animals consuming low quality forages. This may indicate the occurrence of N recycling, where endogenous blood urea-N is transferred into the rumen to supply N for ruminal microbes as a result of low N intake (Egan 1980; Kennedy and Milligan 1980; Bunting et al. 1989). In the current study, CP digestibility of the CONT diet was 46.4%, suggesting that the basal ration did not require extensive N recycling because CP requirements were being met.

Apparent total tract digestibility of DM, NDF, and ADF did not differ (P > 0.41) between diets (Table 5.3). These results agree with those of Reed et al. (2007), who found total tract digestibility of NDF and ADF was unaffected (P > 0.11) when grass hay (6% CP; 69% NDF) was supplemented with graded levels of RUP. Bhatti et al. (2008) saw no difference (P > 0.23) in apparent total tract digestibility of DM, NDF, ADF, cellulose, and hemicellulose when orchardgrass hay was fed with or without alfalfa (3:1 ratio, respectively). Likewise, Lintzenich et al. (1995) and Hannah et al. (1991) found no difference (P > 0.10) in NDF digestibility between steers consuming dormant bluestem forage supplemented with various forms of alfalfa or soybean meal and sorghum grain or not supplemented. However, Lintzenich et al. (1995) noted a tendency for NDF digestibility to increase as a result of alfalfa supplementation. Conversely, while there was no difference in DM digestibility of ammoniated wheat straw, Beck et al. (1992) found NDF digestibility was decreased (P = 0.05) when sorghum grain and/or soybean meal were supplemented. These authors suggested the reduced NDF digestibility was a result of decreased ruminal pH, which limited rumen microbial growth.

5.3.3. Total tract particulate passage rate

Total tract particulate passage rate was not affected ($P = 0.29$) by supplement strategy (Table 5.3). These results were not unexpected since forage DM intake did not differ ($P > 0.05$) among diets fed. Particulate passage rate and forage DM intake have been found to be positively correlated (Thornton and Minson 1973; McCollum and Galyean 1985b; Guthrie and Wagner 1988). However, several studies (Judkins et al. 1987; Stokes et al. 1988; Beck et al. 1992) have found passage rate and forage intake were unaffected ($P > 0.05$) by supplementation of low quality forages.

Average passage rate for all diets, as determined by pulse dosing Yb-labeled forage, was 3.84% per hour. This is similar to the values of Chase and Hibberd (1989), who found particulate passage rate (3.7, 3.9, 3.5, 3.4% h^{-1}; $P = 0.19$) was not affected by level or frequency of maize supplementation of low quality grass hay (5.0% CP). Judkins et al. (1987) also observed similar values of 4.29, 3.35, 3.36% h^{-1} ($P > 0.05$) when ruminally cannulated steers grazing blue gamma (8.6% CP; 66.7% NDF) rangeland were supplemented with pelleted alfalfa, cottonseed meal, or no supplement, respectively. While passage rates were lower (2.2, 2.5, 2.4, 2.4% h^{-1}) for beef cows consuming prairie grass hay (5.6% CP), supplementation with either cottonseed meal and/or corn grain was not different ($P > 0.05$) from the control (Freeman et al. 1992). Conversely, Stokes et al. (1988) found a linear ($P < 0.05$) increase in particulate passage rate (2.21, 3.01, 3.31% h^{-1}) when prairie hay (4.8% CP; 73% NDF) was supplemented with graded levels of soybean meal. Similarly, Guthrie and Wagner (1988) observed a linear ($P < 0.01$) increase (2.08, 2.17, 2.63, 2.86, 3.47% h^{-1}) when supplementing prairie hay (5.2% CP) with soybean meal- or grain-based supplements. Arroquy et al. (2004) also noted linear increases in passage rate when grass hay (5.1% CP; 76.2% NDF) was supplemented with graded levels of casein dosed intraruminally. McCollum and Galyean (1985b) found total mean retention time was reduced when beef steers consuming prairie hay (6.1% CP; 67.7% NDF) were supplemented with cottonseed meal. Finally, Sunvold et al. (1991) reported ruminal indigestible ADF passage rate increased ($P < 0.10$) when dormant bluestem hay (2.0% CP; 78.5% NDF) was supplemented with soybean meal and sorghum grain, a low level of 100% wheat middlings, or a high level of 100% wheat middlings.

5.3.4. Ruminal pH & ammonia nitrogen

There was no effect ($P = 0.20$) of supplement on ruminal pH when rumen fluid was sampled at varying intervals (Figure 5.1). This lack of effect is likely due to the low level of supplement in relation to total feed intake (Freeman et al. 1992). However, typical diurnal patterns were observed, with ruminal pH dropping post-feeding, then recovering. Judkins et al. (1987) observed similar ruminal pH patterns ($P > 0.10$) when blue gamma range (8.6% CP; 66.7% NDF) was supplemented with alfalfa pellets and cottonseed meal cake. In the current study, ruminal pH ranged from 6.38 to 6.76 (Figure 5.1). These levels are suitable for the normal function of cellulolytic bacteria (Mould and Ørskov 1983; Mould et al. 1983; Hoover 1986) and above the threshold of acidosis (pH ≤ 5.8; Beliveau 2008). Average ruminal pH levels found in the current study are similar to those found in other studies (McCollum and Galyean 1985b; Stokes et al. 1988; Sunvold et al. 1991; Beck et al. 1992; Freeman et al. 1992; Koster et al. 1996) when low quality forages were supplemented. However, effect of supplementation has been variable.

Freeman et al. (1992) found ruminal pH (mean = 6.3) was not affected ($P > 0.10$) when beef steers were supplemented with either cottonseed meal or corn grain consuming prairie hay (5.8% CP). McCollum and Galyean (1985b) did not see an effect ($P > 0.10$) of supplementation on ruminal pH (range 6.2 to 6.5) when supplementing steers consuming prairie hay (6.1% CP; 67.7% NDF) with soybean meal. Conversely, Stokes et al. (1988) found a linear trend ($P < 0.10$) for average ruminal pH (6.51, 6.42, 6.41) to decline as soybean meal supplementation of prairie hay (4.8% CP; 73% NDF) increased. Compared to the unsupplemented control (pH = 6.65), Beck et al. (1992) noted only a tendency ($P = 0.10$) for ruminal pH to decrease (6.50, 6.43, 6.54) when ammoniated wheat straw was supplemented with a low level sorghum grain, a high level of sorghum grain, or sorghum grain and soybean meal, respectively. However, sorghum grain and soybean meal supplementation of dormant bluestem range forage (2.0% CP; 78.5% NDF) lowered ($P < 0.01$) ruminal pH in a study by Sunvold et al. (1991). Koster et al. (1996) also saw a decline ($P < 0.01$) in rumen pH as a result of RDP (casein) supplementation of tallgrass prairie hay (1.9% CP; 77% NDF). Based on these results, it is evident that any effect on ruminal pH will depend on forage quality and type and amount of supplement.

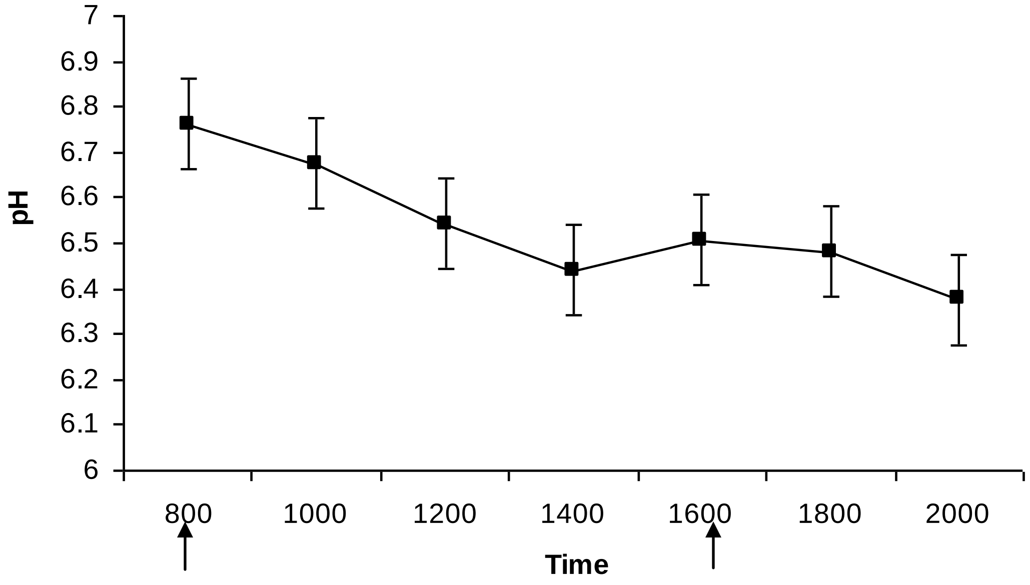


Figure 5.1 Average rumen pH over time (P values: treatment = 0.20; time < 0.01; treatment x time = 0.15; arrows represent feeding times)

Supplemented diets had higher ($P < 0.01$) rumen NH_3-N concentrations than the control diet (Figure 5.2). This agrees with previous research where supplementation of forage diets resulted in higher NH_3-N concentrations than unsupplemented controls (McCollum and Galyean 1985b; Guthrie and Wagner 1988; Stokes et al. 1988; Hunt et al. 1989; Beck et al. 1992; Koster et al. 1996). However, there was no difference ($P > 0.05$) between the DDGS, COMM, and BAR+CM supplemented diets. Ruminal NH_3-N values were affected ($P < 0.01$) by sampling time, paralleling the diurnal patterns observed in ruminal pH measurements. Previous research indicates that peak NH_3-N concentrations are generally observed 1 to 3 h after feeding (McCollum and Galyean 1985b; Stokes et al. 1988; Koster et al. 1996). In the current study, peak NH_3-N occurred at 2 h post feeding for all treatment diets. Stokes et al. (1988) theorized the post- feeding peak of NH_3-N was a result of rapid liberation of N from supplements and slow initiation of ruminal forage digestion.

In this study, average ruminal NH_3-N concentration was 1.13 mg/dL for the CONT treatment. Satter and Slyter (1974) suggested 2 to 5 mg/dL ruminal NH_3-N was required *in vitro* for maximal bacterial synthesis. As such, microbial efficiency may have been compromised for the control diet. While available ruminal NH_3-N is important for fibre

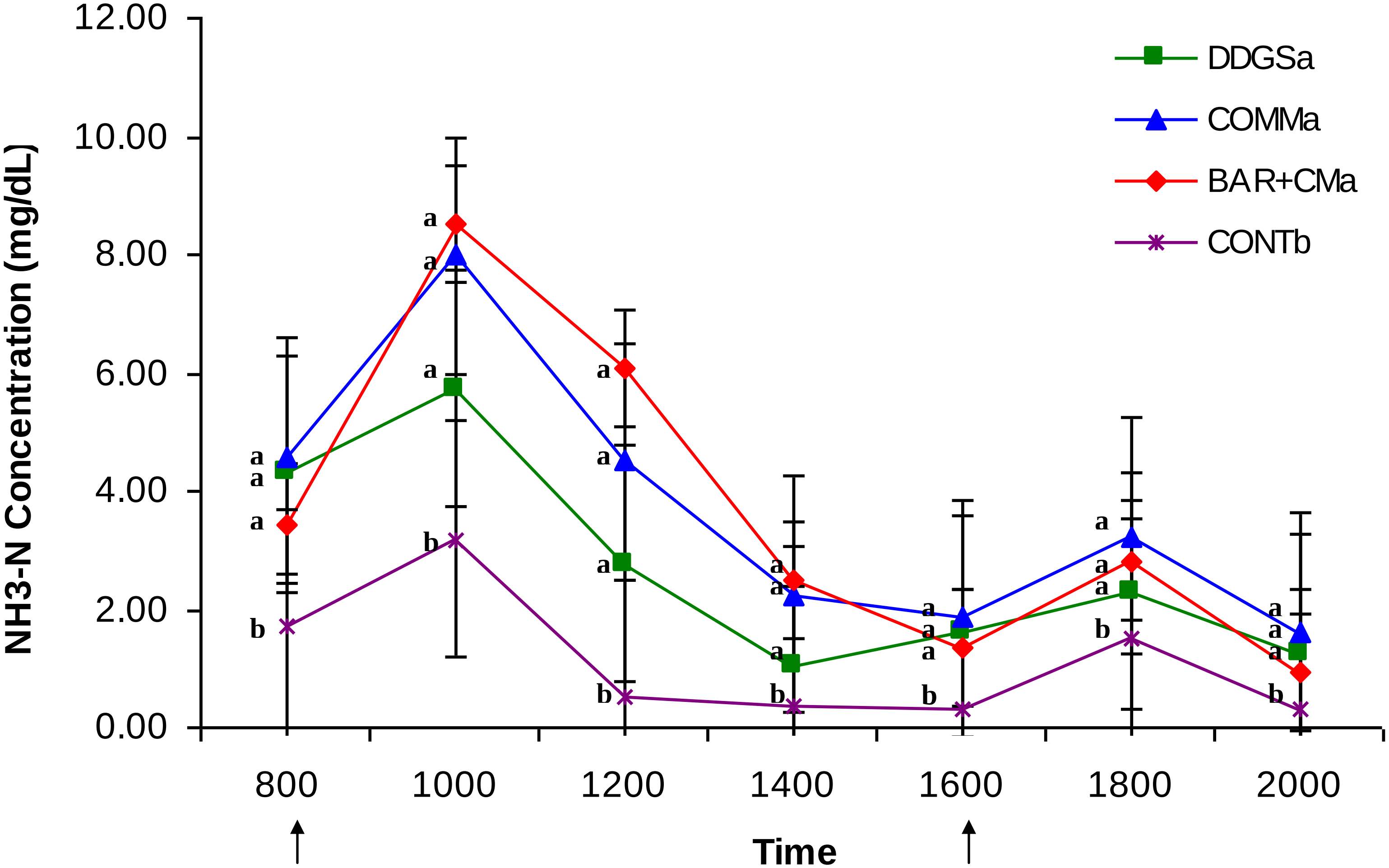


Figure 5.2 Effect of supplementation on ruminal ammonia-N concentration (P values: treatment < 0.01; time < 0.01; treatment x time < 0.01; arrows represent feeding times)

digestion (McCollum and Horn 1990; Mathis et al. 2000), digestibility of DM, NDF, and NDF were not lower ($P > 0.5$) for the control diet compared to the supplemented diets. Furthermore, forage intake was similar ($P > 0.05$) for all diets. Apparent crude protein digestibility was not negative for any of the supplemental diets, including the control, suggesting that CP requirements were being met by the basal forage (straw and hay). Therefore, while rumen microbial synthesis may not have been maximized, it was likely not compromised to any extent which may have affected rumen function.

5.3.5. Rate & extent of forage degradation

On d 21 to 24 of each period, forage was incubated in the rumen to determine the effect of supplementation on the rate and extent of forage DM and NDF degradation. The D fraction of DM and NDF decreased ($P < 0.02$), whereas the U fraction increased ($P < 0.01$) as a result of supplementation (Table 5.4). Because of this, the extent of forage DM and NDF degradation decreased ($P < 0.01$) with supplementation. Supplements may have provided more readily available nutrients to the rumen microbes, potentially meeting nutritional requirements of rumen microflora without extensive degradation of the forage in the diet (Russell and Baldwin 1978). This may account for the reduced extent of forage degradation in the supplemented diets. Alternatively, potential shifts in microbial population as a results of supplement strategy have reduced the extent of forage degradation within the rumen (Bowman and Sanson 2000).

