Refining Recommendations for Grazing Whole Plant Corn

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ABSTRACT

Study objectives were to assess the impacts of grazing allocation and fiber supplementation on animal performance, grazing preference and behavior, ruminal fermentation and whole-system economic costs. Field studies were carried out during the winters of 2015-16 (yr 1) and 2016-17 (yr 2) evaluating replicated (n = 2) whole-plant corn grazing systems: (i) 3d allocation with supplemental fiber (3DF); (ii) 3d allocation without supplemental fiber (3DNF); (iii) 9d allocation with supplemental fiber (9DF); and (iv) 9d allocation without supplemental fiber (9DNF). Ninety-six cows (yr 1 BW = 674 kg ± 53.1, yr 2 BW= 638 kg ± 49.9), including 16 ruminally cannulated cows, were allocated to 1 of 4 replicated systems for 84 and 88 d in yr 1 and 2, respectively. The same 2100 CHU hybrid (P7332R) was seeded in yr 1 and 2 (yr 1, CP =8.6 %, TDN = 69.5%; yr 2, CP = 8.3%, TDN = 70.72%) and a supplemental fiber source was offered each year, at 15% of total DMI in 3DF and 9DF treatment which was an alfalfa-grass mix hay (yr 1 CP = 12.9%, TDN = 60.2%; yr 2, CP =15.5%, TDN = 58.42%). Cow BW, rib fat, BCS, and ADG were not affected by treatment ($P = 0.85$). Total DMI was greater ($P = 0.01$) in 9D forage allocation compared to 3D allocation (12.8 kg hd^{-1} d^{-1}, respectively). The proportion of cob was greatest (34.2%; $P = 0.01$) before a grazing allocation and decreased (1.1%) at the end of allocation, whereas the stem proportion was lowest (48.6%; $P = 0.01$) before and greatest at the end (87.4%) of allocation. When supplemental fiber was offered cattle spent less (48.6 vs. 63.5%, respectively; $P = 0.03$) time grazing corn compared to cows not provided supplemental fiber. Grazing selection results suggest that cobs were heavily selected for at the start of a grazing allocation, which would provide a highly fermentable starch source at the start of the grazing period. Rumen pH parameters were not affected by fiber supplementation or allocation duration ($P > 0.05$). The duration that ruminal pH < 5.8 was greatest (143.18 min; $P = 0.01$) at the start of the grazing allocation compared to middle and end (26.32 and 0.0 min, respectively) of allocation. Total SCFA concentration was greatest (102.12, 99.13 and 86.77 m*M*, respectively; *P* = 0.01) at the start and middle of allocation, compared to the end of allocation. The molar proportions of propionate (*P* = 0.03) and isovalerate (*P* = 0.01) were lower when fiber was supplemented to cows. Fecal starch was greatest (*P* = 0.01) at the start of 9D and middle of 3D grazing allocations but was not affected (*P* = 0.58) by fiber supplementation. Grazing systems costs were not affected (*P* = 0.73) by grazing treatment. Results from the current study suggest that trt had no impact on rumen fermentation however grazing selection as timing within a forage allocation impacts diet fluctuation in all trt. Offering fiber supplementation did not reduce selection of cob or improve forage utilization. Maintaining the current recommendation of 3 d allocation lengths will reduce the diet fluctuation by the animal and potentially improve forage utilization and economic costs.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

ADF	Acid detergent fiber
ADL	Acid detergent lignin
BCS	Body condition score
BW	Body weight
CH_4	Methane
CHU	Corn heat units
CP	Crude protein
d	Day
DIP	Degradable intake protein
DM	Dry matter
DMI	Dry matter intake
DMY	Dry matter yield
DON	Deoxynivalenol
GIS	Global information systems
GPS	Global positioning systems
h	Hour
ha	Hectare
L	Litre
N	Nitrogen
NDF	Neutral detergent fiber
NE_l	Net energy lactation
NE_m	Net energy maintenance
NE_y	Net energy pregnancy
NH_3	Ammonia
NIRS	Near-infrared spectroscopy
MP	Metabolizable protein
P	Probability
PPI	Post partum interval
SARA	Subacute ruminal acidosis
SEM	Standard error of mean
SCFA	Short chain fatty acids
TDN	Total digestible nutrients
TMR	Total mixed ration
TTSD	Total-tract starch digestion
UIP	Undegradable intake protein

1.0 GENERAL INTRODUCTION

Traditionally beef cows are wintered in a drylot, an economically demanding management system. Drylot pen feeding is labour and resource intensive as the feed is brought to the cow for consumption and the manure and waste hauled and spread on land (Hitz and Russell 1998; Kelln et al. 2011). Extensive winter grazing systems are being are used in western Canada as crop development and management strategies are better adapted to the prairie winter climatic conditions (Larson 2015; Sheppard et al. 2015). Extended grazing of stock piled forages, swathed annual cereals, bales, crop residue, and corn have been gaining popularity both in research and in application (Sheppard et al. 2015).

Corn grazing is an attractive extended grazing practice due to it's high yielding potential, nutritive value, and erect stature making it suitable to be grazed into the winter months (Baron et al. 2003; McCartney et al. 2009; Lardner et al. 2017). Whole plant corn often meets or exceeds energy requirements for a beef cow throughout gestation and lactation but may not meet protein requirements in the third trimester and postpartum during early lactation (NASEM 2016b). A large percentage of the total corn crop yield is accounted for in the corn ear (grain and cob 45.9 and 8.2%, respectively of total plant DM; Doig 2013, personal communication). When cattle graze they will often select for the nutrient dense plant parts (Fernandez-Rivera and Klopfenstein 1989b), thus a combination of beef cattle's selective behavior and highly fermentable grain can result in a risk of ruminal acidosis when grazing whole plant corn (Jose 2015).

The objectives of this literature review are (1) to provide an overview of western Canadian winter management of beef cows and their nutrient requirements; (2) to review various extensive grazing practices; (3) to review animal behavior characteristics and how these affect forage utilization and nutrient intake; (4) to discuss rumen fermentation characteristics of beef cattle.

2.0 LITERATURE REVIEW

2.1 Western Canadian Beef Cow Management

The success of beef producers in western Canada depends on the profitability of each beef cow. The total cost of production for beef operations takes into account direct costs such as feed, veterinary expenses, and breeding stock depreciation as well as indirect costs such as yardage, interest payments, and marketing expenses (Larson 2012). Of all production costs, feed costs account for 50 to 60% of total production costs (Volesky et al. 2002; McCartney et al. 2004; Larson 2012). Producers can use winter management systems to reduce feed costs compared to drylot management. Drylot management is an intensive form of cattle management that involves bringing the feed to the cow to be consumed (Hitz and Russell 1998; Damiran et al. 2016). Drylot management typically requires high labor inputs in the form of harvesting, preserving, hauling and providing the feed source (Kelln et al. 2011). Due to the harvesting costs, the cost of feeding round bales in a drylot system is reported to be 37% higher than swath grazing (Volesky et al. 2002). Extensive grazing systems rely on the animal's ability to harvest the feed rather than machinery and manual labor (Volesky et al. 2002; Baron et al. 2003). Western Canadian herds reported calving in the late winter (36% in March) or spring (29% in April/May) which offers opportunities to use winter grazing systems (Larson 2015). It is important when selecting the appropriate winter grazing system that the nutrients provided meet the requirements of the class of livestock being fed (Volesky et al. 2002).