Lag time (T0), the S fraction, and the ED of DM and NDF were not affected ($P > 0.10$) by treatment. Mathison et al. (1999) reported mean DM lag time was 2.8 ± 1.0 h for 65 genotypes of barley straw (4.4 ± 1.08% CP; 75.1 ± 3.8% NDF) collected from the 1994 and 1995 Alberta barley breeding program. Reed et al. (2007) found the NDF lag time of grass hay (6.0% CP; 69.1% NDF) was unaffected ($P > 0.50$) by RUP supplementation and averaged 5.35 hours. These values are considerably higher than DM and NDF lag times found in the current study (mean 0.55 h and 2.07 h, respectively). Forages have a high content of water soluble material that can leave the nylon bags unfermented which may affect lag time measurements (Dewhurst et al. 1995). Greater N availability within the rumen supports microbial growth (Mehrez et al. 1977; Van Soest 1994) and Russell and Baldwin (1978) have demonstrated preferential substrate use within the rumen, which could

Table 5.4 Effect of supplement on *in situ* degradability of dry matter and neutral detergent fibre of incubated forage (75:25 straw:hay)

	Treatment^{z}					
Item	DDGS	COMM	BAR+CM	CONT	SEM	P value
Dry matter (%)						
Degradation rate (Kd; % h^{-1})	4.09	4.04	4.05	2.64	0.453	0.06
Lag time (T0; h)	0.44	0.65	0.77	0.34	0.206	0.53
Immediately soluble fraction (S; %)	12.96	13.07	12.88	12.22	0.286	0.20
Potentially degradable fraction (D; %)	46.47b	46.06b	47.16b	53.88a	1.340	<0.01
Undegradable fraction (U; %)	40.58a	40.87a	39.96a	33.91b	1.399	<0.01
Effective degradability (EDDM; %)	35.57	36.11	35.65	33.15	1.179	0.34
Neutral detergent fibre (% DM)						
Degradation rate (Kd; % h^{-1})	4.02	4.11	3.70	2.72	0.443	0.14
Lag time (T0; h)	1.74	2.42	1.37	2.74	0.524	0.34
Immediately soluble fraction (S; %)	5.90	7.30	5.47	4.87	0.660	0.10
Potentially degradable fraction (D; %)	51.58b	50.09b	53.94b	61.10a	1.675	0.02
Undegradable fraction (U; %)	42.41a	43.03a	40.59a	33.87b	1.823	<0.01
Effective degradability (EDNDF; %)	31.42	32.25	30.84	28.42	1.223	0.27

^{z}DDGS = heifers supplemented with wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); COMM = heifers supplemented with commercial range pellet; BAR+CM = heifers supplemented with 4.8% rolled barley grain and 7.3% canola meal; CONT = heifers received no supplement

$^{a\text{-}c}$Means with different letters in the same row are significantly different (P < 0.05) using Tukey's multi-treatment comparison method. SEM = standard error of mean potentially account for the lower lag times observed in the current study. The S fraction and EDDM observed in the current study (mean 12.78% and 35.12%, respectively) was similar to the values of 12.6 ± 4.1% and 37.0 ± 3.8%, respectively, reported by Mathison et al. (1999).

Rate of DM degradation tended ($P = 0.06$) to be higher in supplemented treatments compared to the control. Mathison et al. (1999) reported mean Kd for barley straw was 2.2 ± 0.44% h^{-1}, similar to the control diet Kd (2.64% h^{-1}) but lower than the DDGS, COMM, and BAR+CM supplemented diets, 4.09, 4.04, and 4.05% h^{-1}, respectively. Microbial efficiency may have been improved as a result of increased N availability within the rumen for the supplemented diets (Ortiz-Rubio et al. 2007). This would improve the rate of forage degradation in the supplemented diets compared to the degradation in the unsupplemented diet. Reed et al. (2004) found no difference ($P = 0.87$) in grass hay Kd as a result of field pea supplementation.

Rate of NDF degradation was not affected ($P = 0.14$) by supplement strategy in the current study. Similarly, Caton et al. (1988) found digestible NDF degradation of dormant bluestem rangeland was not affected ($P > 0.10$) by cottonseed meal supplementation. Likewise, grass hay NDF Kd was not different ($P = 0.24$) between unsupplemented and RUP supplemented treatments in a study by Reed et al. (2007); however, NDF Kd was greater ($P = 0.05$) for the high level (40.6% DM) of RUP supplement compared to the medium level supplement (19.6% DM).

5.4. Conclusion

Supplementing the forage based ration of 75% straw and 25% hay with either DDGS, commercial range pellet, or a combination of barley grain and canola meal did not affect forage intake, apparent total tract digestion, or particulate passage rate compared to the unsupplemented control diet. Forage intake, digestibility, and passage rate have been positively correlated in the literature therefore it is reasonable to observe similar responses of these parameters as a result of supplementation. The lack of supplementation effect may be attributed to the quality of the basal forage ration, which was greater than anticipated and thus met animal requirements with no need for supplementation. Because forage and RDP intake was already high with no supplementation, treatment effects were not observed in this study. Furthermore, the low level of supplement inclusion in the total diet may have also minimized any potential effects of supplementation.

Ruminal pH was not affected by supplementation, thus maintaining a rumen environment favourable to cellulytic bacteria. Supplementation did increase ammonia-N levels in the supplemented diets, which may have relieved sub-acute ruminal N deficiencies within the rumen (McCollum and Horn 1990). The rate of forage DM degradation tended to increase as a result of supplementation while the extent of degradation decreased for both DM and NDF. This would indicate that the rumen microbes used supplemental nutrients to meet their requirements instead of extensively degrading the diet forage. Despite these effects on the rate and extent of forage degradation, intake, digestibility, and passage rate were not affected by supplement treatment.

No differences were observed between the DDGS, commercial range pellet, and barley and canola meal supplemented diets. This would suggest that DDGS has similar supplementation potential as commercial range pellet and barley grain and canola meal. As such, producers in western Canada may include wheat-based DDGS in their feeding programs at a level of up to 8.5% of total diet without negatively effecting forage intake or rumen fermentation.

6. General Discussion & Conclusion

To reduce feed costs, producers may incorporate low quality forages in beef cow diets. Often, these types of forages require supplementation to meet beef cow nutrient requirements, especially in the second and third trimester of pregnancy (NRC 1996). As the ethanol industry in western Canada continues to expand, the supply of wheat-based DDGS will continue to grow. The objective of this research was to evaluate wheat-based DDGS as a supplement for beef cows consuming low quality forages. Beef cow performance and forage utilization were evaluated as cows grazed stockpiled crested wheatgrass pasture or barley straw-chaff residue. Finally, metabolic effects of wheat-based DDGS supplementation were measured when ruminally cannulated heifers were individually fed a basal diet of 75% ground barley straw and 25% ground grass hay.

In the first trial, beef cows grazing stockpiled crested wheatgrass pasture were supplemented with DDGS (70:30 wheat:corn blend; DDGS), commercial range pellet (COMM), or unsupplemented (CONT). All supplements in this study were fed to supply protein to the cows. There was no effect ($P > 0.05$) of supplement strategy on pasture forage utilization. Similarly, cow performance was not affected ($P > 0.05$) by supplement strategy.

The lack of supplement effect was unexpected and may be attributed to the low experimental power, which can reduce the detection of significant differences.

When cows grazed barley straw-chaff piles and were supplemented with 100% DDGS (70:30 wheat:corn blend; DDGS), 50% DDGS and 50% rolled barley grain (50:50), or 100% rolled barley grain (control; BARL) to provide additional energy to the cows, no affect ($P > 0.05$) on forage utilization was observed for any supplement strategy. This was unexpected, as the starch content of the barley grain was anticipated to have a negative associative effect on rumen fermentation, resulting in a substitution of forage by the supplement. The technique used to estimate forage intake may have lacked the sensitivity required to detect forage intake differences as affected by supplementation. Despite similar estimated forage intakes, cows supplemented with 100% DDGS or 50% DDGS and 50% rolled barley had greater ($P < 0.01$) positive BW changes than cows supplemented with 100% rolled barley. Generally, improvements in animal performance as a result of supplementation are attributed to increased forage intake (McCollum and Horn 1990). However, because forage intakes were not found to be different between treatments in this experiment, differences in animal performance may have been the result of the supplements fed.

The digestible energy of DDGS and barley grain, as calculated using the Penn State equations based on ADF (Appendix Equation A.2; Adams 1995), were 3.26 and 3.63 Mcal per kg, respectively. Based on these estimates of DE, cows supplemented with barley grain should have improved performance compared to DDGS. However, the cow performance results indicate that DDGS provided more energy to the diet than barley grain. There are different theories for the high energy content of distillers' co-products, as indicated by animal performance trials. Ham et al. (1994) suggested that the low starch content of DDGS reduces the incidence of negative associated effects, such as sub-acute ruminal acidosis. However, Beliveau (2008) and Vander Pol et al. (2009) reported sustained ruminal pH reduction when wheat DDGS and corn WDGS, respectively, were fed in feedlot rations. Vander Pol et al. (2009) suggested that propionate production and fat digestion were enhanced when corn-based WDGS was included at 40% of the feedlot ration. Other suggestions for the high energy content of distillers' co-products include a high fat content (Schingoethe 2006; Klopfenstein et al. 2008), highly digestible NDF (Nuez-Ortin 2010), and the metabolism of excess RUP for energy (Stock et al. 2000).

The effect of supplement type on forage intake and digestibility, passage rate, rumen fermentation parameters, and the rate and extent of forage degradation were evaluated using ruminally cannulated Hereford heifers individually fed a basal ration of 75% ground barley straw and 25% ground grass hay and supplemented with either DDGS (70:30 wheat:corn; DDGS), commercial range pellet (COMM), rolled barley grain and canola meal (BAR+CM), or unsupplemented (control; CONT). Forage intake, passage rate, and apparent total tract digestibility of DM, NDF, and ADF were not affected ($P > 0.05$) by supplement strategy. Because these parameters have been positively correlated in the literature (McCollum and Galyean 1985b; Guthrie and Wagner 1988; McCollum and Horn 1990; Beaty et al. 1994; Koster et al. 1996; Mathis et al. 1999), similar trends were anticipated in this experiment. However, supplemented diets were expected to increase intake, passage rate, and digestibility. These results are similar to the previous two experiments where supplementing cows with DDGS, commercial range pellet, and barley grain had no effect on forage utilization.

Effect of supplementation is affected by forage quality and supplement type (Kartchner 1980; Huston et al. 1993). The basal forage (75:25 straw:hay) fed in the metabolic work and the stockpiled crested wheatgrass pasture possibly met animal requirements based on NRC (1996) recommendations, minimizing any effects of supplementation. Apparent total tract digestibility of CP was increased ($P = 0.02$) by supplementation which is likely due to the higher CP content of the supplemented diets as well as the greater digestibility of supplement CP compared to forage CP (Stern et al. 1983). Ruminal pH was not affected ($P > 0.05$) by diet and was within the range acceptable for the normal function of cellulolytic bacteria. Ruminal NH_3-N was increased ($P < 0.01$) by supplementation.

The rate of forage DM degradation was increased in supplemented diets compared to the control diet, suggesting the ruminal microbial populations were capable of rapid forage degradation. However, the extent of forage DM and NDF degradation was lower in the DDGS, COMM, and BAR+CM diets compared to the CONT diet. This suggests that rumen microbes were able to satisfy their nutrient requirements with supplemental nutrients, decreasing forage degradation within the rumen (Russell and Baldwin 1978). Reduced extent of forage degradation could account for the lack of supplement effect on forage DMI observed in all experiments, when supplementation was anticipated to increase forage intake but did not.

In this study, the effects of supplementing beef cow rations with wheat-based DDGS were equal to or greater than the effects of supplementing rations with a commercial range pellet, barley, or barley and canola meal. Therefore, the decision to use wheat-based DDGS as a supplement in beef cow diets will depend on the cost of the supplement. Few effects of supplementation were noted in these experiments, possibly due to the higher than anticipated quality of the forages used in the trials. Further research could be conducted studying the effects of wheat-based DDGS as a supplement with very low quality forage (< 4.0% CP) on cow performance and forage intake. Additionally, research should be conducted to determine the effects of feeding beef cow wheat-based DDGS on reproductive performance. Finally, the current research used a 70% wheat, 30% corn DDGS blend. As such, research evaluating 100% wheat DDGS as a supplement for low quality forages is needed.

Using wheat-based dried distillers' grains as a supplement for cows grazing stockpiled crested wheatgrass pasture had similar results on beef cow performance and forage utilization compared to supplementing with a commercial range pellet with similar chemical composition as the DDGS. When beef cows grazed barley straw-chaff residue, wheat-based DDGS supplementation increased cow BW gains when fed at 100% or 50% of the supplement when compared to supplementing 100% barley grain. These results indicate a higher energy value of the DDGS compared to barley grain that is not detected using current wet chemistry laboratory techniques. Similarly, Gibb et al. (2008) and Vander Pol et al. (2009) have also reported that wheat DDGS and corn wet distillers' grains with solubles (WDGS), respectively, have resulted in greater animal performance than predicted. Wheat-based DDGS has good potential as both a protein and energy supplement for pregnant beef cows grazing low quality forages. Wheat-based DDGS supplementation resulted in similar forage intake, passage rate, and apparent total tract DM, NDF, and ADF digestibility as did supplementing with a commercial range pellet or barley grain and canola meal. Furthermore, ruminal pH and ammonia-N, as well as the rate and extent of forage degradation were not different between supplemented treatments. This suggests wheat-based DDGS has similar effects compared to as traditional supplements (commercial range pellet or barley grain and canola meal) in this study. Based on the results of these experiments, wheat-based DDGS can be used as a supplement for pregnant beef cows consuming low quality forages. The decision to include wheat-based DDGS into a supplement program should be based on supplement cost.

REFERENCES

Aasen, A. 2003. Annual crops for grazing. Available at <http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/crop8005?opendocument> Verified April 17, 2008.

Abouguendia, Z., Klein, K., Kowalenko, C. G., Summach, D., Springer, B., Cubbon, D., Barclay, G., Foster, A., Meachem, E. and Robertshaw, P. 2001. Grazing and pasture technology program, 1997-2001 projects: extending the grazing season. Available at <http://www.agr.gov.sk.ca/afif/Projects/19960286a.pdf> Verified September 23, 2009.

Adams, D. C., Nelsen, T. C., Reynolds, W. L. and Knapp, B. W. 1986. Winter grazing activity and forage intake of range cows in the northern great plains. J. Anim. Sci. **62**: 1240-1246.

Adams, D. C., Clark, R. T., Coady, S. A., Lamb, J. B. and Nielsen, M. K. 1994. Extended grazing systems for improving economic returns from Nebraska sandhills cow/calf operations. J. Range Manage. **47**: 258-263.

Adams, R. S. 1995. Dairy nutrition. (108-109) *in* Walker, C. (ed). Dairy Reference Manual. 3rd ed. Northeast Regional Agricultural Engineering Service, Ithaca, NY, USA.

Adesogan, A. T., Givens, D. I. and Owen, E. 2000. Measuring chemical composition and nutritive value in forages. (263-278) *in* 't Mannetje, L. and Jones, R. M. (ed). Field and laboratory methods for grassland and animal production research. CABI Publishing, Wallingford, UK.

Aerts, J. V., De Brabander, D. L., Cottyn, B. G. and Buysse, F. X. 1977. Comparison of laboratory methods for predicting the organic matter digestibility of forages. Anim. Feed Sci. Technol. **2**: 337-349.

Alberta Agriculture Food and Rural Development. 1999. CowBytes Beef Ration Balancer Program. Version 4.

Allden, W. G. 1981. Energy and protein suppements for grazing livestock. (289-307) *in* Morley, F. H. W. (ed). Grazing Ruminants. Elsevier Scientific Publishing Co., Amsterdam.

Allen, M. S. 1996. Physical constraints on voluntary intake of forages by ruminants. J. Anim. Sci. **74**: 3063-3075.

Anderson, B. and Mader, T. 1985. Management to minimize hay waste. NebGuide B-25. Univ. of Nebraska Coop. Serv., Inst. Agric. and Natural Resouces, Lincoln.

Anderson, D. C. 1978. Use of cereal residues in beef cattle production systems. J. Anim. Sci. **46**: 849-861.

Anderson, D. C., Doombos, D. E., Boss, D. L., Kress, D. D. and Shannon, N. H. 1995. Relationship among ultrasound backfat, condition score and weight to height ratio in beef cattle. Proc. West. Sec. Amer. Soc. Anim. Sci. **48**: 106-107.

Anonymous. 2007. Ethanol byproducts pelletized. Available at <http://www.sciencedaily.com/releases/2007/06/070625221035.htm> Verified August 12, 2009.

Aroeira, L. J. M., Lopes, F. C. F., Deresz, F., Verneque, R. S., Dayrell, M. S., de Matos, L. L., Maldonado-Vasquez, H. and Vittori, A. 1999. Pasture availability and dry matter intake of lactating crossbred cows grazing elephant grass (Pennisetum purpureum, Schum.). Anim. Feed Sci. Technol. **78**: 313-324.

Arroquy, J. I., Cochran, R. C., Villarreal, M., Wickersham, T. A., Llewellyn, D. A., Titgemeyer, E. C., Nagaraja, T. G., Johnson, D. E. and Gnad, D. 2004. Effect of level of rumen degradable protein and type of supplemental non-fiber carbohydrate on intake and digestion of low-quality grass hay by beef cattle. Anim. Feed Sci. Technol. **115**: 83-99.

Association of Official Analytical Chemists. 2000. Official methods of analysis. 17th ed. AOAC International. Gaithersburg, MD, USA.

Ayres, H., Ferreira, R. M., Torres Junior, J. R. d. S., Demetrio, C. G. B., Lima, C. G. d. and Baruselli, P. S. 2009. Validation of body condition score as a predictor of subcutaneous fat in Nelore (Bos indicus) cows. Livest. Sci. **123**: 175-179.

Bandyk, C. A., Cochran, R. C., Wickersham, T. A., Titgemeyer, E. C., Farmer, C. G. and Higgins, J. J. 2001. Effect of ruminal vs postruminal administration of degradable protein on utilization of low-quality forage by beef steers. J. Anim. Sci. **79**: 225-231.