2.2 Beef Cow Requirements

Often gestating beef cows primarily receive diets containing forages, however when necessary may be supplemented with protein, energy, minerals and vitamins to meet animal requirements during the year (NASEM 2016b). Biological prioritization of nutrients consumed is as follows; maintenance, growth, basic energy reserves, pregnancy, lactation, accumulation of energy reserves, estrous, and accumulation of excess energy reserves (NASEM 2016b). Cow energy requirements are the lowest at weaning, increase throughout pregnancy and peak in early lactation (NASEM 2016b). As gestation progresses protein and energy requirements increase to meet the needs of the growing fetus, mammary development, and growth requirements of the dam (NASEM 2016b).

Beef cow nutrient requirements during the first and second trimester are relatively low, however it is important that proper nutrition is provided to ensure the viability of the calf and the ability of the cow to successfully calve, lactate and rebreed (Wood et al. 2010). It is important that the cow is in adequate body condition (BCS) at calving, often targeting a BCS of 2.5 to 3, as this reflects the energy status of the dam and is correlated with important reproductive parameters including calving interval, milk production, post partum interval (PPI), calf survival and calving difficulty (AAFRD 2006; Funston 2007). Profitable cow-calf operations rely on a 365-d calving cycle which only results when the cow's PPI is 80 d or less (Dunn and Kaltenbach 1980; NASEM 2016b).

Fetal and placental growth occurs in an exponential pattern accelerating near the third trimester of pregnancy (NASEM 2016b). Fetal growth is determined by genetic potential and maternal nutrient provisions and if inadequate nutrients are supplied to the dam or placental size or blood flow are compromised, the fetus may be undernourished (NASEM 2016b). When feeding gestating beef cows, this knowledge can be applied to keep feeding costs low while having minimal effects on animal performance.

2.2.1 Energy

Energy describes the potential to do work and can be measured as is often measured in calories (NASEM 2016b). Total energy consumed is a result of the energy concentration and digestibility of the feed as well as total feed consumed (Coleman 2005). Energy requirements of beef cows include energy for maintenance (NE_m), energy for lactation (NE_l), energy for tissue growth and replacement (NE_g), and energy for pregnancy and reproduction (NE_y) (NASEM 2016b). Energy for maintenance includes the requirements of tissue turnover, metabolic processes, and temperature regulation and is the amount of energy intake that results in no net loss or gain of energy from the animal's body (NASEM 2016b). Maintenance requirements may differ between animals based on age, sex, breed and varies between regions based on temperature and seasonal stressors to the animal (NASEM 2016b).

Equation.1.1 Net energy for maintenance requirements in a thermo neutral environment.

$NE_m = [0.0007 \times (20-T_p) + 0.77] \times SBW^{0.75}$, where NE_m required changes by 0.0007 Mcal/kg $SBW^{0.75}$ for each degree that the previous temperature falls below 20°C (NASEM 2016b).

Heat production and dissipation by the animal are performed to maintain a nearly constant body temperature (NASEM 2016b). In a winter grazing systems, the challenge is often to produce or conserve heat to deal with the cold stress. The temperature below the thermal neutral zone is known as the lower critical temperature (LCT) and requires that the animal produce or conserve heat, which increases the NE_m requirements of the animal (NASEM 2016b). The effect of LCT on NE_m requirement varies based on the animal's ability to dissipate or conserve heat and the rate of heat production in thermal neutral conditions (NASEM 2016b).

Equation.1.2 Lower critical temperature equation.

$LCT = 39 – 0.85 \times IN \times HE/SA$, where IN is the total insulation (°C m^2 d/Mcal); HE is heat production (Mcal/d); and SA is surface area (m^2) (NASEM 2016b).

Feed intake, physiological state, sex, genotype and activity all factor into an animal's heat production ability (NASEM 2016b). In a winter grazing system, easy access to feed may reduce the energy expenditure needed to access the feed. Baron et al. (2014), reported that animals may have maintained BCS better in a swathed corn grazing system compared to swathed barley due to the increased energy content and forage DM available. Acclimatization to an environment also affects an animals ability to handle cold stress thus affecting the NE_m requirements outside of the thermal neutral zone (NASEM 2016b). Factors affecting acclimatization includes behavioral modification such as cattle using windbreaks or huddling in groups to reduce wind exposure (NASEM 2016b).

Equation.1.3 Increase in NEm required in an environment colder than the animal's LCT.

$ME_{cs} = SA \times (LCT - EAT)/IN$, where ME_{cs} is the increase in NE_m due to the cold stress; SA is the surface area (m^2); EAT is effective ambient temperature adjusted for thermal radiation (°C); IN is the total insulation (°C/Mcal/m^2/day). (NASEM 2016b).

2.2.2 Protein

Protein is essential for tissue turnover and metabolic processes within the animal (Garrett and Johnson 1983). Protein requirements depend on the physiological state of the animal and are often described as the crude protein (CP) requirement on a dry matter (DM) basis at that physiological stage or more accurately described as metabolizable protein (MP; NASEM 2016b). Metabolizable protein system accounts for both the needs of the rumen microbes and the needs of the animals resulting in a more accurate measurement of available protein to be used for maintenance, growth, lactation and fetal development (NASEM 2016b). Rumen degradable protein (RDP) is utilized by rumen microbes and is available for microbial protein synthesis whereas rumen undegradable protein (RUP) is utilized by microbes in the rumen but can be absorbed in the small intestine and contributes to the total MP of the diet (NASEM 2016b).

Metabolizable protein absorbed in the small intestine consists of microbial protein, RDP and endogenous protein (NASEM 2016b). Rumen degradable protein is degraded to peptides and amino acids and used by microbes to produce microbial protein or is deaminated to ammonia (NH3) in the rumen (NASEM 2016b). Ammonia is metabolized to urea in the liver and excreted in urine or recycled back to the rumen. Diets with high amounts of fermentable carbohydrates improve the utilization of NH3 in the rumen as it promotes increase microbial protein synthesis within the rumen (NASEM 2016b).

Metabolic fecal, urinary, scurf (hoof and hair), growth, fetal growth and milk requirements all influence MP requirements (NASEM 2016b). Maintenance requirements for mature beef cows in early to mid-gestation is 7 to 8% CP in the diet or 432 g of metabolizable protein (MP) per d (NASEM 2016b). This requirement increases to 11 to 13% CP in young growing cattle or lactating cows (NASEM 2016b).

Equation 1.4 The metabolizable protein requirement for maintenance.

$MP_m = 3.8 \times SBW^{0.75}$, where MP_m is metabolizable protein requirement for maintenance (g/d) and SBW is shrunk body weight.

2.2.3 Vitamins and minerals

Cattle require 17 minerals, 7 of which are classified as macro minerals as they are required in large amounts often described as percent of DM, whereas the 10 micro minerals are required in small amounts such as mg per kg of DM (NASEM 2016b). Macro minerals include calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), sulfur (S), sodium (Na) and chlorine (Cl) and are important in bone and tissue structure as well as maintaining the acid-base balance, osmotic pressure, membrane-electric potential and nerve transmission (NASEM 2016b). Trace minerals or micro minerals are needed in very low amounts as enzyme cofactors or components of hormones and include cobalt (Co), chromium (Ch), copper (Cu), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se) and zinc(Zn) (NASEM 2016b). Deficiencies in minerals can result from both limited amount within the feedstuff and limited availability of the compounds to the animal. Minerals available in forages depend heavily on crop type and the geographic location as soil mineral components influence mineral concentrations in the forage (Perry and Cecava 1995).

Vitamins are also important nutrients to beef cattle. Vitamins can be classified as fat soluble (vitamins A, D, E, and K) and water soluble (B_{12}, thiamine, niacin, choline, and vitamin C) (NASEM 2016b). Vitamins are required for enzyme cofactors in important metabolic activities such as B vitamins as cofactors of enzymes involved in the production of glucose from propionate (Allen and Piantoni 2013; NASEM 2016b). Ruminants can synthesize water-soluble vitamins if their diet contains the correct precursors such as vitamin B_{12} can be synthesized if cobalt is available in the rumen (Perry and Cecava 1995). Baron et al (2014) found that swathed crops of corn, triticale, and barley had adequate K, Mg, P levels, however they were deficient in Ca which could be easily corrected with a mineral supplement. Lardner et al. (2017) found low heat unit corn grown across the Canadian prairies would meet the Ca and P requirements of dry gestating cows however it would not meet the needs of lactating beef cows or growing beef cattle.

2.2.4 Water

Water is an essential nutrient and directly influences feed intake. Water is an important transporter for many essential nutrients throughout the body (Funston 2007; NASEM 2016b). An animal’s water requirement is met through free water intake, water from feedstuffs and a negligible amount from metabolic processes within the animal (NASEM 2016b). Water intake requirements are affected by environmental temperature, activity, diet type, DMI, and physiological state of the animal (Lardner et al. 2013; NASEM 2016b). Water loss through respiration and perspiration is more extensive than losses through metabolic water use (NASEM 2016b).

Restricting water intake will result in poor animal performance (NASEM 2016b). Water quality attributes can impact animal performance and water intake due to organoleptic qualities (odor and taste; Wright 2007; Lardner et al. 2013; NASEM 2016b). Water tests are widely available to Canadian cow-calf producers and are an important management strategy to ensure cattle have access to suitable water. Water attributes of particular importance are physiochemical components, presence of toxic substances, excess minerals and bacteria (NASEM 2016b). Physiochemical properties include total dissolved solids, total dissolved oxygen, hardness, and pH (NASEM 2016b). When the levels of these physiochemical properties exceed the recommended levels lowered intake and poor performance can be initially observed (Wright 2007). Routinely testing water quality can help to determine if water properties may negatively impact a producer's cow herd (Wright 2007).

In winter grazing systems water supply in terms of quantity available can be a large management hurdle. Water can be supplied through dugouts or electric watering systems but requires infrastructure investments on behalf of the producer which may deter them from using winter grazing systems. Snow grazing can be used without negative effect on BW, BCS, or reproductive performance however only under ideal conditions (Young and Degen 1991). Cattle will choose a fresh water source over snow grazing if it is available (Young and Degen 1991). Weather conditions such as frequent freezing and thawing can cause the snow to crust which the cattle cannot easily lick. Cattle need powdery snow that is easy to lick in order to consume the 20 to 40 lb of snow per head per day to meet their water requirements (Thomas 2016).

2.3 Winter Grazing Systems

Winter feed costs include forage and supplement to maintain or improve body condition score (BCS) prior to calving (Merrill et al. 2008). Cows must achieve a suitable BCS in order to conceive and maintain a 365-d calving interval (Funston 2007; Merrill et al. 2008). In a recent survey of 1009 Canadian beef producers, upwards of 68% of operations that practiced some form of grazing included winter grazing as a management practice (Sheppard et al. 2015). Winter grazing in this study included, in decreasing order of prevalence, grazing rolled or processed bales, bale grazing, grazing stockpiled forage, swath-grazing cereals and grazing standing corn (Sheppard et al. 2015). The most common reasons producers adopted winter grazing systems were to reduce costs associated with labour, feeding, and harvesting as well as improve cattle health and condition and improved environmental and agronomic benefits (Jungnitsch et al. 2011; Sheppard et al. 2015). A similar survey of 411 western Canadian cow-calf producers found that 17% of respondents utilize swath grazing, 33% utilize bale grazing, 18% utilize stockpiled forages, 6% utilize standing corn and 17% utilize crop residue for winter grazing (Larson 2015). Extended winter grazing systems help to reduce manure handling cost because the animals deposit manure and urine throughout the winter directly onto the field which pose many soil benefits for subsequent crops and reduce the need to haul the manure out of the drylot (Jungnitsch et al. 2011; Kelln et al. 2012). Reasons producers were hesitant to adopt winter grazing systems were too much snow, lack of infrastructure, too cold, and concerns over wasted feed, animal health and performance (Sheppard et al. 2015). These authors found it important that producers be properly informed about the risks and benefits of winter grazing systems before they are willing to implement it on their operation.

Environmental factors including extreme cold temperatures and substantial snow depths may be limiting factors for the use of winter grazing systems in Western Canada. Swath grazing annual crops and stockpiled forage grazing are most affected by snow depths as the feed may become inaccessible (Willms et al. 1993). Due to its tall structure, hardy stem, and high stem:leaf ratio, corn is resilient in a winter grazing system even when challenged with high winds and extensive snow depth (Wilms et al. 1993). Fall grazing standing annuals saw a cost savings of $47 per cow when compared to drylot management (Willms et al. 1993). More recent work found an 18% cost savings of winter grazing systems (bale grazing, swath grazing and straw chaff grazing) compared to drylot management (Kelln et al. 2011). Overall, winter grazing systems such as swath grazing, bale grazing, and stockpiled forages are viable alternatives to drylot management of beef cows (Willms et al. 1993; Volesky et al. 2002; Kelln et al. 2011).

2.3.1 Swath Grazing

Swath grazing involves seeding the cereal crop, swathing it at soft-dough stage and grazing the swaths in late fall or winter (McCartney et al. 2008). Swath grazing takes advantage of high-yielding spring cereals and improves the cow's ability to graze in the snow (McCartney et al. 2008). The annual crop used for swath grazing has a large impact on carrying capacity and nutritive value of the forage. Several studies have looked at swath grazing barley (*Hordeum vulgare*) (Volesky et al. 2002; McCartney et al. 2008; Kelln et al. 2011). However, work using oat (*Avena sativa*) and triticale (× *Triticosecale*) for swath-grazing has also been completed (Baron et al. 2014). Forage varieties of these three crops often have high yielding potential, maintain their quality throughout the winter and can be grown successfully in most parts of western Canada. Seeding is often delayed by 4 to 6 weeks when compared to combined cereal crops to limit the amount of time the swath is exposed to environmental deterioration prior to freezing however this may decrease the yield of some annual cereals (McCartney et al. 2008; Baron et al. 2012; Baron et al. 2014).

Compared to stockpiled forage grazing, swath grazing may increase DMI during winter storms or extreme cold temperatures because the feed is consolidated into a windrow making it more accessible (Baron et al. 2003). Swath grazing annuals in the fall and winter months can improve animal BCS offering a cost-effective way to maintain beef cows (Willms et al. 1994). Winter feeding costs can be reduced 37% when compared to feeding bales due to the reduction in feed handling and labour costs (Volesky et al. 2002; Kelln et al. 2011). However, swath grazing requires some management to provide the feed to the animals and minimize waste. Forage allocation is often limited to 2 to 3 d intervals by electric fence in an effort to limit waste (Volesky et al. 2002; McCartney et al. 2008; Kelln et al. 2012).

2.3.2 Bale Grazing

Bale grazing involves harvesting the forage into round bales and either leaving the bales in the field or hauling bales and arranging them in a grid pattern in a field for cattle to graze in the winter months (Lardner et al. 2014). Bale grazing reduces labor and machinery costs as manure handling is eliminated and feed handling is slightly reduced throughout the winter (Jungnitsch et al. 2008). Producers often limit the number of bales offered at a given time by using electric fence to restrict animal access (Kelln et al. 2011; Lardner et al. 2014). Time and labour savings are the result when bales are set out ahead of time and twine is removed and only fences need to be moved when the animals need to be fed (Kallenbach 2006). Bale grazing is an attractive system as many producers are often already growing forages and preserving it as round bales. This management system allows producers to implement winter grazing relatively easily as it does not require extensive cropping knowledge.