Banta, J. P., Lalman, D. L., Owens, F. N., Krehbiel, C. R. and Wettemann, R. P. 2006. Effects of interval-feeding whole sunflower seeds during mid to late gestation on performance of beef cows and their progeny. J. Anim. Sci. **84**: 2410-2417.

Barnes, R. F., Nelson, C. J., Moore, K. J. and Collins, M. 2003. Forages: the science of grassland agriculture. Volume II. 6th ed. Blackwell Publishing. Ames, Iowa, USA.

Baron, V. S., Dick, A. C., Bjorge, M. and Lastiwka, G. 2004. Stockpiling potential of perennial forage species adapted to the Canadian western prairie parkland. Agron. J. **96**: 1545-1552.

Baron, V. S., Dick, A. C., Bjorge, M. and Lastiwka, G. 2005. Accumulation period for stockpiling perennial forages in the Western Canadian prairie parkland. Agron. J. **97**: 1508-1514.

Baron, V. S., Dick, A. C., McCartney, D., Basarab, J. A. and Okine, E. K. 2006. Carrying capacity, utilization, and weathering of swathed whole plant barley. Agron. J. **98**: 714-721.

Beaty, J. L., Cochran, R. C., Lintzenich, B. A., Vanzant, E. S., Morrill, J. L., Brandt, R. T., Jr and Johnson, D. E. 1994. Effect of frequency of supplementation and protein concentration in supplements on performance and digestion characteristics of beef cattle consuming low-quality forages. J. Anim. Sci. **72**: 2475-2486.

Beck, P. A., Gunter, S. A. and Phillips, J. M. 2006. Evaluation of supplementation programs for growing catte grazing tall fescue. Prof. Anim. Sci. **22**: 325-333.

Beck, T. J., Simms, D. D., Cochran, R. C., Brandt, R. T., Jr, Vanzant, E. S. and Kuhl, G. L. 1992. Supplementation of ammoniated wheat straw: performance and forage utilization characteristics in beef cattle receiving energy and protein supplements. J. Anim. Sci. **70**: 349-357.

Beliveau, R. M. 2008. Effect of graded levels of wheat-based distiller's grains in a barley ration on the growth performance, carcass quality and rumen characteristics of feedlot steers. M. Sc. Thesis. University of Saskatchewan, Saskatoon, SK, Canada.

Beliveau, R. M. and McKinnon, J. J. 2008. Effect of graded levels of wheat-based dried distillers' grains with solubles on performance and carcass characteristics of feedlot steers. Can. J. Anim. Sci. **88**: 677-684.

Belyea, R. L., Rausch, K. D. and Tumbleson, M. E. 2004. Composition of corn and distillers dried grains with solubles from dry grind ethanol processing. Bioresour. Technol. **94**: 293-298.

Beverlin, S. K., Havstad, K. M., Ayers, E. L. and Petersen, M. K. 1989. Forage intake responses to winter cold exposure of free-ranging beef cows. Appl. Anim. Behav. Sci. **23**: 75-85.

Bhatti, S. A., Bowman, J. G. P., Firkins, J. L., Grove, A. V. and Hunt, C. W. 2008. Effect of intake level and alfalfa substitution for grass hay on ruminal kinetics of fiber digestion and particle passage in beef cattle. J. Anim. Sci. **86**: 134-145.

Blümmel, M. and Ørskov, E. R. 1993. Comparison of in vitro gas production and nylon bag degradability of roughages in predicting feed intake in cattle. Anim. Feed Sci. Technol. **40**: 109-119.

Bodine, T. N., Purvis, H. T., II and Lalman, D. L. 2001. Effects of supplement type on animal performance, forage intake, digestion, and ruminal measurements of growing beef cattle. J. Anim. Sci. **79**: 1041-1051.

Bodine, T. N. and Purvis, H. T., II. 2003. Effects of supplemental energy and/or degradable intake protein on performance, grazing behavior, intake, digestibility, and fecal and blood indices by beef steers grazed on dormant native tallgrass prairie. J. Anim. Sci. **81**: 304-317.

Bohnert, D. W., Schauer, C. S. and DelCurto, T. 2002a. Influence of rumen protein degradability and supplementation frequency on performance and nitrogen use in ruminants consuming low-quality forage: cow performance and efficiency of nitrogen use in wethers. J. Anim. Sci. **80**: 1629-1637.

Bohnert, D. W., Schauer, C. S., Bauer, M. L. and DelCurto, T. 2002b. Influence of rumen protein degradability and supplementation frequency on steers consuming low-quality forage: I. Site of digestion and microbial efficiency. J. Anim. Sci. **80**: 2967-2977.

Boila, R. J. and Ingalls, J. R. 1994. The ruminal degradation of dry matter, nitrogen and amino acids in wheat-based distillers' dried grains in sacco. Anim. Feed Sci. Technol. **48**: 57-72.

Bothast, R. J. and Schlicher, M. A. 2005. Biotechnological processes for conversion of corn into ethanol. Appl. Microbiol. Biotechnol. **67**: 19-25.

Bourne, J. L. 2007. Evaluation of the NRC 1996 winter feed requirements for beef cows in western Canada. M. Sc. Thesis. University of Saskatchewan, Saskatoon, SK, Canada.

Bowman, J. G. P. and Sanson, D. W. 1996. Starch- or fiber-based energy supplements for grazing ruminants. Proc. West. Sec. Amer. Soc. Anim. Sci. **47**: 118-135.

Bowman, J. G. P., Sowell, B. F., Surber, L. M. M. and Daniels, T. K. 2004. Nonstructural carbohydrate supplementation of yearling heifers and range beef cows. J. Anim. Sci. **82**: 2724-2733.

Bowman, J. P. and Sanson, D. W. 2000. Energy/protein supplementation considerations for grazing ruminants. Oregon State University Station Bulletine SB 683. Strategic supplementation of beef cattle consuming low-quality roughages in the western United States. Oregon State University Agriculture Experiment Station.

Broderick, G. A. and Kang, J. H. 1980. Automated simultaneous determination of ammonia and total amino acids in ruminal fluid and in vitro media. J. Dairy Sci. **63**: 64-75.

Broderick, G. A. 1994. Quantifying forage protein quality. (200-228) *in* Fahey Jr, G. C., Collins, M. C., Mertens, D. R. and Moser, L. E. (ed). Forage Quality, Evaluation, and Utilization. ASA-CSSA-SSSA, Madison, WI, USA.

Broster, W. H. and Thomas, C. 1981. The influence of level and pattern of concentrate input on milk output. (49-69) *in* Haresign, W. (ed). Recent Advances in Animal Nutrition - 1981. Butterworths, London.

Brouk, M. J. 1994. Net energy for lactation and ruminal degradability of wet corn distillers grains. PhD Dissertation. South Dakota State University, Brookings, SD, USA.

Bruynooghe, J. D. 1997. Forage production and performance of beef yearlings grazing diploid and tetraploid crested wheatgrasses. M. Sc. Thesis. University of Saskatchewan, Saskatoon, SK, Canada.

Bunting, L. D., Boling, J. A. and MacKown, C. T. 1989. Effect of dietary protein level on nitrogen metabolism in the growing bovine: I. Nitrogen recycling and intestinal protein supply in calves. J. Anim. Sci. **67**: 810-819.

Burns, J. C., Pond, K. R. and Fisher, D. S. 1994. Measurement of forage intake. (494-532) *in* Fahey Jr, G. C., Collins, M. C., Mertens, D. R. and Moser, L. E. (ed). Forage Quality, Evaluation, and Utilization. ASA-CSSA-SSSA, Madison, WI, USA.

Campling, R. C. 1970. Physical regulation of voluntary intake. (226-234) *in* Phillipson, A. T. (ed). Physiology of Digestion and Metabolism in the Ruminant. Oriel Press, Ltd., Newcastle, UK.

Canadian Council on Animal Care. 1993. Guide to the care and use of experimental animals. Vol 1. 2nd ed. Olfert, E. D., Cross, B. M. and McWilliam, A. A., Canadian Council on Animal Care. Ottawa, ON, Canada.

Canadian Renewable Fuels Association (CRFA). 2009. Available at <http://greenfuels.org/index.php> Verified August 12, 2009.

Capper, B. S., Thomson, E. F. and Rihawi, S. 1989. Voluntary intake and digestibility of barley straw as influenced by variety and supplementation with either barley grain or cottonseed cake. Anim. Feed Sci. Technol. **26**: 105-118.

Caton, J. S., Freeman, A. S. and Galyean, M. L. 1988. Influence of protein supplementation on forage intake, in situ forage disappearance, ruminal fermentation and digesta passage rates in steers grazing dormant blue grama rangeland. J. Anim. Sci. **66**: 2262-2271.

Chase, C. C. and Hibberd, C. A. 1987. Utilization of low-quality native grass hay by beef cows fed increasing quantities of corn grain. J. Anim. Sci. **65**: 557-566.

Chase, C. C. and Hibberd, C. A. 1989. Effect of level and frequency of maize supplementation on the utilization of low-quality grass hay by beef cows. Anim. Feed Sci. Technol. **24**: 129-139.

Cherney, J. H. and Kalenback, R. L. 2003. Forage systems for temperate humid areas. (277-290) *in* Barnes, R. F., Nelson, C. J., Moore, K. J. and Collins, M. (ed). Forages: the science of grassland agriculture. 6th. Blackwell Publishing, Ames, Iowa, USA.

Church, D. C. and Santos, A. 1981. Effect of graded levels of soybean meal and of a nonprotein nitrogen-molasses supplement on consumption and digestibility of wheat straw. J. Anim. Sci. **53**: 1609-1615.

Clanton, D. C. and Zimmerman, D. R. 1970. Symposium on pasture methods for maximum production in beef cattle: protein and energy requirements for female beef cattle. J. Anim. Sci. **30**: 122-132.

Cline, H. J., Neville, B. W., Lardy, G. P. and Caton, J. S. 2009. Influence of advancing season on dietary composition, intake, site of digestion, and microbial efficiency in beef steers grazing a native range in western North Dakota. J. Anim. Sci. **87**: 375-383.

Coates, D. B. and Penning, P. 2000. Measuring animal performance. (353-402) *in* 't Mannetje, L. and Jones, R. M. (ed). Field and laboratory methods of grassland and animal production research. CABI Publishing, Wallingford, UK.

Cochran, R. C., Adams, D. C., Currie, P. O. and Knapp, B. W. 1986. Cubed alfalfa hay or cottonseed meal-barley as supplements for beef cows grazing fall-winter range. J. Range Manage. **39**: 361-364.

Cochran, R. C. and Galyean, M. L. 1994. Measurement of in vivo forage digestion by ruminants. (613-643) *in* Fahey Jr, G. C., Collins, M. C., Mertens, D. R. and Moser, L. E. (ed). Forage Quality, Evaluation, and Utilization. ASA-CSSA-SSSA, Madison, WI, USA.

Colucci, P. E., Falk, D., Macleod, G. K. and Grieve, D. G. 1992. In situ organic matter degradability of untreated and urea-treated varieties of spring barley and oat straws, and of untreated varieties of winter wheat straws. Anim. Feed Sci. Technol. **37**: 73-84.

Cook, C. W. and Stubbendieck, J. 1986. Range research: basic problems and techniques. Society of Range Management. Denver, CO, USA.

Corbett, J. L. 1978. Meauring animal performance. (163-231) *in* 't Mannetje, L. (ed). Measurement of Grassland Vegetation and Animal Production. Commonwealth Agric. Bur. Bull. 52. CAB International, Farnham Royal, UK.

Cordova, F. J., Wallace, J. D. and Pieper, R. D. 1978. Forage intake by grazing livestock: a review. J. Range Manage. **31**: 430-438.

Crabtree, J. R. and Williams, G. L. 1971. The voluntary intake and utilization of roughage-concentrate diets by sheep. Anim. Prod. **13**: 71.

Crawford, G. I. 2007. Managing sulfur concentrations in feed and water. Proc. 68th Minnisota Nutrition Conference. Minneapolis, MN, USA. September 18-19, 2007.

Cromwell, G. L., Herkelman, K. L. and Stahly, T. S. 1993. Physical, chemical, and nutritional characteristics of distillers dried grains with solubles for chicks and pigs. J. Anim. Sci. **71**: 679-689.

Currie, P. O. 1970. Influence of spring, fall, and spring-fall grazing on crested wheatgrass range. J. Range Manage. **23**: 103-108.

De Boever, J. L., Cottyn, B. G., Andries, J. I., Buysse, F. X. and Vanacker, J. M. 1988. The use of a cellulase technique to predict digestibility, metabolizable and net energy of forages. Anim. Feed Sci. Technol. **19**: 247-260.

DelCurto, T., Cochran, R. C., Harmon, D. L., Beharka, A. A., Jacques, K. A., Towne, G. and Vanzant, E. S. 1990a. Supplementation of dormant tallgrass-prairie forage: I. Influence of varying supplemental protein and(or) energy levels on forage utilization characteristics of beef steers in confinement. J. Anim. Sci. **68**: 515-531.

DelCurto, T., Cochran, R. C., Corah, L. R., Beharka, A. A., Vanzant, E. S. and Johnson, D. E. 1990b. Supplementation of dormant tallgrass-prairie forage: II. Performance and forage utilization characteristics in grazing beef cattle receiving supplements of different protein concentrations. J. Anim. Sci. **68**: 532-542.

DelCurto, T., Hess, B. W., Huston, J. E. and Olson, K. C. 1999. Optimum supplementation strategies for beef cattle consuming low-quality roughages in the western United States. Proc. Amer. Soc. Anim. Sci.

DelCurto, T. and Olson, K. C. 2000. Physical form of crude protein for supplementation of low-quality roughages. Oregon State University Station Bulletine SB 683. Strategic supplementation of beef cattle consuming low-quality roughages in the western United States. Oregon State University Agriculture Experiment Station.

Dewhurst, R. J., Hepper, D. and Webster, A. J. F. 1995. Comparison of in sacco and in vitro techniques for estimating the rate and extent of rumen fermentation of a range of dietary ingredients. Anim. Feed Sci. Technol. **51**: 211-229.

Dien, B. S., Bothast, R. J., Nichols, N. N. and Cotta, M. A. 2003. The US corn ethanol industry: an overview of current technology and future prospects. Proc. 3rd International Starch Technology Conference - Coproduct Progam Proceedings. University of Illinios. June 2-4, 2003. pg 10-21.

Dixon, R. M., Mathison, G. W. and Milligan, L. P. 1981. Effect of rumen degradability of supplements on intake of barley straw by steers. Can. J. Anim. Sci. **61**: 1055-1058.

Domecq, J. J., Skidmore, A. L., Lloyd, J. W. and Kaneene, J. B. 1995. Validation of body condition scores with ultrasound measurements of subcutaneous fat of dairy cows. J. Dairy Sci. **78**: 2308-2313.

Dove, H. and Mayes, R. W. 1996. Plant wax components: a new approach to estimating intake and diet composition in herbivores. J. Nutr. **126**: 13-26.

Egan, A. R. 1965. Nutritional status and intake regulation in sheep II. The influence of sustained deodenal industions of casein or urea upon voluntary intake of low protein roughages. Aust. J. Agric. Res. **16**: 451-461.

Egan, A. R. 1980. Host animal-rumen relationships. Proc. Nutr. Soc. **39**: 79.

Egan, A. R. 1981. "Bypass" protein - a review. (42-51) *in* Farrell, D. J. (ed). Recent Advances in Animal Nutrition in Australia. University of New England Publishing Unit, Armidale, NSW, AU.

Ellis, W. C. 1978. Determinants of grazed forage intake and digestibility. J. Dairy Sci. **61**: 1828-1840.

Engel, C. L., Patterson, H. H. and Perry, G. A. 2008. Effect of dried corn distillers grains plus solubles compared with soybean hulls, in late gestation heifer diets, on animal and reproductive performance. J. Anim. Sci. **86**: 1697-1708.

Fahey, G. C., Jr. and Jung, H. G. 1983. Lignin as a marker in digestion studies: a review. J. Anim. Sci. **57**: 220-225.

Farmer, C. G., Cochran, R. C., Simms, D. D., Klevesahl, E. A., Wickersham, T. A. and Johnson, D. E. 2001. The effects of several supplementation frequencies on forage use and the performance of beef cattle consuming dormant tallgrass prairie forage. J. Anim. Sci. **79**: 2276-2285.

Faverdin, P., Dulphy, J. P., Coulon, J. B., Vérité, R., Garel, J. P., Rouel, J. and Marquis, B. 1991. Substitution of roughage by concentrates for dairy cows. Lives. Prod. Sci. **27**: 137-156.

Fawcett, R. H., Jessop, N. S., Herrero, M. and Illius, A. W. I. 2005. New approach to intake predictions. Proc. Society of Feed Technologists: Ruminant Nutrition. 27 April 2004.

Ferreira, L. M. M., Olivan, M., Rodrigues, M. A. M., Osoro, K., Dove, H. and Dias-Da-Silva, A. 2004. Estimation of feed intake by cattle using controlled-release capsules containing n-alkanes or chromium sesquioxide. J. Agric. Sci. **142**: 225-234.