2.3.3 Stockpiled Forage Grazing

Stockpiled forages are a sustainable way to reduce feed costs while utilizing already established forages if the nutritive value meets the animal requirements (Willms et al. 1993; Hitz and Russell 1998; Kulathunga et al. 2016). Grazing stockpiled forages often involves harvesting one or two hay crops in the summer months then allowing the forage to grow until fall resulting in an accumulation of biomass for the winter months (Hitz and Russell 1998; Kulathunga et al. 2016). Due to their senescent growth phase, stockpiled forages often have reduced digestibility, palatability, and CP, consequently leaving a nutrient deficit for late gestation beef cows (Willms et al. 1993; Kulathunga et al. 2016). Low quality stockpiled forages, such as fescue prairie, may be used as a fall and winter grazing system; however, supplementation may be required during the winter to achieve optimal body condition at calving (Willms et al. 1993). Grazing stockpiled forages in October to December may work well for a spring calving herd as the forage can potentially meet the beef cow's nutritional requirements during early- to mid-gestation (Kulathunga et al. 2016). In a stockpiled fescue system, forage nutritive value can be quite different in the winter compared to the summer months. Willms et al. (1993) observed CP values of 8.6, 5.4 and 4.1% in the summer, fall and winter months, respectively. These authors also found that the fescue prairie consistently had the lowest DM digestibility compared to annuals used in the study including winter wheat and corn (Willms et al. 1993). Combinations of alfalfa (*Medicago sativa L.*) and western wheatgrass (*Pascopyrum smithii*) had the highest yield and nutritive value in the late summer and fall when compared to various warm and cool season forages in the semiarid prairies (Biligetu et al. 2014).

In a study by Hitz and Russel (1998), stockpiled tall fescue-alfalfa performed better than stockpiled smooth bromegrass and corn residue, meaning cattle had greater BW and BCS gains. For all stockpiled forages studied, these authors provided a grass-legume hay source to supplement the diets when average BCS declined below 2.5 (5 point scale) or following heavy snow events, however a reduction in hay consumption when winter grazing stockpiled forages was still observed (Hitz and Russell 1998). Adding a legume into the forage mixture of a stock piled grazing system improves forage nutritive value compared to a monoculture of grass (Hitz and Russell 1998). If stockpiled forages are being used as an extended grazing system, nutritive value should be closely monitored as protein or energy supplements may be necessary (Baron et al. 2016). Weathering can drastically decrease the CP and energy content of the stockpiled forage (Kulathunga et al. 2016). As the forage weathers NDF content increases which will limit DMI of the forage (Hitz and Russell 1998).

2.3.4 Crop Residue Grazing

Crop residues offer a feed source that would otherwise be used as bedding, burned, or incorporated back into the soil (Soon and Arshad 2004). Western Canada produces millions of tonnes of cereal crops each year, and crop residues can provide additional forage in an extensive system (Damiran et al. 2016). Crop residues may be used as the basal forage in a beef cows diet; however, supplemental energy and protein are necessary (McCartney et al. 2006; Damiran et al. 2016). Oat, pea and barley crop residues have recently been studied in western Canada (Krause et al. 2013; Damiran et al. 2016). In a Saskatchewan oat and pea grazing study, costs/head/d were \$0.77 and \$0.49 lower than drylot feeding, for oat and pea residue grazing, respectively (Krause et al. 2013). In crop residue grazing systems, environmental conditions play a large role in their success (Krause et al. 2013). Energy and protein supplements will increase the success of a crop residue grazing system. Wheat dried distillers grains with solubles (DDGS) and canola meal were used with barley residue grazing and found that a combination of the two provided adequate protein and energy when supplemented at 0.41% of BW (Damiran et al. 2016). In the same study, crop residue grazing with DDGS or canola meal supplementation cost 36% less relative to drylot feeding (Damiran et al. 2016).

Corn crop residues (stalks) have been grazed in the mid-western United States for many years due to the high prevalence of corn grain production. Corn residues are often of limited nutrient value for beef cows and weathering can reduce its nutritive value over the winter months (Hitz and Russell 1998). Compared to stockpiled forages, corn crop residues appear to be more susceptible to soluble nutrient loss (Hitz and Russell 1998).

2.3.5 Whole Plant Corn Grazing

Corn grazing in western Canada is limited to areas that receive at least 2000 corn heat units (CHU) per year (SMA 2008). Corn heat units is a measure of how heat affects corn growth and is calculated from daily maximum and minimum temperatures with a base temperature of 10°C needed for corn growth (Chetner et al. 2003). The optimum day time temperature for corn is 30°C and CHU's begin to accumulate when three consecutive days with a mean temperature of 12.8°C is achieved and stop accumulating when the first fall frost occurs with a minimum temperature equal to or less than -3°C (Chetner et al. 2003; Lardner et al. 2017). In recent years, low CHU hybrids have been developed which better suited for western Canada (Lardner et al. 2017). Corn cob formation is imperative for yield and nutritive value and occurs late in the growing season. If an early frost damages the corn plant prior to corn grain filling, the nutritive value and yield can be greatly reduced (SMA 2008). Corn has the potential to yield better than other annuals grown for winter grazing but often at a higher cost per acre. In a recent study, corn hybrids yielded 40% greater than barley (Lardner et al. 2017). Corn typically has lower CP values than other annual crops used in winter grazing; however, the moderate CP levels of 7 to 9% are often suitable for early to mid gestation beef cattle (Baron et al. 2003; NASEM 2016b; Lardner et al. 2017).

A study comparing short stature, grazing, and conventional corn varieties saw no advantage for the grazing varieties in terms of yield and maintaining quality through the growing season (Baron et al. 2003). However, the costs of seed, planting, and weed control as well as the variety yield, nutritive value and nutritive value hardiness when exposed to inclement weather should be considered when selecting a corn variety for winter grazing (Baron et al. 2003). The crops ability to maintain an erect structure while retaining cobs and leaves is important to keep the forage accessible to the animal. If corn and stover are covered by snow the forage is likely inaccessible to the animal (Baron et al. 2003).

Corn hybrids were traditionally bred for grain production but more recently have been bred for silage and grazing. The silage and grazing hybrids often have more floury endosperm compared to the hard vitreous endosperm present in grain corn. Increased vitreousness reduces ruminal starch degradation (Lopes et al. 2009). Grain corn is traditional ground or rolled or when ensiled it passes through a kernel processor to expose the starch granules to microbial activity. Floury endosperms have a more soluble protein matrix surrounding the starch granules which make it more easily digested by rumen microbes (Taylor and Allen 2005; Lopes et al. 2009).

Whole plant corn has been shown to provide adequate energy to non-lactating cows (Willms et al. 1993; Baron et al. 2003; Baron et al. 2014). Corn varieties grown in western Canada have been shown to have upwards of 2.49 to 2.55 Mcal per kg (Lardner et al. 2017). In comparison to barley or triticale, the energy value of corn is often higher (Baron et al. 2014). Corn, barley, and triticale often have adequate protein to meet the nutritional needs of dry pregnant cows in the winter (Baron et al. 2014). If beef cows are grazing corn during lactation, supplemental protein may be necessary as CP content of whole-plant corn often does not meet requirements. Lardner et al. (2017) reported corn hybrids had CP levels of 6.8 to 9.3% compared to barley varieties with CP levels of 10.3 to 14.3% when grown across different sites in western Canada (Lardner et al. 2017). Supplemental protein that is readily rumen degradable such as alfalfa, soybean meal, and sunflower meal can meet supplemental protein requirements of summer calving cows in peak lactation (Lardy et al. 1999). Protein supplementation can influence microbial activity in the rumen and dry matter digestibility (Mathison et al. 1981).