Ferrell, C. L., Kreikemeier, K. K. and Freetly, H. C. 1999. The effect of supplemental energy, nitrogen, and protein on feed intake, digestibility, and nitrogen flux across the gut and liver in sheep fed low-quality forage. J. Anim. Sci. **77**: 3353-3364.

Fick, K. R., Ammerman, C. B., McGowan, C. H., Loggins, P. E. and Cornell, J. A. 1973. Influence of supplemental energy and biuret nitrogen on the utilization of low quality roughage by sheep. J. Anim. Sci. **36**: 137-143.

Firkins, J. L., Berger, L. L. and Fahey, G. C., Jr. 1985. Evaluation of wet and dry distillers grains and wet and dry corn gluten feeds for ruminants. J. Anim. Sci. **60**: 847-860.

Firkins, J. L., Bowman, J. G. P., Weiss, W. P. and Naderer, J. 1991. Effects of protein, carbohydrate, and fat sources on bacterial colonization and degradation of fiber in vitro. J. Dairy Sci. **74**: 4273-4283.

Fisher, D. J., McKinnon, J. J., Mustafa, A. F., Christensen, D. A. and McCartney, D. 1999. Evaluation of wheat-based thin stillage as a water source for growing and finishing beef cattle. J. Anim. Sci. **77**: 2810-2816.

Forbes, J. M. 2007. Voluntary food intake and diet selection in farm animals. CAB International. Wallingford, UK.

Fox, D. G., Tedeschi, L. O., Tylutki, T. P., Russell, J. B., Van Amburgh, M. E., Chase, L. E., Pell, A. N. and Overton, T. R. 2004. The Cornell Net Carbohydrate and Protein System model for evaluating herd nutrition and nutrient excretion. Anim. Feed Sci. Technol. **112**: 29-78.

Freeman, A. S., Galyean, M. L. and Caton, J. S. 1992. Effects of supplemental protein percentage and feeding level on intake, ruminal fermentation, and digesta passage in beef steers fed prairie hay. J. Anim. Sci. **70**: 1562-1572.

Freeze, B. S., Willms, W. D. and Rode, L. 1999. Economics of maintaining cow condition on fescue prairie in winter. J. Range Manage. **52**: 113-119.

Getachew, G., Blümmel, M., Makkar, H. P. S. and Becker, K. 1998. In vitro gas measuring techniques for assessment of nutritional quality of feeds: a review. Anim. Feed Sci. Technol. **72**: 261-281.

Gibb, D. J., Hao, X. and McAllister, T. A. 2008. Effect of dried distillers' grains from wheat on diet digestibility and performance of feedlot cattle. Can. J. Anim. Sci. **88**: 659-665.

Gibb, M. J. and Baker, R. D. 1988. Performance of young steers offered stack-treated ammoniated hay or untreated hay with or without a supplement. Anim. Prod. **47**: 223.

Goldman, A., Genizi, A., Yulzari, A. and Seligman, N. G. 1987. Improving the reliability of the two-stage in vitro assay for ruminant feed digestibility by calibration against in vivo data from a wide range of sources. Anim. Feed Sci. Technol. **18**: 233-245.

Gosselink, J. M. J., Dulphy, J. P., Poncet, C., Jailler, M., Tamminga, S. and Cone, J. W. 2004. Prediction of forage digestibility in ruminants using in situ and in vitro techniques. Anim. Feed Sci. Technol. **115**: 227-246.

Greenprint for Ethanol Production in Saskatchewan. 2002. Available at <http://www.econet.sk.ca/pdf/SKGreenprintonethanol.pdf> Verified July 9, 2009.

Gunter, S. A., Cassida, K. A., Beck, P. A. and Phillips, J. M. 2002. Winter-annual pasture as a supplement for beef cows. J. Anim. Sci. **80**: 1157-1165.

Guthrie, M. J. and Wagner, D. G. 1988. Influence of protein or grain supplementation and increasing levels of soybean meal on intake, utilization and passage rate of prairie hay in beef steers and heifers. J. Anim. Sci. **66**: 1529-1537.

Hall, Z. C., Rasby, R. J. and Dragastin, M. 2008. Supplementing beef cows grazing cornstalk residue with a distillers based cube. Nebraska Beef Cattle Report. MP 91. University of Nebraska Cooperative Extension.

Ham, G. A., Stock, R. A., Klopfenstein, T. J., Larson, E. M., Shain, D. H. and Huffman, R. P. 1994. Wet corn distillers byproducts compared with dried corn distillers grains with solubles as a source of protein and energy for ruminants. J. Anim. Sci. **72**: 3246-3257.

Hannah, S. M., Cochran, R. C., Vanzant, E. S. and Harmon, D. L. 1991. Influence of protein supplementation on site and extent of digestion, forage intake, and nutrient flow characteristics in steers consuming dormant bluestem-range forage. J. Anim. Sci. **69**: 2624-2633.

Hao, X., Benke, M. B., Gibb, D. J., Stronks, A., Travis, G. and McAllister, T. A. 2009. Effects of dried distillers' grains with solubles (wheat-based) in feedlot cattle diets on feces and manure composition. J. Environ. Quality. **38**: 1709-1718.

Harris, H. L., Cupp, A. S., Roberts, A. J. and Funston, R. N. 2008. Utilization of soybeans or corn milling by-products in beef heifer development diets. J. Anim. Sci. **86**: 476-482.

Hart, R. H. 1991. Developing strategies for integrating forage parameters to meet the nutritional needs of grazing livestock. Proc. 2nd Grazing Livest. Nutr. Conf. Okla. Agric. Exp. Stn. Misc. Publ. 133. Oklahoma State University, Stillwater. pg 64-69.

Heendeniya, R. G. 2008. Utilization of canola seed fractions in ruminant feeds. M. Sc. Thesis. University of Saskatchewan, Saskatoon, SK, Canada.

Heldt, J. S., Cochran, R. C., Stokka, G. L., Farmer, C. G., Mathis, C. P., Titgemeyer, E. C. and Nagaraja, T. G. 1999. Effects of different supplemental sugars and starch fed in combination with degradable intake protein on low-quality forage use by beef steers. J. Anim. Sci. **77**: 2793-2802.

Hertz, R. W. and Mertens, D. R. 1996. Effects of sodium sulfite on recovery and composition of detergent fiber and lignin. J. AOAC Int. **79**: 16-22.

Hiltner, P. and Dehority, B. 1983. Effect of soluble carbohydrates on digestion of cellulose by pure cultures of rumen bacteria. Appl. Environ. Microbiol. **46**: 642-648.

Holechek, J. L., Vavra, M. and Pieper, R. D. 1982. Botanical composition determination of range herbivore diets: a review. J. Range Manage. **35**: 309-315.

Holechek, J. L., Pieper, R. D. and Herbel, C. H. 2004. Range Management: practises and principles. 5th ed. Pearson Prentice Hall. Upper Saddle River, New Jersey, USA.

Hoover, W. H. 1986. Chemical factors involved in ruminal fiber digestion. J. Dairy Sci. **69**: 2755-2766.

Horrocks, R. D. and Vallentine, J. F. 1999. Harvested Forages. Academic Press. San Diego, CA, USA.

Hunt, C. W., Parkinson, J. F., Roeder, R. A. and Falk, D. G. 1989. The delivery of cottonseed meal at three different time intervals to steers fed low-quality grass hay: effects on digestion and performance. J. Anim. Sci. **67**: 1360-1366.

Hunter, R. A. 1991. Strategic supplementation for survival, reproduction and growth of cattle. Proc. 2nd Grazing Livestock Nutrition Conf. Stillwater, Oklahoma, USA, Agric. Exp. Sta. MP-133. pg 32-47.

Huntington, J. A. and Givens, D. I. 1995. The in situ technique for studying the rumen degradation of feeds: a review of the procedure. Nutrition Abstracts and Reviews. Series B, Livestock Feeds and Feeding. **65**: 63-93.

Huston, J. E. and Pinchak, W. E. 1991. Nutritive value of forages. (44-47) *in* Heitschmidt, R. K. and Stuth, J. W. (ed). Grazing Management: an ecological perspective. Timber Press.

Huston, J. E., Thompson, P. V. and Taylor, C. A., Jr. 1993. Combined effects of stocking rate and supplemental feeding level on adult beef cows grazing native rangeland in Texas. J. Anim. Sci. **71**: 3458-3465.

Huston, J. E., Lippke, H., Forbes, T. D., Holloway, J. W. and Machen, R. V. 1999. Effects of supplemental feeding interval on adult cows in western Texas. J. Anim. Sci. **77**: 3057-3067.

Hutton, G., Perillat, B., McCartney, D. and Ohama, A. J. 2004. Swath grazing in western Canada: an introduction. Agri-Facts. Agdex 420/56-2. Alberta Agriculture, Food, and Rural Development.

Iantcheva, N., Steingass, H., Todorov, N. and Pavlov, D. 1999. A comparison of in vitro rumen fluid and enzymatic methods to predict digestibility and energy value of grass and alfalfa hay. Anim. Feed Sci. Technol. **81**: 333-344.

Iowa Beef Center. 2008. Using distillers' grains in alternative cow-calf production systems. Cows & Plows. Angus Journal. pg 192-194.

Jacques, K. A., Lyons, T. P. and Kelsall, D. R. 2003. The alcohol textbook. 4th ed. Notthingham University Press.

Jacques, K. A. 2003. Ethanol production and the modern livestock feed industry: a relationship continuing to grow. (377-385) *in* Jacques, K. A., Lyons, T. P. and Kelsall, D. R. (ed). The Alcohol Textbook. 4th ed. Notthingham University Press.

Jasmer, G. E. and Holechek, J. L. 1984. Determining grazing intensity on rangeland. J. Soil Water Conserv. **39**: 32-35.

Jensen, K. B., Johnson, D. A., Asay, K. H. and Olson, K. C. 2002. Seasonal-accumulated growth and forage quality of range grasses for fall and winter grazing. Can. J. Plant Sci. **82**: 329-336.

Johnson, J. and Wand, C. 1999. Stockpiling perennial forages for fall and winter grazing. Agridex 131/53. Factsheet, Field Crops. Ontario Ministry of Agriculture, Food and Rural Affairs. Toronto, ON, Canada.

Johnson, J. A., Caton, J. S., Poland, W., Kirby, D. R. and Dhuyvetter, D. V. 1998. Influence of season on dietary composition, intake, and digestion by beef steers grazing mixed-grass prairie in the northern Great Plains. J. Anim. Sci. **76**: 1682-1690.

Johnson, L. A. and May, J. B. 2003. Wet milling: the basis for corn biorefineries. (449-494) *in* White, P. J. and Johnson, L. A. (ed). Corn Chemistry and Technology. American Association of Cereal Chemists, Inc., St. Paul, MN, USA.

Johnson, R. R. and Dehority, B. A. 1968. A comparison of several laboratory techniques to predict digestibility and intake of forages. J. Anim. Sci. **27**: 1738-1742.

Jones, D. I. H. and Hayward, M. V. 1975. The effect of pepsin pretreatment of herbage on the prediction of dry matter digestibility from solubility in fugal cellulase solutions. J. Sci. Food Agric. **26**: 711-718.

Jones, D. I. H. and Wilson, A. D. 1987. Nutritive quality of forage. (65-85) *in* Hacker, J. B. and Ternouth, J. H. (ed). The Nutrition of Herbivores. Academic Press, Australia.

Judkins, M. B., Wallace, J. D., Galyean, M. L., Krysl, L. J. and Parker, E. E. 1987. Passage rates, rumen fermentation, and weight change in protein supplemented grazing cattle. J. Range Manage. **40**: 100-105.

Kaiser, R. M. 2005. Variation in composition of distillers wet grains with solubles. Proc. 4-State Dairy Nutrition and Management Conference. Midwest Plan Service. pg 191-197.

Kaliel, D. and Kotowich, J. 2002. Economic evaluation of cow wintering systems - provincial swath grazing survey analysis. Alberta Production Economics Branch, Alberta Agriculture Food and Rural Development. Edmonton, AB.

Kartchner, R. J. 1980. Effects of protein and energy supplementation of cows grazing native winter range forage on intake and digestibility. J. Anim. Sci. **51**: 432-438.

Kelln, B., Lardner, H. A., Schoenau, J. J. and King, T. 2007. Effect of winter feeding systems on cow performance & crop yield. Factsheet #2007-02. Western Beef Development Centre.

Kellner, R. J. and Kirchgessner, M. 1976. Zur methodiek der in vitro verdaulichkeitsbestimmung van grun- und rauhfutter mit cellulase. Landwirtsch. Forsch. **29**: 204-210.

Kempton, T. J., Nolan, V. V. and Leng, R. A. 1997. Principles for the use of nonprotein nitrogen and by-pass protein in diets for ruminants. World Anim. Rev. **22**: 2.

Kennedy, P. M. and Milligan, L. P. 1980. The degradation and utilization of endogenous urea in the gastrointestinal tract of ruminants: A review. Can. J. Anim. Sci. **60**: 205-221.

Ketelaars, J. J. and Tolkamp, B. J. 1992. Toward a new theory of feed intake regulation in ruminants. I. Causes of differences in voluntary feed intake: critique of current views. Lives. Prod. Sci. **30**: 269-296.

Kincaid, R. 1988. Macro elements for ruminants. (326-341) *in* Church, D. C. (ed). The ruminant animal: digestive physiology and nutrition. Waveland Press Inc., Long Grove, IL, USA.

Klein, L. 2006. Winter swath grazing. Saskatchewan Agriculture and Food. Farm Facts.

Kleinschmit, D. H., Anderson, J. L., Schingoethe, D. J., Kalscheur, K. F. and Hippen, A. R. 2007. Ruminal and intestinal degradability of distillers grains plus solubles varies by source. J. Dairy Sci. **90**: 2909-2918.

Klopfenstein, T. J. and Adams, D. C. 2005. Using ethanol industry coproducts in diets for forage fed cattle. J. Anim. Sci. **83 (Suppl. 2)**: 49.

Klopfenstein, T. J., Erickson, G. E. and Bremer, V. R. 2007. Feeding corn milling byproducts to feedlot cattle. Vet. Clin. North Am. Food Anim. Pract. **23**: 223-245.

Klopfenstein, T. J., Erickson, G. E. and Bremer, V. R. 2008. Board-invited review: Use of distillers by-products in the beef cattle feeding industry. J. Anim. Sci. **86**: 1223-1231.

Kononoff, P. J. and Erickson, G. E. 2006. Feeding corn milling co-products to dairy and beef cattle. Proc. 21st Annual SW Nutrition and Management Conf. Tempe, AZ, USA.

Koster, H. H., Cochran, R. C., Titgemeyer, E. C., Vanzant, E. S., Abdelgadir, I. and St-Jean, G. 1996. Effect of increasing degradable intake protein on intake and digestion of low-quality, tallgrass-prairie forage by beef cows. J. Anim. Sci. **74**: 2473-2481.

Kowalenko, C. G. 1993. Extraction of available sulfur. (65-74) *in* Carter (ed). Soil Sampling and Methods of Analysis. Lewis Publishers, Boca Raton, FL, USA.

Krysl, L. J. and Hess, B. W. 1993. Influence of supplementation on behavior of grazing cattle. J. Anim. Sci. **71**: 2546-2555.

Lacefield, G., Smith, R., Henning, J., Johns, J. and Burris, R. 2006. Stockpiling for fall and winter pasture. University of Kentucky Cooperative Extension Service. AGR-162.

Lamb, C. S. and Eadie, J. 1979. The effect of barley supplements on the voluntary intake and digestion of low quality forages by sheep. J. Agric. Sci. **92**: 235.

Lardner, H. A. 2005. Effect of winter feeding systems on beef cow performance. Factsheet #2005-03. Western Beef Development Centre.

Lardner, H. A. and Froehlich, L. 2006. Swath grazing golden german millet with beef cows. Western Beef Development Centre. Revised Factsheet #2006-02.1.

Larson, E. M., Stock, R. A., Klopfenstein, T. J., Sindt, M. H. and Huffman, R. P. 1993. Feeding value of wet distillers byproducts for finishing ruminants. J. Anim. Sci. **71**: 2228-2236.

Leaver, J. D. 1985. Milk production from grazed temperate grassland. J. Dairy Res. **52**: 313-344.

Lee, W. J., Sosulski, F. W. and Sokhansamj, S. 1991. Yield and composition of soluble and insoluble fractions from corn and wheat stillages. Cereal Chem. **68**: 559-562.

Leibholz, J. and Kellaway, R. C. 1984. The utilization of low quality roughages. 1. the role of nitrogen and energy supplements. Australian Meat Research Committee Reviews. No. 48. pg 1-21. AMRC. Sydney, NSW, AU.