2.4 Winter Grazing Management Considerations

Supplementation of an energy or protein source may be necessary under certain winter conditions. This often leads to a substitution effect of the supplement in place of the available forage which depending on the forage nutritive value, quantity and cost may meet the demands of the cow in a more cost-effective way (Wright 2001). The substitution rate is the change in forage DMI per unit of supplement (DM) provided (Wright 2001). Substitution rate is often influenced by type and level of supplement, physiological state of the animal and forage nutritive value and quantity (Wright 2001). High energy supplements can decrease fiber digestibility but due to the high fermentability of the supplement, often results in increased total diet digestibility (Wright 2001).

2.4.1 Agronomic Inputs and Crop Selection

Managing crop residues are a common concern to producers when extensive grazing systems are used. Mitigating waste can be accomplished by managing the forage supply and demand for 1 or 2 d allocations however, this will increase labor requirements (Volesky et al. 2002). The seedbed must be properly prepared in the spring to ensure good emergence. Often fields need to be tilled or sprayed with herbicide to reduce the amount of competition from weed pressure upon emergence (Legesse et al. 2012).

Warm season annuals are becoming more commonly used in western Canada due to improved hybrid suitability for the cool climate and include corn, sorghum, millet and some brassicas are being utilized in winter grazing systems (May et al. 2007; McCartney et al. 2009). Sorghum has been shown to yield less than corn but performs well in drought conditions (McCartney et al. 2009). Millet establishes easily and grows quickly with limited moisture, however often yields less than corn and more similar to oat and barley (May et al. 2007; McCartney et al. 2009). Seed and input costs as well as biomass and feed quality should be considered when producers are selecting a crop for winter grazing.

Corn is limited to areas achieving a minimum of 2000 to 2100 CHU to reach maturity and achieve the crops yield potential (McCartney et al. 2009). Soil temperature should reach 10C before corn is seeded and corn should be seeded 4 to 5 cm deep (SMA 2010). Plant density of 80,000 plants ha^{-1} is often targeted to achieve corns yield potential but more recent work in a cool-season environment indicates that upwards of 100,000 plants ha^{-1} would further maximize whole-plant yield (Baron et al. 2006). Higher density plant populations are needed for smaller, earlier-maturing varieties. Increasing plant density encourages the plant to direct nutrients towards cob development (Baron et al. 2006). Corn has high fertility requirements often needing 100-150 kg N ha^{-1} to achieve high grain yield however if grown for grazing these fertility requirements can be decreased when grown for grazing (Cambouris et al. 2016; Lardner et al. 2017). Soil fertility amendments should be applied based on soil test recommendations.

2.4.2 Environmental Factors

To reduce impacts of cold stress in extensive grazing systems, cattle often modify behavior to reduce the impacts of temperature and wind on body temperature (Olson and Wallander 2002; NASEM 2016b). They achieve this by grouping with other animals, maximizing exposure to solar radiation and seek shelter to decrease wind exposure (Olson and Wallander 2002; NASEM

2016b). Shelter in the form of windbreaks may provide protection from winds in the cold winter months as cattle seek microclimates (Olson and Wallander 2002). Using the above strategies may reduce the extent of cold stress on increasing maintenance requirements (NASEM 2016b). Grazing time and forage intake are often affected by cold temperatures which may limit DMI in extreme conditions for less experienced animals (Adams et al. 1986). Increasing the quantity of forage available can decrease the amount of time spent finding a feeding area and make the animals time spent grazing more efficient which may further reduce the impacts of winter cold stress on cow performance (Heitshmidt and Stuth 1991). For animals to thrive on a winter grazing program an adaptation period is prudent to allow the animals time to acclimate to the system (Fernandez-Rivera and Klopfenstein 1989a).

2.4.3 Manure Nutrient Management

Nitrogen (N) fertilizer often carries the greatest input cost when planting corn (Beauchamp et al. 2004). The amount of nitrate available to the corn plant during the growing season depends on soil N dynamics (temperature and moisture), amount and kind of crop residue and manure present, as well as the organic N content of the soil (Beauchamp et al. 2004). In winter grazing systems, nutrients deposited through the feed residue as well as manure and urine outputs can be valuable nutrients for subsequent growing years (Jungnitsch et al. 2011). Urine and feces can provide excellent soil nutrients and can help improve water holding capacity of the soil thus preventing water runoff and soil erosion (Jungnitsch et al. 2011; Kelln et al. 2012). Previous research has shown both soil nutrient and crop biomass improvements on subsequent crops following winter grazing events (Kelln et al. 2012). Nutrients provided by excreta can help meet the high N requirements of corn and reduce total N inputs during seeding following grazing. Dry matter yield (DMY) of forage crops grown after manure spread on the land from drylot production compared to manure deposition during extensive grazing resulted in 1.4 to 1.7 times the DMY and 3.3 to 3.4 times the DMY, respectively compared to no manure application (Jungnitsch et al. 2011). Excretion of N by the animal is affected by the quantity and form of N consumed (NASEM 2016b). In the same study, field recovery of N and P was 30-40% of original feed N and 20-30% of original feed P in the extensive grazing scenario compared to only 1 and 3% of original feed N and P in the drylot scenario (Jungnitsch et al. 2011). A major benefit of winter grazing systems is the improved nutrient recycling efficiency (Jungnitsch et al. 2011). In the same study the winter grazing systems resulted in a two-fold increase in CP yield compared to the control (no manure applied) and the areas where composted or raw manure were spread (Jungnitsch et al. 2011). Corn has high fertilizer requirements often needing 90-150 kg actual N ha^{-1} and 50-70 kg actual P ha^{-1} depending on yield targets (Marsalis et al. 2010). Soil tests are necessary to know how much is available in the soil and will help keep costs of fertilizer application down by reducing the risk of over application (Marsalis et al. 2010).

2.4.4 Anti-Quality Factors

Producers must also consider the development of molds or toxins in the winter forage they plan on using for winter grazing. *Fusarium* head blight affects cereal crops, including barley, oats, rye, sorghum, wheat and corn which results in low quality grain, damaged starch granules, and potentially dangerous mycotoxins (Atanassov et al. 1994). *Fusarium* species produce a variety of mycotoxins including deoxynivalenol (DON) and nivalenol (NIV) type trichothecenes, T-2 toxin, HT-2 toxin, and zearalenone (Millet et al. 1983; Atanassov et al. 1994; Cowan et al. 2015). In Saskatchewan, DON and zearalenone are quite common in corn crops (Miller et al. 1983). High humidity, increased rainfall and warm temperatures increase the formation of zearalenone in standing and stored corn (Miller et al. 1983). Soft kernel texture found in floury type corn may increase the risk for mycotoxins as they are more susceptible to damage when compared to the hard, vitreous grain corn kernel (Rankin and Grau 2002). Corn left in the field for grazing may be at higher risk for mycotoxin formation as the kernels are exposed to the environment longer allowing more time for inoculation with *Fusarium* spores compared to corn that is harvested for silage and stored (Rankin and Grau 2002).

Disease factors associated with the mycotoxins can range from feed refusal and gastrointestinal disturbance to dermal necrosis, abortion and infertility (Cowan et al. 2015). Guidelines provided by Barry Blakley (Blakley and Cowan 2017) indicate that livestock species may exhibit decreased DMI or poor performance when the combined concentration of DON mycotoxins exceed 1000 µg/kg, T-2 exceeds 1000 µg/kg, or when HT-2 exceeds 100 µg/kg. Ergot alkaloids may also infect cereal grains, and the ergot alkaloids produced can cause symptoms including reduced growth, feed intake, reduced milk production, and vasoconstriction (Grusie et al. 2015). The current guideline for a total mixed ration or a total feed is anything greater than 100 to 200 µg/kg may lead to adverse effects (Grusie et al. 2015). By testing forages for mycotoxins prior to winter grazing producers can plan feeding strategies accordingly to mitigate the risks if mycotoxins are present.

Another concern with grazing annuals is the risk of poisonings often associated with frost events or sudden disruptions in plant growth (McCartney et al. 2009). Nitrate poisoning can occur when a killing frost occurs to a rapidly growing plant or excessive amounts of N fertilizer are applied. The plant accumulates high levels of nitrates and when ingested by the animal these nitrates are converted to nitrites which interferes with the oxygen carrying capacity of the blood leading to death (McCartney et al. 2009). Corn can be tested prior to grazing for nitrates and mycotoxins and if the levels are a concern diet dilution by providing a supplement, such as hay, can help mitigate the risks.

2.4.5 Winter Grazing System Economics

Winter feed costs account for the largest proportion of total productions costs to producers (AAFRD 2018). Efforts to extend the grazing period and limit the amount of drylot feeding have been proven to reduce costs in western Canada (Kelln et al. 2011; Baron et al. 2014). Research comparing bale grazing and swath grazing systems with drylot management found bale grazing and swath grazing to be 8 and 29%, respectively, less costly than drylot management for dry pregnant beef cattle (Kelln et al. 2011). An Alberta study, found swath grazing triticale, corn or barley costs 37 to 61% less than traditional drylot winter feeding (Baron et al. 2014).

Costs often factored into economic analysis for extensive winter feeding systems include equipment costs to prepare the forage for consumption (e.g, swathing, baling, combining), labour and equipment costs to allocate the feed, mineral, supplementation (if required), bedding (if required) and depreciation of the infrastructure (e.g., portable windbreak, watering system, electric fence) (Kelln et al. 2011). Baron et al. (2014) reported inputs over a 100 d grazing period for 100 cows to be 46.7 h of labour in the swath grazing system vs. 137.7 h in the drylot system. The authors also reported 2741 vs. 663 L of diesel fuel and $5880 vs. $3063 in non-fuel costs when comparing drylot to swath grazing feeding in the same study (Baron et al. 2014). Lardner et al. (2014) evaluated heifer development systems comparing bale grazing to drylot feeding (Lardner et al. 2014). These authors noted a slight economic advantage of bale grazing over drylot feeding over a 202 d feeding study with a savings of $0.06/hd per day.

Aside from reducing feed costs, manure nutrient deposition resulting from the cows being fed in the field rather than in a drylot pen saves producers money by removing manure handling costs and provides beneficial soil nutrients (Jungnitsch 2008, Baron et al. 2014). Another economic benefit of using high yielding annuals for extended grazing means producers can increase the carrying capacity for their land base and either expand the operation on the given land base or use the freed up land for other economically beneficial uses (Baron et al. 2014).

2.5 Animal Performance Indicators

Monitoring animal performance is critical to evaluate the effectiveness of a management system. Animals must be in adequate body condition to reproduce and contribute to a farm profitability (AAFRD 2006; Wood et al. 2010). Body weight, BCS and ultrasonography for body fat reserves can be useful indicators of animal performance for cow-calf producers and researchers. Body weight change is an objective measurement to monitor animal weight gain or loss as well as monitor BW in comparison to breed or herd standards.

Body condition score is a subjective assessment that allows producers or technicians to assess the animals body fat reserves (AAFRD 2006). The body condition scoring system commonly used in Canada involves a scale of 1 through 5 (1=emaciated; 3=good, 5=obese; AAFRD 2006). Body condition scoring is most useful when done repeatedly over time, such as at breeding and weaning, to monitor BCS changes as a result of effects of on farm management, environment, and physiological status. The optimum BCS for beef cows at calving is 2.5 for mature females and 3 for 2 yr old cows while the optimum BCS at breeding for all females is 2.5 (AAFRD 2006). Producers may use the results from BCS assessments to manage cows differently to improve the reproductive success of the herd (AAFRD 2006). Studies have shown there is a positive correlation between BCS and subcutaneous fat measurements when both measures were taken at the thurl, tail head and lumbar regions (Domecq et al. 1995; Schroder and Staufenbiel 2006). Ultrasonography can be used to measure subcutaneous fat thickness to estimate body fat reserves (Domecq et al. 1995). Adequate body condition is crucial at calving to ensure a short PPI and successful breeding of the cow and is considered one of the primary indexes of nutritional status and has a profound effect on reproductive potential (Merrill et al.

2008). Wood et al. (2010) reported that cow condition may influence the performance of the calf she is rearing. Obese or over conditioned females often have reduced milk yields resulting in lighter calves at weaning (Wood et al. 2010).

2.6 Forage Availability and Quality

Animal performance is dependent on nutrient intake, which is directly influenced by feed quality and the quantity available. In a grazing system, adequate forage must be accessible to the cow (Brosh et al. 2006) and critical steps in evaluating a grazing plan are to understand how much forage is available and the nutritive value of the forage (Mathis and Sawyer 2007). Forage availability and quality determines any need to supplement the animal's diet to attain the desired levels of productivity (NASEM 2016b).

2.6.1 Forage Nutritive Value

Forage nutritive value changes rapidly during the growing season and as forages senesce the structural carbohydrate content increases making the forage less digestible (Mathis and Sawyer 2007). As annual forages mature the non-structural carbohydrate proportion also increases, the grain portion, making total plant nutritive quality higher which can offset the reduced digestibility from increased NDF content (Rosser et al. 2013). Recent work by Rosser et al. (2013) found that whole plant effectively degradable DM increased with increasing stage of maturity at swathing oat and barley. Forage nutritive value is also affected by plant type, climate, season, and soil type, fertility and moisture. Maximizing nutritive value helps to reduce costs associated with supplementation (NASEM 2016b). Forages are typically high in fiber and structural carbohydrates, and the digestibility of the fiber can be reported as acid detergent fiber (ADF) or neutral detergent fiber (NDF) or undigested NDF. The carbohydrate fractions include plant cell contents and cell wall structure (NASEM 2016b). Plant cell contents are more readily digestible, of greater nutritive value. Plant cell contents, or the non-fiber fraction includes soluble sugars, starch, pectins and fructans (NASEM 2016b). The plant cell wall fraction is often described as the fiber carbohydrates or neutral detergent fiber (NASEM 2016b). The NDF fraction includes cellulose, hemicellulose and lignin (NASEM 2016b). The difference between NDF and ADF is an estimate of hemicellulose content, while the difference between ADF and acid detergent lignin (ADL) is an estimate of cellulose content of a feedstuff (Jung 1997). Warm season grasses (C4 species) usually contain greater levels of NDF and ADL than cool season grasses (C3 species; NASEM 2016b). As a plant reaches a maturity and stops growing, lignification and secondary wall deposition of the cell wall begins (Jung 1997). The secondary cell wall is mainly made up of cellulose so as a plant matures the amount of cellulose and lignin increases reducing overall digestibility of the plant (Jung 1997).