Lintzenich, B. A., Vanzant, E. S., Cochran, R. C., Beaty, J. L., Brandt, R. T., Jr and St Jean, G. 1995. Influence of processing supplemental alfalfa on intake and digestion of dormant bluestem-range forage by steers. J. Anim. Sci. **73**: 1187-1195.

Loneragan, G. H., Wagner, J. J., Gould, D. H., Garry, F. B. and Thoren, M. A. 2001. Effects of water sulfate concentration on performance, water intake, and carcass characteristics of feedlot steers. J. Anim. Sci. **79**: 2941-2948.

Lopez Molinero, A. L., Castillo, J. R. and de Vega, A. 1988. Determination of ytterbium by AES-ICP. Application to samples of biological origin. Fresenius. J. Anal. Chem. **88**: 721-724.

Lowman, B. G., Scott, N. A. and Sommerville, S. H. 1976. Condition scoring for cattle. East of Scotland College of Agriculture Bulletin No. 6. Edinburgh School of Agriculture. Edinburgh. pg 31.

Loy, D. D. and Wright, K. N. 2003. Nutritional properties and feeding value of corn and its by-products. (695-721) *in* White, P. J. and Johnson, L. A. (ed). Corn Chemistry and Technology. 2nd ed. American Association of Cereal Chemists, Inc., St. Paul, MN, USA.

Loy, T. W., MacDonald, J. C., Klopfenstein, T. J. and Erickson, G. E. 2007. Effect of distillers grains or corn supplementation frequency on forage intake and digestibility. J. Anim. Sci. **85**: 2625-2630.

Lusby, K. S., Wettemann, R. P., Ovenell, K. H. and Cox, D. A. 1991. Effects of lactation on performance of grazing beef cows wintered with supplements containing soybean meal, wheat middings, or soubean meal-wheat middlings mixtures. Prof. Anim. Sci. **7**: 30-34.

MacDonald, J. C., Klopfenstein, T. J., Erickson, G. E. and Griffin, W. A. 2007. Effects of dried distillers grains and equivalent undegradable intake protein or ether extract on performance and forage intake of heifers grazing smooth bromegrass pastures. J. Anim. Sci. **85**: 2614-2624.

MacDonald, K. A., Penno, J. W. and Verkerk, G. A. 1999. Validation of body condition scoring by using ultrasound measurements of subcutaneous fat. Proc. New Zealand Soc. Anim. Prod. **59**: 177-179.

Mackie, R. I., Gilchrist, F. M. C., Robberts, A. M., Hannah, P. E. and Schwartz, H. M. 1978. Microbiological and chemical changes in the rumen during the stepwise adaptation of sheep to high concentrate diets. J. Agric. Sci. **90**: 241-254.

Mader, T. L., Teeter, R. G. and Horn, G. W. 1984. Comparison of forage labeling techniques for conducting passage rate studies. J. Anim. Sci. **58**: 208-212.

Maisch, W. F. 2003. Fermentation processes and products. (695-721) *in* White, P. J. and Johnson, L. A. (ed). Corn Chemistry and Technology. 2nd ed. American Association of Cereal Chemists, Inc., St. Paul.

Males, J. R., McReynolds, W. E., Gaskin, C. T. and Preston, R. L. 1982. Supplementation of wheat straw diets to optimize performance of wintering beef cows. J. Anim. Sci. **54**: 384-390.

Males, J. R. 1987. Optimizing the utilization of cereal crop residues for beef cattle. J. Anim. Sci. **65**: 1124-1130.

Manitoba Agriculture Food and Rural Initiatives. 2008. A quick guide to extended grazing. Growing Opportunities Factsheet. February 2008.

Marston, T. T., Lusby, K. S., Wettemann, R. P. and Purvis, H. T. 1995. Effects of feeding energy or protein supplements before or after calving on performance of spring-calving cows grazing native range. J. Anim. Sci. **73**: 657-664.

Martin, C. L., Millet, G., Fonty, G. and Michalet-Doreau, B. 2001. Cereal supplementation modified the fibrolytic activity but not the structure of the cellulolytic bacterial community associated with rumen solid digesta. Reprod. Nutr. Dev. **41**: 413-424.

Martin, J. L., Cupp, A. S., Rasby, R. J., Moline, K. V., Bergman, J. W., Dragastin, M. and Funston, R. N. 2007a. Utilization of dried distillers grains for developing beef heifers. Nebraska Beef Cattle Report. MP 90. University of Nebraska Cooperative Extension.

Martin, J. L., Cupp, A. S., Rasby, R. J., Hall, Z. C. and Funston, R. N. 2007b. Utilization of dried distillers grains for developing beef heifers. J. Anim. Sci. **85**: 2298-2303.

Matches, A. G. and Burns, J. C. 1995. Systems of grazing management. (179-192) *in* Barnes, R. F., Nelson, C. J., Moore, K. J. and Collins, M. (ed). Forages: the science of grassland agriculture. Iowa State University Press, Ames, IA, USA.

Mathis, C. P., Cochran, R. C., Stokka, G. L., Heldt, J. S., Woods, B. C. and Olson, K. C. 1999. Impacts of increasing amounts of supplemental soybean meal on intake and digestion by beef steers and performance by beef cows consuming low-quality tallgrass-prairie forage. J. Anim. Sci. **77**: 3156-3162.

Mathis, C. P., Cochran, R. C., Heldt, J. S., Woods, B. C., Abdelgadir, I. E., Olson, K. C., Titgemeyer, E. C. and Vanzant, E. S. 2000. Effects of supplemental degradable intake protein on utilization of medium- to low-quality forages. J. Anim. Sci. **78**: 224-232.

Mathis, C. P. and Sawyer, J. E. 2007. Nutritional management of grazing beef cows. Vet. Clin. North Am. Food Anim. Pract. **23**: 1-19.

Mathison, G. W., Soofi-Siawash, R., Okine, E. K., Helm, J. and Juskiw, P. 1999. Factors influencing composition and ruminal degradability of barley straw. Can. J. Anim. Sci. **79**: 343-351.

Mayes, R. W., Lamb, C. S. and Colgrove, P. M. 1986. The use of dosed and herbage n-alkanes as markers for the determination of herbage intake. J. Agric. Sci. **107**: 161-170.

McCartney, D., Basarab, J. A., Okine, E. K., Baron, V. S. and Depalme, A. J. 2004a. Alternative fall and winter feeding systems for spring calving beef cows. Can. J. Anim. Sci. **84**: 511-522.

McCartney, D., Townley-Smith, L., Vaage, A. and Pearen, J. 2004b. Cropping systems for annual forage production in northeast Saskatchewan. Can. J. Plant Sci. **84**: 187-194.

McCartney, D., Fraser, J. and Ohama, A. J. 2008. Annual cool season crops for grazing by beef cattle. A Canadian review. Can. J. Anim. Sci. **88**: 517-533.

McCartney, D. H., Block, H. C., Dubeskj, P. L. and Ohama, A. J. 2006. The composition and availability of straw and chaff from small grain cereals for beef cattle in western Canada. Can. J. Anim. Sci. **86**: 443-455.

McCollum, F. T., Galyean, M. L., Krysl, L. J. and Wallace, J. D. 1985. Cattle grazing blue grama rangeland I. Seasonal diets and rumen fermentation. J. Range Manage. **38**: 539-543.

McCollum, F. T. and Galyean, M. L. 1985a. Cattle grazing blue grama rangeland II. Seasonal forage intake and digesta kinetics. J. Range Manage. **38**: 543-546.

McCollum, F. T. and Galyean, M. L. 1985b. Influence of cottenseed meal supplementation on voluntary intake, rumen fermentation and rate of passage of prairie hay in beef steers. J. Anim. Sci. **60**: 570-577.

McCollum, F. T. and Horn, G. W. 1990. Protein supplementation of grazing livestock: a review. Prof. Anim. Sci. **6**: 1-16.

McGechan, M. B. and Topp, C. F. E. 2004. Modelling environmental impacts of deposition of excreted nitrogen by grazing dairy cows. Agriculture, Ecosystems & Environment. **103**: 149-164.

McGee, M. and Drennan, M. J. 2008. Performance of beef suckler cows and their progeny to slaughter on intensive and extensive grassland systems. Biodiversity and animal feed: future challenges for grassland production. Proc. 22nd General Meeting of the European Grassland Federation. Uppsala, Sweden. 9-12 June 2008. pg 968-970.

McKinnon, J. J., Olubobokum, J. A., Christensen, D. A. and Cohen, R. D. H. 1991. The influence of heat and chemical treatment on ruminal disappearance of canola meal. Can. J. Anim. Sci. **71**: 773-780.

McLeod, M. N. and Minson, D. J. 1978. The accuracy of the pepsin-cellulase technique for estimating the dry matter digestibility in vivo of grasses and legumes. Anim. Feed Sci. Technol. **3**: 277-287.

Mehrez, A. Z., Orskov, E. R. and McDonald, I. 1977. Rates of rumen fermentation in relation to ammonia concentration. Br. J. Nutr. **38**: 437-443.

Mehrez, A. Z. and Orskov, E. R. 1977. A study of artificial fibre bag technique for determining the digestibility of feeds in the rumen. J. Agric. Sci. **88**: 645-650.

Meijs, J. A. C. 1986. Concentrate supplementation of grazing dairy cows. 2. Effects of concentrate composition on herbage intake and milk production. Grass Forage Sci. **41**: 229-235.

Menke, K. H. and Steingass, H. 1988. Estimation of the energetic feed value obtained from chemical analysis and *in vitro* gas production using rumen fluid. Anim. Res. Dev. **29**: 7-55.

Mertens, D. R. 1983. Using neutral detergent fiber to formulate dairy rations and estimate the net energy content of forages. Proc. Cornell Nutrition Conference for Feed Manufacturers. Cornell University.

Mertens, D. R. 1987. Predicting intake and digestibility using mathematical models of ruminal function. J. Anim. Sci. **64**: 1548-1558.

Mertens, D. R. 1994. Regulation of forage intake. (450-493) *in* Fahey Jr, G. C., Collins, M. C., Mertens, D. R. and Moser, L. E. (ed). Forage Quality, Evaluation, and Utilization. ASA-CSSA-SSSA, Madison, WI, USA.

Meyer, A. M., Kerley, M. S., Kallenbach, R. L. and Perkins, T. L. 2009. Comparison of grazing stockpiled tall fescue versus feeding hay with or without supplementation for gestating and lactating beef cows during winter. Prof. Anim. Sci. **25**: 449-458.

Meyer, R. M., Bartley, E. E., Julius, F. and Fina, L. R. 1971. Comparison of four in vitro methods for predicting in vivo digestibility of forages. J. Anim. Sci. **32**: 1030-1036.

Miller, R. F., Haferkamp, M. R. and Angell, R. F. 1990. Clipping date effects on soil water and regrowth in crested wheatgrass. J. Range Manage. **43**: 253-257.

Minson, D. J. 1990. Forages in Ruminant Nutrition. Academic Press. San Diego, USA.

Moore, J. E., Brant, M. H., Kunkle, W. E. and Hopkins, D. I. 1999. Effects of supplementation on voluntary forage intake, diet digestibility, and animal performance. J. Anim. Sci. **77**: 122-135.

Moore, K. J. and Hatfield, R. D. 1994. Carbohydrates and forage quality. (229-280) *in* Fahey Jr, G. C., Collins, M. C., Mertens, D. R. and Moser, L. E. (ed). Forage quality, evaluation, and utilization. ASA-CSSA-SSSA, Madison, WI, USA.

Morris, S. E., Klopfenstein, T. J., Adams, D. C., Erickson, G. E. and Vander Pol, K. J. 2005. The effects of dried distillers grains on heifers consuming low or high-quality forage. Nebraska Beef Cattle Report. MP 83-A. 18-20.

Morris, S. E., MacDonald, J. C., Adams, D. C., Klopfenstein, T. J., Davis, R. L. and Teichert, J. R. 2006. Effects of supplementing dried distillers grains to steers grazing summer sandhill range. Nebraska Beef Cattle Report. MP 88-A. pg 30-32.

Morse, D., Head, H. H., Wilcox, C. J., Van Horn, H. H., Hissem, C. D. and Harris, B., Jr. 1992. Effects of concentration of dietary phosphorus on amount and route of excretion. J. Dairy Sci. **75**: 3039-3049.

Mould, F. L., Ørskov, E. R. and Mann, S. O. 1983. Associative effects of mixed feeds. I. effects of type and level of supplementation and the influence of the rumen fluid pH on cellulolysis in vivo and dry matter digestion of various roughages. Anim. Feed Sci. Technol. **10**: 15-30.

Mould, F. L. and Ørskov, E. R. 1983. Manipulation of rumen fluid pH and its influence on cellulolysis in sacco, dry matter degradation and the rumen microflora of sheep offered either hay or concentrate. Anim. Feed Sci. Technol. **10**: 1-14.

Mulholland, J. G., Coombe, J. B. and McManus, W. R. 1976. Effect of starch in the utilization by sheep of a straw diet supplemented with urea and minerals. Aust. J. Agric. Res. **27**: 139.

Mustafa, A. F., McKinnon, J. J. and Christensen, D. A. 2000a. Chemical characterization and in situ nutrient degradability of wet distillers' grains derived from barley-based ethanol production. Anim. Feed Sci. Technol. **83**: 301-311.

Mustafa, A. F., McKinnon, J. J. and Christensen, D. A. 2000b. The nutritive value of thin stillage and wet distillers' grains for ruminants. Asian-Aus. J. Anim. Sci. **13**: 1609-1618.

Mustafa, A. F., McKinnon, J. J., Ingledew, W. M. and Christensen, D. A. 2000c. The nutrtive value for ruminants of thin stillage and distillers' grains derived from wheat, rye, triticale, and barley. J. Sci. Food Agric. **80**: 607-613.

National Research Council: Nutrient Requirements of Beef Cattle. 1996. 7th Revised Ed. National Academy Press. Washington, DC, USA.

Nayigihugu, V., Schleicher, A. D., Koch, D. W., Held, L. J., Flake, J. W. and Hess, B. W. 2007. Beef cattle production, nutritional quality, and economics of windrowed forage vs. baled hay during winter. Agron. J. **99**: 944-951.

Nozière, P. and Michalet-Doreau, B. 1996. Validation of in sacco method: influence of sampling site, nylon bag or rumen contents, on fibrolytic activity of solid-associated microorganisms. Anim. Feed Sci. Technol. **57**: 203-210.

Nuez-Ortin, W. G. and Yu, P. 2009a. Comparison of NRC-2001 chemical approach with biological approach (in situ animal study) in the determination of digestible nutrients and energy values of dry distillers grains with solubles in ruminants. J. Anim. Sci. **87**: (E-Suppl. 2).

Nuez-Ortin, W. G. and Yu, P. 2009b. Nutrient variation and availability of wheat DDGS, corn DDGS and blend DDGS from bioethanol plants. J. Sci. Food Agric. **89**: 1754-1761.

Nyachoti, C. M., House, J. D., Slominsky, B. A. and Seddon, I. R. 2005. Energy and nutrient digestibilities in wheat dried distillers' grains with solubles fed to growing pigs. J. Sci. Food Agric. **85**: 2581-2586.

Ojowi, M., Christensen, D. A., McKinnon, J. J. and Mustafa, A. F. 1996. Thin stillage from wheat-based ethanol production as a nutrient supplement for cattle grazing crested wheatgrass pastures. Can. J. Anim. Sci. **76**: 547-553.

Ojowi, M., McKinnon, J. J., Mustafa, A. F. and Christensen, D. A. 1997. Evaluation of wheat-based wet distillers' grains for feedlot cattle. Can. J. Anim. Sci. **77**: 447-454.

Olar, M., Romain, R., Bergeron, N. and Klein, K. 2004. Ethanol industry in Canada. Research series SR.04.08. Centre for Research in the Economics of Agrifood. Larval University.

Oldham, J. D. 1982. Amino acid requirements for lactation in high-yielding dairy cows. (49-81) *in* Haresign, W. and Cole, D. J. A. (ed). Recent Developments in Ruminant Nutrition. Butterworths, London.

Olson, K. C., Cochran, R. C., Jones, T. J., Vanzant, E. S., Titgemeyer, E. C. and Johnson, D. E. 1999. Effects of ruminal administration of supplemental degradable intake protein and starch on utilization of low-quality warm-season grass hay by beef steers. J. Anim. Sci. **77**: 1016-1025.

Olson, K. C. 2005. Range management for efficient reproduction. J. Anim. Sci. **83**: (E-Suppl.): E107-116.

Orskov, E. R. and McDonald, J. 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. J. Agric. Sci. **92**: 499-503.

Orskov, E. R., DeB Hovell, F. D. and Mould, F. 1980. The use of the nylon bag technique for the evaluation of feedstuffs. Trop. Anim. Prod. **5**: 195-213.

Orskov, E. R. 1986. Starch digestion and utilization in ruminants. J. Anim. Sci. **63**: 1624-1633.