Forage nutritive value can be analyzed using several techniques. Proper subsampling and sample prep results in the most accurate analysis of the feedstuff provided to the animal. In a grazing scenario forage clipping, bale cores, or swath samples can all be dried and sent for analysis (Mathis and Sawyer 2007). Forage nutritive value can be estimated using wet chemistry or near infrared spectroscropy (NIRS). Standard wet chemistry analysis is done according to established standard operating procedures for mineral, fat, fiber, and protein determination in feeds. Minerals are analyzed using atomic absorption spectrophotometry (method 985.01; AOAC 2012). Crude fat is determined using the ether extract procedure (method 2003.05; AOAC 2012). Fiber fractions, including NDF, ADF, and lignin are analyzed based on the Van Soest et al. (1991) digestion technique (methods 2002.04 and 873.18 for NDF and ADF/ADL, respectively AOAC 2012). Crude protein is determined using a LECO nitrogen combustion analyser (method 990.03; AOAC 2012). Starch is determined using enzyme hydrolysis (Hall 2009; method 920.40; AOAC 2012).

Near-infrared spectroscopy is a non-destructive and rapid method to analyze feedstuffs (Wolfrum 2009; Jung 1997). Near-infrared spectroscopy uses multivariate statistics to correlate NIR spectra of a population to analytical chemistry from the same population, the resulting equation is the calibration for the given feedstuff (Wolfrum et al. 2009; Gous et al. 2012). The sample spectra is collected by a NIRS machine where the infrared light, between 730 and 2500 nm is shone at the sample and selective absorption, transmission and reflectance of the samples organic compounds are read as the samples spectra profile (Lovett et al. 2005; Gous et al. 2012). The NIR spectral bands form overlapping overtones correspond to chemical bonds (Gous et al. 2012). Calibration equations can be made on a global or a local scale. Global meaning large data sets from different regions whereas local includes data sets from a region or analyzed in a lab (Andeuza et al. 2011). The local approach allows for higher accuracy however some samples may fall outside of the calibration population and may not work with that equation (Andueza et al. 2011). Near-infrared spectroscopy allows for rapid analysis of feedstuffs often at a decreased cost compared to wet chemistry analysis (Wolfrum et al. 2009).

Near-infrared spectroscopy has recently been developed to be used on undried forage samples however most current NIRS calibrations are for dried ground forage samples (Lovett et al. 2005). Lovett et al. (2005) studied particle size, oven drying temperature, and the presence of residual moisture on the accuracy of NIRS to predict corn silage quality and found dry samples ground to 1 mm to be most accurate with residual moisture having the least impact on accuracy when determining in vitro digestibility and fermentability as well as in situ degradability. The ability to use NIRS on fresh, undried forage samples is appealing as it removes the risk of drying and the potential impacts oven drying can have on nutritive value (Lovett et al. 2005).

2.6.2 Forage Yield Estimation

Forage yield varies depending on soil type and fertility, precipitation, environmental temperature as well as crop type and variety (Mathis and Sawyer 2007). Forage yield or biomass can be measured via non-destructive or destructive mechanisms. Non-destructive include visual estimates while destructive includes more labour intensive but often more accurate clipping and weighing of the forage (Mathis and Sawyer 2007). Forage yield estimates can be measured by clipping a defined area of land to a reference height and weighing the resulting forage thus ending up with a good estimate for forage yield (Mathis and Sawyer 2007). Visual estimates are often used by experienced range managers in which an estimate for percent of grazed plants or percent of forage removed can be estimates of remaining forage but fail to give an accurate estimate of yield in terms of kg of biomass per hectare (Jasmer and Holechek 1984).

2.6.3 Prediction of Dry Matter Intake

Nutrient intake of grazing cattle is difficult to define as forage intake and digestibility are challenging to accurately measure (Lardy et al. 1999). Dry matter intake is the overall amount of feed consumed daily by the grazing animal. Level of estimated DMI is influenced by animal, environmental and plant factors (NASEM 2016b). Animal factors include sex, age, physiological state, size and body composition, while environmental factors include the effect of temperature as the animal must maintain a constant body temperature (NASEM 2016b). As the temperature drops feed intake must increase to maintain sufficient body temperature achieved through increased movement, rumination and heat of fermentation until rumen fill limits DMI (NASEM 2016b). Plant factors are highly dependent on forage type and growth stage and can be characterized as plant digestibility and palatability (NASEM 2016b). Maximized forage intake in a grazing setting is estimated to be 2250 kg DM ha^{-1} (NASEM 2016b). As forage yield decreases beyond 2 T DM ha^{-1}, animal bite size decreases and an increase in grazing effort is seen to achieve the same level of intake when forage yields are greater (Valentine 1990; NASEM 2016b). Animal intake can be calculated through observing bite size (g/bite), feeding rate (bites/min) and grazing time (minutes/d); however, this method is impractical due to the large time requirements (Valentine 1990). This method highlights the influence on bite size which is shown to be the largest influence of intake (Hacker 1982; Valentine 1990). Cattle compensate for small bite size through increasing feeding rate and grazing time (Valentine 1990). Dry pregnant cows are predicted to consume up to 2.5% of BW in DM per d when TDN values of the forage offered exceed 59 % (NASEM 2016b). Gestation does not lead to an increase in DMI; however, near parturition, within the last 2 weeks of gestation a drop in DMI can be observed thought to be due to the effects of fetal size on rumen capacity (Jordan et al. 1973).

Direct measurements of DMI can be obtained by weighing the feed prior to feeding and weighing the refusals; however, this is impossible in a grazing system (Coleman 2005). Indirect measurements often need to be used in these scenarios; however, they are usually less accurate compared to the direct methods (Coleman 2005). Dry matter intake or forage intake can be estimated by several techniques including measuring standing forage before and after grazing, using indigestible markers, or by observing animal behavior (Cordova et al. 1978; Undi et al. 2008; Reis et al. 2015). Measuring the available biomass prior to grazing and the remaining biomass following grazing gives a good estimate on the amount of forage consumed (Volesky et al. 2002; Coleman 2005). The forage weight method does not account for losses due to weathering and consumption by wildlife and is more accurate on short term grazing events. The cage method involves clipping forage inside and outside of a cage which was placed prior to the grazing study (Undi et al. 2008). The cage method was shown to have the highest variability for predicting DMI when compared to an *n*-alkane dosing technique and DMI estimation equations

(Undi et al. 2008). A common marker technique to estimate DMI includes *n*-alkanes, often dotriacontane (C32) and hexatriacontane (C36), sprayed onto a feed supplement (Reis et al. 2015). In addition to dosing the cattle with the alkane using a feed supplement, fecal samples must be collected daily to collect fecal concentration of the *n*-alkane to calculate the amount of feed consumed based on the concentration in the feces compared to the concentration in the supplement (Reis et al. 2015). Dosing of *n*-alkane may be done using controlled release capsules prior to fecal sample collection (Undi et al. 2008). Recent work by Undi et al. (2008), suggests monitoring the rate of release for the capsule as a side study while using it to monitor grazing intake as the release rate can be highly variable. To do this Undie et al. (2008) would remove capsules placed in cannulated animals alongside the main study and periodically remove and measure the controlled release capsules to monitor disappearance of the capsules. Hand plucking can provide a good estimation of diet quality; however, falters when estimating DMI due to the high labour demands (Mathis and Sawyer 2007). During hand plucking the observer takes grab samples of forage within the grazing paddock as they observe grazing behavior by the animal (Mathis and Sawyer 2007). Direct observation to monitor bite-count can allow researchers to record the number of bites taken from each species providing a good indicator of diet quality but a poor indicator of total DM intake (Holechek et al. 1982). Observational data collection varies in precision and accuracy based on the variability between observers, the amount of training the observer receives, and the complexity of the sward that is being studied (Holechek et al. 1982).