Ortiz-Rubio, M. A., Ørskov, E. R., Milne, J. and Galina, H. M. A. 2007. Effect of different sources of nitrogen on in situ degradability and feed intake of Zebu cattle fed sugarcane tops (Saccharum officinarum). Anim. Feed Sci. Technol. **139**: 143-158.

Owens, F. N. and Hanson, C. F. 1992. External and internal markers for appraising site and extent of digestion in ruminants. J. Dairy Sci. **75**: 2605-2617.

Pell, A. N. and Schofield, P. 1993. Computerized monitoring of gas production to measure forage digestion in vitro. J. Dairy Sci. **76**: 1063-1073.

Petersen, M. K. 1987. Nitrogen supplementation of grazing livestock. Proc. Grazing Livest. Nutr. Conf. Jackson, WY, USA. pg 115-121.

Poore, M. H., Scott, M. E. and Green, J. T., Jr. 2006. Performance of beef heifers grazing stockpiled fescue as influenced by supplemental whole cottonseed. J. Anim. Sci. **84**: 1613-1625.

Prescott, M. L., Havstad, K. M., Olson-Rutz, K. M., Ayers, E. L. and Petersen, M. K. 1994. Grazing behavior of free-ranging beef cows to initial and prolonged exposure to fluctuating thermal environments. Appl. Anim. Behav. Sci. **39**: 103-113.

Qian, P., Schoenau, J. J. and Karamanos, R. E. 1994. Simultaneous extraction of available phosphorus and potassium with a new soil test: a modification of Kelowna extraction. Commun. Soil Sci. Plant Anal. **25**: 627-635.

Redmon, L. A., McCollum, F. T., III, Horn, G. W., Cravey, M. D., Gunter, S. A., Beck, P. A., Mieres, J. M. and Julian, R. S. 1995. Forage intake by beef steers grazing winter wheat with varied herbage allowances. J. Range Manage. **48**: 198-201.

Redmon, R. G., Kellaway, R. C. and Leibholz, J. 1980. Utilization of low quality roughages: effects of urea and protein supplements of differing solublility on digesta flows, intake and growth rate of cattle eating oatten chaff. Br. J. Nutr. **44**: 343-354.

Reed, J. J., Lardy, G. P., Bauer, M. L., Gilbery, T. C. and Caton, J. S. 2004. Effect of field pea level on intake, digestion, microbial efficiency, ruminal fermentation, and in situ disappearance in beef steers fed forage-based diets. J. Anim. Sci. **82**: 2185-2192.

Reed, J. J., O'Neil, M. R., Lardy, G. P., Vonnahme, K. A., Reynolds, L. P. and Caton, J. S. 2007. Effect of undegradable intake protein supplementation on intake, digestion, microbial efficiency, in situ disappearance, and plasma hormones and metabolites in steers fed low-quality grass hay. J. Anim. Sci. **85**: 1092-1101.

Rich, A. R., Luebbe, M. K., Erickson, G. E., Klopfenstein, T. J. and Bentonn, J. R. 2009. Effects of feeding fibre from wet corn gluten feed and silage in diets containing 30% modified wet distillers grains plus solubles on feedlot cattle performance and nitrogen mass balance. Proc. ADSA-ASAS-CSAS Joint Annual Meeting. Montreal, QC, Canada. July 12-16, 2009.

Riesterer, J. L., Undersander, D. J., Casler, M. D. and Combs, D. K. 2000. Forage yield of stockpiled perennial grasses in the upper midwest USA. Agron. J. **92**: 740-747.

Rinne, M., Olt, A., Nousiainen, J., Seppal, A., Tuori, M., Paul, C., Fraser, M. D. and Huhtanen, P. 2006. Prediction of legume silage digestibility from various laboratory methods. Grass Forage Sci. **61**: 354-362.

Rittenhouse, L. R., Clanton, D. C. and Streeter, C. L. 1970. Intake and digestibility of winter-range forage by cattle with and without supplements. J. Anim. Sci. **31**: 1215-1221.

Robinson, P. H., Fadel, J. G. and Tamminga, S. 1986. Evaluation of mathematical models to describe neutral detergent residue in terms of its susceptibility to degradation in the rumen. Anim. Feed Sci. Technol. **15**: 249-271.

Robinson, P. H., Tamminga, S. and Van Vuuren, A. M. 1987. Influence of declining level of feed intake and varying the proportion of starch in the concentrate on milk production and whole tract digestibility in dairy cows. Lives. Prod. Sci. **17**: 19-35.

Rosentrater, K. 2007. Corn ethanol coproducts - some current constraints and potential opportunities. Internat. Sugar J. **109**: 685-697.

Russell, J. B. and Baldwin, R. L. 1978. Substrate preferences in rumen bacteria: evidence of catabolite regulatory mechanisms. Appl. Environ. Microbiol. **36**: 319-329.

Sanford, B. J., Grove, A. V. and Hunt, C. W. 2003. Evaluation of barley characteristics that are associated with digestible energy for beef cattle. Prof. Anim. Sci. **19**: 281-285.

Sanson, D. W. and Clanton, D. C. 1989. Intake and Digestibility of Low-Quality Meadow Hay by Cattle Receiving Various Levels of Whole Shelled Corn. J. Anim Sci. **67**: 2854-2862.

Sanson, D. W., Clanton, D. C. and Rush, I. G. 1990. Intake and digestion of low-quality meadow hay by steers and performance of cows on native range when fed protein supplements containing various levels of corn. J. Anim. Sci. **68**: 595-603.

SAS Institute Inc. 2003. SAS User's Guide: Statistics. Version 9.1.3. Statistical Analysis Systems. Cary, N. C., USA.

SAS Institute Inc. 2005. SAS User's Guide: Statistics. Version 9.1.3. Statistical Analysis Systems. Cary, N. C., USA.

Saskatchewan Ministry of Agriculture (SMA). 2006. Farm machinery custom and rental rate guide. 2006-2007. Regina, SK, Canada.

Satter, L. D. and Slyter, L. L. 1974. Effect of ammonia concentration on rumen microbial protein production in vitro. Br. J. Nutr. **32**: 199.

Saxton, A. M. 1998. A macro for converting mean separation output to letter groupings in Proc Mixed. Proc. 23rd SAS Users Group Intl. Cary, NC, USA. pg 1243-1246.

Scales, G. H., Streeter, C. L., Denham, A. H. and Ward, G. M. 1974. A comparison of indirect methods of predicting *in vivo* digestibility of grazed forage. J. Anim. Sci. **38**: 192-199.

Scarbrough, D. A., Coblentz, W. K., Coffey, K. P., Harrison, K. F., Smith, T. F., Hubbell, D. S., III, Humphry, J. B., Johnson, Z. B. and Turner, J. E. 2004. Effects of nitrogen fertilization rate, stockpiling initiation date, and harvest date on canopy height and dry matter yield of autumn-stockpiled bermudagrass. Agron. J. **96**: 538-546.

Schaafsma, A. W., Limay-Rios, V., Paul, D. E. and Miller, J. D. 2009. Mycotoxins in fuel ethanol co-production derived from maize: a mass balance for deoxymivalenol. J. Sci. Food Agric. **89**: 1574-1580.

Schauer, C. S., Bohnert, D. W., Ganskopp, D. C., Richards, C. J. and Falck, S. J. 2005. Influence of protein supplementation frequency on cows consuming low-quality forage: performance, grazing behavior, and variation in supplement intake. J. Anim. Sci. **83**: 1715-1725.

Schingoethe, D. J. 2006. Feeding ethanol byproducts to dairy and beef cattle. Proc. 2006 Calif. Anim. Nutr. Conf. Fresno, CA, USA. May 10-11, 2006. pg 49-63.

Schroder, U. J. and Staufenbiel, R. 2006. Invited Review: methods to determine body fat reserves in the dairy cow with special regard to ultrasonographic measurement of backfat thickness. J. Dairy Sci. **89**: 1-14.

Silvey, M. W. and Haydock, K. P. 1978. A note on live-weight adjustment for pregnancy in cows. Anim. Prod. **27**: 113-116.

Smith, C. D., Whittier, J. C., Pas, Schutz, D. N. and Couch, D. 2001. Comparison of alfalfa hay and distillers dried grains with solubles, along or in compbination with cull beans, as protein sources for beef cows grazing native winter range. Prof. Anim. Sci. **17**: 139-144.

Sniffen, C. J., O'Connor, J. D., Van Soest, P. J., Fox, D. G. and Russell, J. B. 1992. A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. J. Anim. Sci. **70**: 3562-3577.

Spiehs, M. J., Whitney, M. H. and Shurson, G. C. 2002. Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. **80**: 2639-2645.

Spiehs, M. J. and Varel, V. H. 2009. Nutrient excretion and odorant production in manure from cattle fed corn wet distillers grains with solubles. J. Anim. Sci. **87**: 2977-2984.

Stalker, L. A., Adams, D. C. and Klopfenstein, T. J. 2006. A system for wintering beef heifers using dried distillers grains. Nebraska Beef Cattle Report. MP 88-A. pg 13-15. University of Nebraska Cooperative Extension.

Steele, J. D., Banta, J. P., Wettemann, R. P., Krehbiel, C. R. and Lalman, D. L. 2007. Drought-stressed soybean supplementation for beef cows. Prof. Anim. Sci. **23**: 358-365.

Stern, M. D., Ortega, M. E. and Satter, L. D. 1983. Retention time in rumen and degradation of protein supplements fed to lactating dairy cattle. J. Dairy Sci. **66**: 1264-1271.

Stock, R. A., Lewis, J. M., Klopfenstein, T. J. and Milton, C. T. 2000. Review of new information on the use of wet and dry milling feed by-products in feedlot diets. J. Anim. Sci. **(E-Suppl.)**:

Stokes, S. R., Goetsch, A. L., Jones, A. L. and Landis, K. M. 1988. Feed intake and digestion by beef cows fed prairie hay with different levels of soybean meal and receiving postruminal administration of antibiotics. J. Anim. Sci. **66**: 1778-1789.

Streeter, C. L. 1969. A review of techniques used to estimate the *in vivo* digestibility of grazed forage. J. Anim. Sci. **29**: 757-768.

Sultan, J. I. and Loerch, S. C. 1992. Effects of protein and energy supplementation of wheat straw-based diets on site of nutrient digestion and nitrogen metabolism of lambs. J. Anim. Sci. **70**: 2228-2234.

Sunvold, G. D., Cochran, R. C. and Vanzant, E. S. 1991. Evaluation of wheat middlings as a supplement for beef cattle consuming dormant bluestem-range forage. J. Anim. Sci. **69**: 3044-3054.

Sunvold, G. D. and Cochran, R. C. 1991. Technical note: evaluation of acid detergent lignin, alkaline peroxide lignin, acid insoluble ash, and indigestible acid detergent fiber as internal markers for prediction of alfalfa, bromegrass, and prairie hay digestibility by beef steers. J. Anim. Sci. **69**: 4951-4955.

Surber, G., Fisher, T., Cash, D., Dixon, P. and Moore, J. 2001. Swath/windrow grazing: an alternative livestock feeding technique. Montguide MT2001106 AG 8/2001. Montana State University Extension Service.

't Mannetje, L. 2000. Measuring biomass of grassland vegetation. (151-178) *in* 't Mannetje, L. and Jones, R. M. (ed). Field and laboratory methods of grassland and animal production research. CABI Publishing, Wallingford, UK.

Tamminga, S. 1980. Energy-protein relationships in ruminant feeding: similarities and differences between rumen fermentation and postruminal utilization. (4-17) *in* Miller, E. L., Pike, I. H. and Van Es, A. J. H. (ed). Protein Contribution of Feedstuffs for Ruminants: Application to Feed Formulation. Butterworth Scientific, London.

Tamminga, S. and Van Vuuren, A. M. 1988. Formation and utilization of end products of lignocellulose degradation in ruminants. Anim. Feed Sci. Technol. **21**: 141-159.

Ternouth, J. H. 1989. Endogenous losses of phosphorus by sheep. J. Agric. Sci. **113**: 291-297.

Thaler, B. 2002. Use of distillers grains with solubles (DDGS) in swine diets. Extension Extra. ExEx 2035 Animal and Range Sciences. South Dakota State Cooperative Extension Service.

Thonney, M. L., Duhaime, D. J., Moe, P. W. and Reid, J. T. 1979. Acid insoluble ash and permanganate lignin as indicators to determine digestibility of cattle rations. J. Anim. Sci. **49**: 1112-1116.

Thornton, R. F. and Minson, D. J. 1973. The relationship between apparent retention time in the rumen, volunatry intake and apparent digestibility of legume and grass diets in sheep. Aust. J. Agric. Res. **24**: 889-898.

Tibelius, C. 1996. Co-products and near co-products of fuel ethanol fermentation from grain. Agriculture and Agri-Food Canada - Canadian Green Plan Ethanol Program Starchy Waste Streams Evaluation Project.

Tilley, J. M. A. and Terry, R. A. 1963. A two-stage technique for the *in vitro* digestion of forage crops. J. Br. Grassld. Soc. **18**: 104-111.

Titgemeyer, E. C., Drouillard, J. S., Greenwood, R. H., Ringler, J. W., Bindel, D. J., Hunter, R. D. and Nutsch, T. 2004. Effect of forage quality on digestion and performance responses of cattle to supplementation with cooked molasses blocks. J. Anim. Sci. **82**: 487-494.

Trenkle, A. 1997. Substituting wet distillers grains or condensed solubles for corn grain in finishing diets for yearling heifers. Beef Research Report, Iowa State University. ASRI 451.

Uden, P. 1988. The effect of grinding and pelleting hay on digestibility, fermentation rate, digesta passage and rumen and faecal particle size in cows. Anim. Feed Sci. Technol. **19**: 145-157.

Undi, M., Wilson, C., Ominski, K. H. and Wittenberg, K. M. 2008. Comparison of techniques for estimation of forage dry matter intake by grazing beef cattle. Can. J. Anim. Sci. **88**: 693-701.

Ungar, E. D., Henkin, Z., Gutman, M., Dolev, A., Genizi, A. and Ganskopp, D. 2005. Inference of animal activity from GPS collar data on free-ranging cattle. Rangeland Ecology & Management. **58**: 256-266.

University of Saskatchewan. 2009. Wheat-based DDGS website. Available at <http://ddgs.usask.ca/portal/DesktopDefault.aspx> Verified August 12, 2009.

Vallentine, J. F. 2001. Grazing management. 2nd ed. Academic Press. San Diego, CA, USA.

van der Pol, M., Hristov, A. N., Zaman, S., Delano, N. and Schneider, C. 2009. Effect of inclusion of peas in dairy cow diets on ruminal fermentation, digestibility, and nitrogen losses. Anim. Feed Sci. Technol. **150**: 95-105.

Van Dyne, G. M. and Torrell, D. T. 1964. Development and use of the esophageal fistula: a review. J. Range Manage. **17**: 7-19.

Van Keulen, J. and Young, B. A. 1977. Evaluation of acid-insoluble ash as a natural marker in ruminant digestibility studies. J. Anim. Sci. **44**: 282-287.

Van Soest, P. J. 1967. Development of a comprehensive system of feed analyses and its application to forages. J. Anim. Sci. **26**: 119-128.

Van Soest, P. J., Robertson, J. B. and Lewis, B. A. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. **74**: 3583-3597.

Van Soest, P. J. 1994. Nutritional ecology of the ruminant. 2nd ed. Cornell University Press. Ithaca, NY, USA.

Vander Pol, K. J., Luebbe, M. K., Crawford, G. I., Erickson, G. E. and Klopfenstein, T. J. 2009. Performance and digestibility characteristics of finishing diets containing distillers grains, composites of corn processing coproducts, or supplemental corn oil. J. Anim. Sci. **87**: 639-652.

Vanzant, E. S., Cochran, R. C. and Johnson, D. E. 1991. Pregnancy and lactation in beef heifers grazing tallgrass prairie in the winter: influence on intake, forage utilization, and grazing behavior. J. Anim. Sci. **69**: 3027-3038.

Vanzant, E. S., Cochran, R. C., Titgemeyer, E. C., Stafford, S. D., Olson, K. C., Johnson, D. E. and St Jean, G. 1996. In vivo and in situ measurements of forage protein degradation in beef cattle. J. Anim. Sci. **74**: 2773-2784.

Vanzant, E. S., Cochran, R. C. and Titgemeyer, E. C. 1998. Standardization of in situ techniques for ruminant feedstuff evaluation. J. Anim. Sci. **76**: 2717-2729.

Vicente, F., Sarraseca, A., de Vega, A. and Guada, J. A. 2004. Performance of several Cr and Yb analytical techniques applied to samples of different biological origin (digesta or faeces). J. Sci. Food Agric. **84**: 2035-2040.

Villalobos, G., Adams, D. C., Klopfenstein, T. J., Nichols, J. T. and Lamb, J. B. 1997. Grass hay as a supplement for grazing cattle I. Animal performance. J. Range Manage. **50**: 351-356.

Vogel, G. J., Phillips, W. A., Horn, G. W., Ford, M. J. and McNew, R. W. 1989. Effects of supplemental silage on forage intake and utilization by steers grazing wheat pasture or bermudagrass. J. Anim. Sci. **67**: 232-240.

Volesky, J. D., Adams, D. C. and Clark, R. T. 2002. Windrow grazing and baled-hay feeding strategies for wintering calves. J. Range Manage. **55**: 23-32.

von Keyserlingk, M. A. G., Swift, M. L., Puchala, R. and Shelford, J. A. 1996. Degradability characteristics of dry matter and crude protein of forages in ruminants. Anim. Feed Sci. Technol. **57**: 291-311.

Wainman, F. W., Dewey, P. J. S. and Boyne, A. W. 1981. Compound feedingstuffs for ruminants. Feedingstuffs Evaluation Unit. Third Report. pg 49. Rowett Research Institute. Aberdeen, UK.

Walburger, K. J. 2007. Strategic supplementation of beef cattle on rangelands. Proc. Western Nutrition Conference. Saskatoon, SK, Canada.

Waldron, B. L., ZoBell, D. R., Olson, K. C., Jensen, K. B. and Snyder, D. L. 2006. Stockpiled forage kochia to maintain beef cows during winter. Range. Ecology Manage. **59**: 275-284.

Weigel, J. C., Loy, D. and Kilmer, L. 2005. Feed co-products of the dry corn milling process. Iowa State University and Iowa Corn Promotion Board. Available at <http://www.dakotagold.org/files/dry-milling-book.pdf> Verified August 5, 2009.

Weiss, W. P. 1993. Predicting energy values of feeds. J. Dairy Sci. **76**: 1802-1811.

Wildman, E. E., Jones, G. M., Wagner, P. E., Boman, R. L., Troutt, H. F., Jr. and Lesch, T. N. 1982. A dairy cow body condition scoring system and its relationship to selected production characteristics. J. Dairy Sci. **65**: 495-501.

Willms, W. D., Rode, L. M. and Freeze, B. S. 1993. Winter performance of Hereford cows on fescue prairie and in drylot as influenced by fall grazing. Can. J. Anim. Sci. **73**: 881-889.

Willms, W. D., Rode, L. M. and Freeze, B. S. 1998. Protein supplementation to enhance the performance of pregnant cows on rough fescue grasslands in winter. Can. J. Anim. Sci. **78**: 89-94.

Wilson, A. D., Weir, W. C. and Torell, D. T. 1971. Comparison of methods of estimating the digestibility of range forage and browse. J. Anim. Sci. **32**: 1046-1050.

Wilson, A. D. 1982. Environmental and nutritional factors affecting herbage quality. (111-125) *in* Hacker, J. B. (ed). Nutritional limits to animal production from pastures. C.A.B.

Winterholler, S. J., Lalman, D. L., Hudson, M. D. and Goad, C. L. 2009. Supplemental energy and extruded-expelled cottonseed meal as a supplemental protein source for beef cows consuming low-quality forage. J. Anim. Sci. **87**: 3003-3012.

Wise, M. B., Ordoveza, A. L. and Barrick, E. R. 1963. Influence of variations in dietary calcium:phosphorus ratio on performance and blood constituents of calves. J. Nutr. **79**: 79-84.

Yu, P., Christensen, D. A. and McKinnon, J. J. 2004. In situ rumen degradation kinetics of timothy and alfalfa as affected by cultivar and stage of maturity. Can. J. Anim. Sci. **84**: 255-263.

Yu, P. 2005. Modeling nutrient supply to dairy cattle from a feedstuff using NRC-2001 (a TDN-based model) with inputs based on in situ and mobile bag technique measurements. Can. J. Anim. Sci. **85**: 513-519.

Zorrilla-Rios, J., Horn, G. W. and McNew, R. W. 1989. Effect of ammoniation and energy supplementation on the utilization of wheat straw by sheep. Anim. Feed Sci. Technol. **22**: 305-320.

Zorrilla-Rios, J., Horn, G. W., Phillips, W. A. and McNew, R. W. 1991. Energy and protein supplementation of ammoniated wheat straw diets for growing steers. J. Anim. Sci. **69**: 1809-1819.

Zulu, V. C., Nakao, T., Moriyoshi, M., Nakada, K., Sawamukai, Y., Tanaka, Y. and Zhang, W. 2001. Relationship between body condition score and ultrasonographic measurement of subcutaneous fat in dairy cows. Asian-Australian Journal of Animal Science. **14**: 816-820.

APPENDIX A

Table A.1 Feed ingredient composition of commercial range pellet

Item	Composition (% DM)
Soybean meal (46%)	39.7
Wheat shorts	15.0
Canola meal	40.0
Ground barley	4.3
Molasses	1.0

Table A.2 Average daily meteorological data for Termuende Research Ranch, September 2007[z]

	Temperature (°C)			Precipitation (mm)		
Day	Maximum	Minimum	Mean	Rain	Snow[y]	Total
1	26	6.6	17.8	0	0	0
2	22.5	3.4	13.7	0	0	0
3	25.7	10.9	17.1	0	0	0
4	26.5	10.5	18.5	0	0	0
5	22.4	7	15.3	0	0	0
6	12.9	5.4	10.1	11.7	0	11.7
7	13.4	1.9	8.3	0	0	0
8	17.2	0.3	8.4	0.5	0	0.5
9	17.2	2.3	9.7	0	0	0
10	15.7	3.1	10.7	0	0	0
11	18.4	-1	9.3	0	0	0
12	12.9	3.9	7.5	5.1	0	5.1
13	8	-2.7	2.9	0.3	0	0.3
14	16.9	-5	6.4	0	0	0
15	23.3	-0.5	11.9	0	0	0
16	29.6	3.3	15.2	0	0	0
17	15.4	6	8.9	0	0	0
18	18.1	2.3	9.8	0	0	0
19	13.1	2.5	8.1	0	0	0
20	13.3	2.8	8.4	0	0	0
21	13.9	0.1	6.4	0	0	0
22	24.4	2.2	12.5	0	0	0
23	9.5	5.5	7.2	10.2	0	10.2
24	9.5	-2	5.3	2.3	0	2.3
25	16.8	-3	6.8	0.3	0	0.3
26	16.3	2	8.8	0	0	0
27	17.4	1.2	8.3	0	0	0
28	24.4	7.6	13.9	0	0	0
29	15.7	2.1	9	0	0	0
30	14.1	-4.8	5.2	0	0	0
Monthly average	17.7	2.5	10.0	-	-	30.4
30 year average[x]	17.9	4.7	11.3	41.4	1.2	42.6

[z] Meteorological data from Agri-Environment Services Branch, Agriculture and Agri-Food Canada

[y] Snow of ground, measured early morning (Environment Canada National Weather Archive, Esk, SK)

[x] 30 year average from 1971 to 2000 (Environment Canada National Weather Archive, Watrous, SK)

Table A.3 Average daily meteorological data for Termuende Research Ranch, October 2007[z]

	Temperature (°C)			Precipitation (mm)		
Day	Maximum	Minimum	Mean	Rain	Snow[y]	Total
1	18.7	4.4	11.2	0	0	0
2	18.8	-1.4	8.4	0	0	0
3	14.2	-1.7	6.2	0	0	0
4	10.3	-4.9	2.5	0	0	0
5	7.2	0	3.3	1	0	1
6	4.7	2.4	3.4	2	0	2
7	11.6	-0.7	4.7	0	0	0
8	11.4	0	5.9	0	0	0
9	12.8	-1.9	6	0	0	0
10	9.9	-1.6	5.2	0	0	0
11	4.9	-0.1	2.6	6.1	0	6.1
12	15	1.1	6.8	0	0	0
13	11.7	5.4	7.7	1.8	0	1.8
14	15.1	2.3	7.1	0	0	0
15	16.6	2.7	8.8	0	0	0
16	14.8	0.2	7.2	0	0	0
17	8.2	5.6	7	0	0	0
18	9.9	1.5	7.1	0.8	0	0.8
19	14.3	-4.5	3.7	0	0	0
20	11.3	-3.3	3.5	0.3	0	0.3
21	9.3	-4.9	1.3	0	0	0
22	11	-6	2.7	0	0	0
23	11.8	0.3	5.9	0	0	0
24	20.9	0.6	10.9	0	0	0
25	16.2	-4.1	6	0	0	0
26	5.4	-10.3	-2.7	0	0	0
27	3.3	-13.3	-4	0	0	0
28	13.3	-3.6	3.4	0	0	0
29	15.3	1.5	6.1	0	0	0
30	7.4	-1.8	2.1	1.3	0	1.3
31	10.3	-5.3	0.4	0	0	0
Monthly average	11.8	-1.3	4.9	-	-	13.3
30 year average[x]	10.5	-1.5	4.5	20.7	7.3	28.0

[z] Meteorological data from Agri-Environment Services Branch, Agriculture and Agri-Food Canada

[y] Snow of ground, measured early morning (Environment Canada National Weather Archive, Esk, SK)

[x] 30 year average from 1971 to 2000 (Environment Canada National Weather Archive, Watrous, SK)

Table A.4 Average daily meteorological data for Termuende Research Ranch, November 2007[z]

	Temperature (°C)			Precipitation (mm)		
Day	Maximum	Minimum	Mean	Rain	Snow[y]	Total
1	7.3	-5.5	-0.4	0	0	0
2	6.2	-5.5	0.8	0	0	0
3	7.9	-5.8	0.2	0	0	0
4	4.6	-2.8	0	0.5	1	1.5
5	-1.8	-13.6	-5.7	0	0	0
6	2.8	-14.1	-4.3	0	0	0
7	2	-9.1	-3.8	0	0	0
8	4.1	-5.9	-1	1	0	1
9	-0.1	-7.9	-3.2	0	0	0
10	8.1	-6.1	-0.1	0	0	0
11	5.5	-7	0.5	0	0	0
12	8.6	-5.9	2.3	0	0	0
13	10.2	-2.7	3.2	0	0	0
14	2.2	-9.6	-2.8	0	0	0
15	2.5	-10.8	-3.6	0	0	0
16	-1.2	-7.4	-3.3	0	0	0
17	-1.3	-4.1	-2.7	0	0	0
18	4.3	-2.8	-0.7	1.5	0	1.5
19	0.1	-8.7	-3.8	0	0	0
20	-7.2	-15.8	-10	0	0	0
21	-4.4	-18.3	-11.1	0	0	0
22	-4.2	-14.8	-8	0	1	1
23	-5.9	-10.2	-8.4	0	1	1
24	-2	-9.2	-4.8	0	2	2
25	-1.9	-24.6	-13.2	0	2	2
26	-19.1	-30	-23.4	0	5	5
27	-15.9	-29.5	-19.8	0	9	9
28	-17.4	-24.1	-20.5	0	9	9
29	-19.2	-25.9	-22.6	0	9	9
30	-14.7	-23.7	-18.1	0	9	9
Monthly average	-1.3	-12.0	-6.3	-	-	51.0
30 year average[x]	-1.5	-10.4	-6.0	1.4	11.5	13.0

[z] Meteorological data from Agri-Environment Services Branch, Agriculture and Agri-Food Canada

[y] Snow of ground, measured early morning (Environment Canada National Weather Archive, Esk, SK)

[x] 30 year average from 1971 to 2000 (Environment Canada National Weather Archive, Watrous, SK)

Table A.5 Average daily meteorological data for Termuende Research Ranch, December 2007[z]

	Temperature (°C)			Precipitation (mm)		
Day	Maximum	Minimum	Mean	Rain	Snow[y]	Total
1	-15.5	-19.8	-18	0		0
2	-16.1	-24	-18.3	0		0
3	-14.4	-17	-15.5	0		0
4	-14.3	-25.3	-17.4	0		0
5	-13.7	-25.4	-17.3	0		0
6	-15.4	-27.3	-21.6	0		0
7	-19.5	-28.6	-23.2	0		0
8	-19.5	-32.9	-25.4	0		0
9	-11.3	-22	-16.7	0		0
10	-10.1	-20.8	-14.9	0		0
11	-10	-23.5	-15.5	0		0
12	-8.4	-16.8	-11.5	0		0
13	-16.8	-21.4	-19.2	0		0
14	-8.4	-23	-13.8	0		0
15	-11.1	-21.9	-14.1	0		0
16	-3.5	-18.3	-10.4	0		0
17	-12.3	-23	-17	0		0
18	-11.9	-18.5	-14.8	0		0
19	-2.8	-16.6	-9.7	0		0
20	-10.9	-18.3	-13.3	0		0
21	-8.3	-19.4	-14.4	0		0
22	-16.5	-31.1	-23.3	0		0
23	-14.8	-31.3	-24.1	0		0
24	-2.5	-14.8	-7.6	0		0
25	-4.3	-14.6	-9.4	0		0
26	-5.4	-12.1	-8.4	0		0
27	-6	-15.6	-9.3	0		0
28	-6.8	-22.6	-11.8	0		0
29	-16	-24	-18.3	0		0
30	-14	-21.4	-16.9	0		0
31	-18	-27.6	-21.5	0		0
Monthly average	-11.6	-21.9	-15.9	-	-	-
30 year average[x]	-9.2	-18.6	-13.9	1.7	16.9	18.6

[z] Meteorological data from Agri-Environment Services Branch, Agriculture and Agri-Food Canada

[y] Snow of ground, measured early morning (Environment Canada National Weather Archive, Esk, SK)

[x] 30 year average from 1971 to 2000 (Environment Canada National Weather Archive, Watrous, SK)

Table A.6 Average daily meteorological data for Termuende Research Ranch, January 2008[z]

	Temperature (°C)			Precipitation (mm)		
Day	Maximum	Minimum	Mean	Rain	Snow[y]	Total
1	-12.1	-29.1	-19.7	0		0
2	-1.2	-22.6	-10.1	0		0
3	-0.1	-8.3	-4.7	0		0
4	4.3	-6.2	-3	0		0
5	3.8	-5.3	-0.9	0		0
6	1.1	-12.1	-3.5	0		0
7	-8.2	-16.5	-11.9	0		0
8	-12.7	-20.5	-16.5	0	0	0
9	-14.5	-20	-17.2	0	12	12
10	-12.7	-18.8	-15.1	0		0
11	-10.2	-19.3	-14.2	0	12	12
12	-5.6	-12.2	-8.6	0	12	12
13	-11.9	-18.5	-14.4	0		0
14	-4.6	-19.6	-10.9	0		0
15	-0.5	-18.3	-8.4	0		0
16	-12.8	-27.2	-19.6	0		0
17	-9.8	-28.6	-17.9	0		0
18	-19.7	-32.6	-25.9	0		0
19	-17.8	-28.3	-20.1	0		0
20	-18.8	-32	-24.5	0		0
21	-13.6	-24.4	-18.5	0		0
22	-14	-27.6	-18.8	0		0
23	-15.8	-28.3	-20.7	0		0
24	-8.9	-23.3	-14.1	0		0
25	-9.7	-20.1	-13.8	0		0
26	-9.8	-21.6	-16	0		0
27	-9.3	-16.5	-11.3	0		0
28	-13.9	-31.4	-24.1	0		0
29	-31.4	-39.2	-34.6	0		0
30	-25.9	-38.8	-33.8	0		0
31	-18.9	-32	-25.5	0		0
Monthly average	-10.8	-22.6	-16.1	-	-	12.0
30 year average[x]	-11.7	-21.8	-16.8	0.7	16.8	17.5

[z] Meteorological data from Agri-Environment Services Branch, Agriculture and Agri-Food Canada

[y] Snow of ground, measured early morning (Environment Canada National Weather Archive, Esk, SK)

[x] 30 year average from 1971 to 2000 (Environment Canada National Weather Archive, Watrous, SK)

Table A.7 Average daily meteorological data for Termuende Research Ranch, August 2008[z]

	Temperature (°C)			Precipitation (mm)		
Day	Maximum	Minimum	Mean	Rain	Snow[y]	Total
1	30.7	8.2	20.1	0	0	0
2	24.7	9.8	17.2	0	0	0
3	23.1	6.1	15.4	0	0	0
4	22.7	7.9	15.5	0	0	0
5	27.1	6.4	15.9	1	0	1
6	24.9	6.9	16.9	0	0	0
7	28.9	6.8	19	0	0	0
8	30.8	12.7	21.2	0	0	0
9	27	15.5	20.5	0	0	0
10	30.7	14	20.8	0.5	0	0.5
11	27.7	11.4	19.2	0	0	0
12	21.8	9.1	14.7	2.8	0	2.8
13	17.5	10.6	14	1.8	0	1.8
14	23.8	11.3	16.8	0	0	0
15	27.9	7.7	18.5	0	0	0
16	31.3	10.8	20.8	0	0	0
17	27.5	9.8	18.7	0	0	0
18	30.9	7.9	20.4	0	0	0
19	36.8	14.3	25	0	0	0
20	32.6	16.4	23.6	0	0	0
21	28.8	12.7	20	0	0	0
22	15.6	5.8	11.7	0.3	0	0.3
23	21.4	0.6	11.3	0	0	0
24	29	4.9	18.3	0	0	0
25	36.5	14.3	25.3	0	0	0
26	23.6	8.7	16.1	5.3	0	5.3
27	21.5	5.7	12.1	0	0	0
28	22.7	3.4	11.8	0	0	0
29	24.3	4.8	14.2	0	0	0
30	26.1	9.8	18.2	0	0	0
31	11.6	6.1	9	2	0	0
Monthly average	26.1	9.0	17.5	-	-	11.7
30 year average[x]	24.4	10.1	17.3	53.0	0.0	53.0

[z] Meteorological data from Agri-Environment Services Branch, Agriculture and Agri-Food Canada

[y] Snow of ground, measured early morning (Environment Canada National Weather Archive, Esk, SK)

[x] 30 year average from 1971 to 2000 (Environment Canada National Weather Archive, Watrous, SK)

Table A.8 Average daily meteorological data for Termuende Research Ranch, September 2008[z]

	Temperature (°C)			Precipitation (mm)		
Day	Maximum	Minimum	Mean	Rain	Snow[y]	Total
1	12	7.5	9.2	0	0	0
2	18.1	4	10.2	0.3	0	0.3
3	21.5	0.6	11.6	0	0	0
4	19	4.1	11	4.6	0	4.6
5	18	0.9	9.3	0.3	0	0.3
6	12.7	2.4	7.9	5.3	0	5.3
7	12.8	1.3	6.9	0.3	0	0.3
8	18.4	2.1	9.3	0.3	0	0.3
9	23.7	5	14.1	0	0	0
10	18.3	2.7	10.3	0	0	0
11	22.5	0.9	12.3	0	0	0
12	25.4	5.7	14.4	0	0	0
13	16.2	0.6	9.2	0	0	0
14	21.5	-1.8	10.3	0	0	0
15	26.8	1.3	14.1	0	0	0
16	24.3	3.4	13.9	0	0	0
17	16.7	5.8	10.3	0	0	0
18	29.3	4	15.2	0	0	0
19	16.8	1.8	9.4	0	0	0
20	15.5	2.3	8.4	0	0	0
21	25	5.2	13.7	0.3	0	0.3
22	18.7	4.6	13.3	0	0	0
23	16.3	0.7	8.4	0	0	0
24	17.4	-2.4	6.8	0	0	0
25	20.7	-0.5	9.1	0	0	0
26	14.8	-2.4	5.7	0	0	0
27	17.6	-1.1	9.9	0	0	0
28	13.1	-2.3	7.5	0	0	0
29	21.9	-5.5	8.1	0	0	0
30	22.7	1.7	11.7	0	0	0
Monthly average	19.3	1.8	10.4	-	-	11.4
30 year average[x]	17.9	4.7	11.3	41.4	1.2	42.6

[z] Meteorological data from Agri-Environment Services Branch, Agriculture and Agri-Food Canada

[y] Snow of ground, measured early morning (Environment Canada National Weather Archive, Esk, SK)

[x] 30 year average from 1971 to 2000 (Environment Canada National Weather Archive, Watrous, SK)

Table A.9 Average daily meteorological data for Termuende Research Ranch, October 2008[z]

	Temperature (°C)			Precipitation (mm)		
Day	Maximum	Minimum	Mean	Rain	Snow[y]	Total
1	25.9	-0.9	12.4	0	0	0
2	27.6	1.4	14.2	0	0	0
3	25.9	6.8	15.6	0	0	0
4	25.2	7	17	0	0	0
5	16.5	11.1	12.6	18	0	18
6	11.3	5.6	8.5	2.5	0	2.5
7	13.9	-2.3	7.6	0	0	0
8	7.6	3.7	5.6	10.4	0	10.4
9	6.7	0.2	3.5	1.3	0	1.3
10	4.6	-3.1	1.3	0	0	0
11	3.6	-4.6	0.2	0	0	0
12	2.9	-1.9	0.6	0	0	0
13	10.9	-0.1	3.9	0	0	0
14	7.2	-0.1	4.4	5.6	0	5.6
15	8.3	-2.8	1.4	0	0	0
16	11.9	-5.7	1.9	0	0	0
17	15	-3.9	3.9	0	0	0
18	12.2	-1.4	3.6	1	0	1
19	8.2	-5.8	0.5	0	0	0
20	10.5	-6.1	3.4	0	0	0
21	8.5	3.9	6	8.1	0	8.1
22	10.2	-1.6	3.4	0	0	0
23	14.6	-0.4	6.2	0	0	0
24	15.1	-6.4	3.9	0	0	0
25	9	-0.9	4.2	0	0	0
26	0.3	-11.9	-3.5	0	0	0
27	6.2	-12.8	-3.3	0	0	0
28	15.4	-7	3.4	0	0	0
29	18.3	0.4	7	0	0	0
30	9.5	-4.8	4.3	0	0	0
31	10.6	-7.5	1	0	0	0
Monthly average	12.1	-1.7	5.0	-	-	46.9
30 year average[x]	10.5	-1.5	4.5	20.7	7.3	28.0

[z] Meteorological data from Agri-Environment Services Branch, Agriculture and Agri-Food Canada

[y] Snow of ground, measured early morning (Environment Canada National Weather Archive, Esk, SK)

[x] 30 year average from 1971 to 2000 (Environment Canada National Weather Archive, Watrous, SK)

Table A.10 Average daily meteorological data for Termuende Research Ranch, November 2008[z]

	Temperature (°C)			Precipitation (mm)		
Day	Maximum	Minimum	Mean	Rain	Snow[y]	Total
1	18.7	-2.1	5.1	0	0	0
2	9.3	-7.9	1.5	0	0	0
3	10.3	3.2	5.9	1.8	0	1.8
4	5.9	2.6	5	0	0	0
5	2.7	-2.8	-0.8	0	0	0
6	-2.8	-9.9	-5.1	0	0	0
7	-3.1	-11.3	-7.8	0	0	0
8	-1.3	-13.3	-7.8	0	0	0
9	2.5	-9.9	-3.8	0	0	0
10	-1.1	-5.8	-3.2	0.3	0	0.3
11	0.2	-6.5	-2.5	0.3	0	0.3
12	0.3	-1.7	-0.5	3.6	0	3.6
13	2.9	-3.1	0.2	5.3	0	5.3
14	-0.4	-7.1	-2.9	0	0	0
15	1.3	-6.6	-1.9	0	0	0
16	-0.4	-9.9	-4.5	0	0	0
17	-2.5	-11.9	-6	0	0	0
18	-0.4	-4.4	-2.8	0	0	0
19	-3.1	-19.5	-8.2	0		0
20	-9.4	-19.9	-13.8	0	3	3
21	-4.4	-17.9	-11.2	0	3	3
22	4.5	-15	-4.6	0		0
23	1.4	-10.7	-3.5	0	2	2
24	2.4	-14.1	-5.3	0	1	1
25	6.8	-8.6	-2.5	0	0	0
26	1.4	-5.4	-1.6	0	0	0
27	1.8	-11.6	-6	0	0	0
28	-2	-13.4	-9	0	0	0
29	2	-13	-3.5	0	0	0
30	-1	-14.9	-5.9	0	1	1
Monthly average	1.4	-9.1	-3.6	-	-	12.5
30 year average[x]	-1.5	-10.4	-6.0	1.4	11.5	13.0

[z] Meteorological data from Agri-Environment Services Branch, Agriculture and Agri-Food Canada

[y] Snow of ground, measured early morning (Environment Canada National Weather Archive, Esk, SK)

[x] 30 year average from 1971 to 2000 (Environment Canada National Weather Archive, Watrous, SK)

Table A.11 Average daily meteorological data for Termuende Research Ranch, December 2008[z]

	Temperature (°C)			Precipitation (mm)		
Day	Maximum	Minimum	Mean	Rain	Snow[y]	Total
1	3.5	-9.8	-1.8	0	1	1
2	1	-9.4	-6.8	0	1	1
3	-7.6	-13.9	-12.3	0	1	1
4	-10.5	-13.5	-12.5	0	1	1
5	-5.1	-13.7	-9.4	0	2	2
6	-11.4	-22.9	-15.3	0	2	2
7	-8.6	-21.6	-12.7	0	6	6
8	-13.1	-20	-14.9	0	6	6
9	-15.2	-22.5	-18.9	0	8	8
10	-9.9	-19.6	-15.2	0	8	8
11	-10.9	-26	-16.7	0	8	8
12	-3.9	-17.9	-8.9	0	10	10
13	-17.9	-32.6	-27.4	0	10	10
14	-30.3	-37	-33.2	0	10	10
15	-23.2	-34	-28.8	0	10	10
16	-19	-32	-26	0	10	10
17	-20.5	-33	-26.4	0	10	10
18	-22.4	-33.4	-26.8	0	10	10
19	-22	-25	-23.3	0	11	11
20	-23.8	-31.4	-25.5	0	13	13
21	-26.5	-35.5	-32.3	0	14	14
22	-24.1	-38.1	-32.8	0	14	14
23	-24.6	-36.4	-31.7	0	14	14
24	-18.1	-29.8	-22.8	0	14	14
25	-13.3	-29.3	-20.1	0	13	13
26	-15.7	-30.2	-21.1	0	13	13
27	-13.3	-30.6	-22.5	0	13	13
28	-8.8	-26.4	-16.4	0	13	13
29	-21.7	-31.9	-27.1	0	16	16
30	-17.6	-31.8	-25.7	0	16	16
31	-17.1	-32.8	-23.4	0	0	16
Monthly average	-15.2	-26.5	-20.6	-	-	16.0
30 year average[x]	-9.2	-18.6	-13.9	1.7	16.9	18.6

[z] Meteorological data from Agri-Environment Services Branch, Agriculture and Agri-Food Canada

[y] Snow of ground, measured early morning (Environment Canada National Weather Archive, Esk, SK)

[x] 30 year average from 1971 to 2000 (Environment Canada National Weather Archive, Watrous, SK)

Table A.12 Average daily meteorological data for Termuende Research Ranch, January 2009[z]

	Temperature (°C)			Precipitation (mm)		
Day	Maximum	Minimum	Mean	Rain	Snow[y]	Total
1	-16.7	-31.4	-24	0	0	0
2	-18.9	-32.3	-22.7	0	0	0
3	-18.6	-37.1	-26.4	0	0	0
4	-29.5	-40.2	-35.3	0	20	20
5	-17.9	-34.6	-24.5	0	22	22
6	-16.7	-20.9	-18.9	0	22	22
7	-15.4	-27.3	-20	0	22	22
8	-16.9	-30.5	-23.6	0	21	21
9	-15.8	-25	-19.8	0	22	22
10	-9.8	-19.8	-15.1	0	22	22
11	-9	-20.7	-12.3	0	22	22
12	-20.8	-26.4	-23.1	0	22	22
13	-20.2	-30.4	-24	0	24	24
14	-26.8	-38.6	-34.5	0	24	24
15	-15.2	-38.5	-24.9	0	24	24
16	-1.5	-15.4	-8	0	23	23
17	-2.2	-7.5	-4.2	0	23	23
18	1.8	-7.3	-2.6	2.3	22	24.3
19	3.1	-12	-5.3	0	21	21
20	-4	-13.8	-8.5	0	20	20
21	-6	-18.5	-10.9	0	20	20
22	-8.3	-24.5	-15.4	0	22	22
23	-22.1	-31	-26.5	0	22	22
24	-24.2	-32.3	-28.4	0	22	22
25	-23.4	-34	-29.5	0	22	22
26	-20.2	-34.5	-28	0	22	22
27	-8.9	-26.3	-17.1	0	0	0
28	-9.1	-16.2	-11.6	0	22	22
29	-6	-22.1	-12.2	0	24	24
30	1.8	-6.9	-2.7	0.3	24	24.3
31	3	-8.1	-2.9	0	23	24.3
Monthly average	-12.7	-24.6	-18.2	-	-	24.3
30 year average[x]	-11.7	-21.8	-16.8	0.7	16.8	17.5

[z] Meteorological data from Agri-Environment Services Branch, Agriculture and Agri-Food Canada

[y] Snow of ground, measured early morning (Environment Canada National Weather Archive, Esk, SK)

[x] 30 year average from 1971 to 2000 (Environment Canada National Weather Archive, Watrous, SK)

Table A.13 Study feed costs

	Year	
	2007	2008
DDGS^z, \$ mt^{-1}	\$140.00	\$175.00
Commercial range pellet, \$ mt^{-1}	\$330.00	\$330.00
Barley grain, \$ mt^{-1}	\$191.27	\$236.52
Grass hay, \$ mt^{-1}	\$55.11	\$68.34
Mineral, \$ 25kg^{-1}	\$24.47	\$31.80
Limestone, \$ 25kg^{-1}	\$6.50	\$6.80
Salt, \$ block^{-1}	\$4.85	\$5.48

[z] Wheat-based dried distillers grains with solubles (70:30 wheat:corn blend)

Equation A.1 Penn State grass-legume equation (Adams 1995)

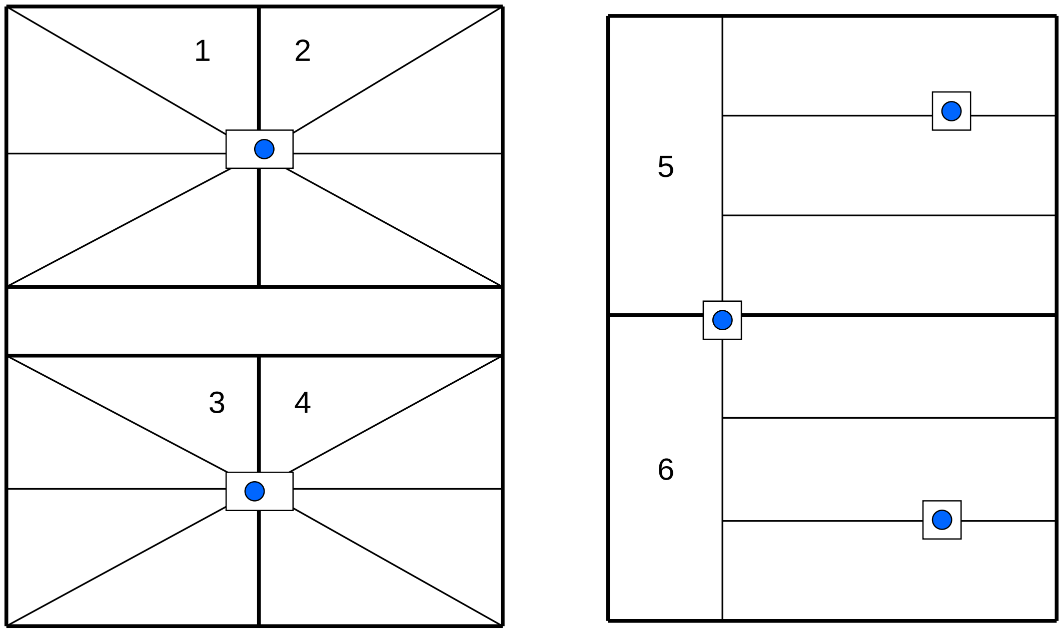
$$\textit{Digestible Energy (Mcal kg}^{-1}\textit{; DE)} = 0.04409 \times (4.898 + [1.044 - \{0.0119 \times ADF(\%)\}] \times 89.796$$

Equation A.2 Penn State cereal grain equation (Adams 1995)

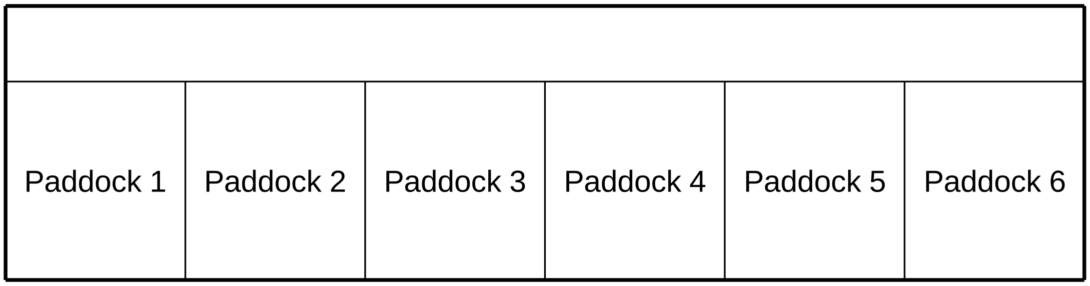
$$\textit{Digestible Energy (Mcal kg}^{-1}\textit{; DE)} = 0.04409 \times (4.898 + [0.9265 - \{0.00793 \times ADF(\%)\}] \times 89.796$$

Equation A.3 Estimated forage intake (Mertens 1987)

$$\textit{Dry matter intake (DMI)} = (1.2\% \times \textit{body weight}) / (\%\ NDF)$$



Appendix Figure A.1 Experiment I field plot schematic



Appendix Figure A.2 Experiment II field plot schematic