Dry matter intake can also be predicted using various equations. The net energy equation (Equation 2.1) described in NASEM (2016b) considers the animals body weight and the net energy of the standing forage provided (Undi et al. 2008; NASEM 2016b). Another equation is the Minson Equation, an equation that considers animal BW and average daily gain (Equation

2.2.; ADG; Minson and McDonald 1987; Undi et al. 2008). The Minson equation has exhibited greater variation in DMI predictions when compared to the Net Energy equation (Undi et al. 2008). Both the Minson Equation and Net Energy equation offer a less labour intensive option to estimate intake compared to most behavior observation based techniques. These methods fail to take into account environmental factors and varying forage nutritive quality when estimating DMI (Undi et al. 2008). These equations are useful for rapid DMI estimation however are not as accurate as the N-alkane marker technique when assessing DMI on pasture (Undi et al. 2008).

Equation.2.1 Net energy equation.

NE_m intake (Mcal d^{-1}) = $BW^{0.75} \times (0.04997 \times NE_m^2 + 0.04631)$; where DMI= NE_m intake/dietary NE_m; Where NE_m is the standing forage NE_m.

Equation.2.2 The Minson equation.

DMI (kg d^{-1}) = $(1.185 + 0.00454BW – 0.0000026BW^2 + 0.315ADG)^2$.

2.7 Grazing Behavior

Ruminants are energy maximizers, indicating they feed optimally to consume the greatest amount of energy and nutrition (Heitshmidt and Stuth 1991). Grazing animals have a series of instinctive processes that lead to the point of prehension of the available forage (Heitshmidt and Stuth 1991). Diet selection involves two levels of selection including spatial and species choice (Heitshmidt and Stuth 1991). Spatial choice positions the animal within the landscape and can be described as animal distribution (Heitshmidt and Stuth 1991; Bailey et al. 1996). Spatial distribution is observed more discretely on large landscapes over time, i.e. observing a home range or herbivore camp on a large land area (Bailey et al. 1996). Once an animal has selected a grazing site they will use their senses such as smell and taste to make bite selections within the canopy (Hacker et al. 1982). Species choice involves the factors that make the plant or sward more or less desirable to the animal (Hacker et al. 1982). Animals will often select more palatable plant structures such as green, live plant tissue instead of brown or dead plant material (Hacker et al. 1982).

2.7.1 Land area usage

Spatial distribution can be observed on a small scale, however is often reflected as short periods of times at areas such as feeding stations or feeding sites (Bailey et al. 1996). These authors describe feeding stations when an animal remains stationary, which is often for only 5 to 100 s whereas a feeding site is defined as a feeding bout by the animal where they undergo continuous grazing and can occur for 1 to 4 hours (Bailey et al. 1996). When forage nutritive value is highest during new growth, animals often spend more time finding feeding stations to select the most nutrition per bite, whereas as the forage senesces over the growing season less time is spent searching for feeding sites and more time is spent grazing at each feeding site (Hacker and Ternouth 1987). Many characteristics of features of a landscape can influence the grazer's distribution such as boundaries, plant communities, and distribution of foci (Heitshmidt and Stuth 1991). Foci are locations which animals are likely to return to day-after-day such as the water, bedding, and mineral or salt sources (Heitshmidt and Stuth 1991). In most grazing scenarios, water is the primary foci for the ruminant. In the summer, cattle may visit the water station 3 to 4 times per d whereas only 1 to 2 times per d in the winter (Valentine 1990).

Cattle grazing activity is a function of forage nutritive value, thermal balance and the stability of the forage supply (Valentine 1990). In hot weather, they are more inclined to graze during the cool dawn and dusk temperatures. When available forage digestibility declines animals are forced to spend less time grazing and more time ruminating as retention time of the digesta increases often leading to decreased intake (Jordan et al. 1973; Valentine 1990). Animal grazing activity is highly dependent on pasture attributes such as plant community, slope, elevation, water sites, and available shade (Thomson et al. 2015). Factors affecting distribution can be characterized as abiotic or biotic factors. Biotic includes living factors such as forage nutritive value and quantity. Abiotic factors include slope, distance to water, physical barriers and weather (George et al. 2007). Abiotic factors, except weather, remain relatively constant whereas forage nutritive value and quantity varies between season and are influenced by many external factors such as grazing pressure, rainfall, and plant growth stage (George et al. 2007). Grazing animal distribution may also be influenced by the need for thermoregulation such as finding shade from the sun on warm days or protection from the wind on cold winter days (George et al. 2007).

2.7.1.1 Global Positioning Systems Application

Animal grazing behavior is highly variable and difficult to monitor using visual observation due to labour and time constraints. Global positioning systems (GPS) allow researchers to better monitor animal movement and collect valuable information over extended periods of time (Turner et al. 2000, Thompson et al. 2015). These GPS collars can be placed on animals over a period of time and collect animal position data at pre-determined intervals also known as GPS fixes (Thompson et al. 2015). The GPS collars contain lightweight internal receivers that track an array of up to 24 satellites orbiting earth to determine the position coordinates of the collar (Johnson and Ganskopp 2008). The collars are equipped with onboard memory to retain these coordinates to be retrieved later (Johnson and Ganskopp 2008). When using GPS collars in research, both memory space and battery life can limit the duration of the study or the frequency of GPS fixes able to be obtained. This data can be imported into global information systems (GIS) to map and interpret the data thus giving accurate animal movement data (Turner et al. 2000). Precise animal location data is valuable to evaluate animal performance and behavior as well as forage utilization (Turner et al. 2000). Researchers can then use this information to compare management systems and/or paddock attributes such as shade, water, and other attractants (Turner et al. 2000). Early GPS collar models did not include motion sensors and only provided location information, however newer technology includes sensors that monitor the animals head movement (Thompson et al. 2015). Algorithms can be used to determine grazing activity through location and sensor information (Thompson et al. 2015).

2.7.1.2 Global Information Systems Application

Coordinates obtained using GPS collars can be uploaded into ArcGIS (ESRI, Redlands, CA) as an efficient data management and mapping tool. Records from GPS collars often include latitude, longitude, elevation, a dilution of precision value, as well as 2- or 3- dimensional records, ambient air temperature and satellite information (Johnson and Ganskopp 2008). Latitude and longitude values are easily mapped using many different mapping tools to give an indication of animal movement, location, and preferred habitat areas when compared to base maps or selected features of interest. The dilution of precision value indicates the accuracy of the fix location accuracy and is reported as an index of satellite geometry (Johnson and Ganskopp 2008).

Linking data points together to find distance moved over a given time interval can be an excellent indicator of animal activity (Augustine and Derner 2013). For example, long distance movement likely indicates travelling without feeding while intermediate distances with stops over a length of time may indicate grazing behavior (Augustine and Derner 2013). When utilizing GPS location data, increased frequency supplies more coordinates to infer activities such as total distance traveled whereas when GPS intervals are increased more reliance on estimated values results. Increasing fix frequency may be critical to accurately measure distance travelled and more accurately establish weather patches of vegetation (i.e. weeds) are being heavily grazed or only walked through (Gonzalez et al. 2015). For each decrease in GPS sampling intervals, a decrease in frequency estimates for distance traveled per d per cow dropped by about 10% (Johnson and Ganskopp 2008). To accurately identify activity using interval data alone, large data sets are needed to ensure that overlap of activities are not missed (Augustine and Derner 2013). Ganskopp et al. (2000) used GPS collar data in combination with GIS to map cattle pathways and compare them to the slope and terrain of the study and to map animal pathways. Using GIS systems, Ganskopp et al. (2000) was able to map pathways of 'least-effort' within a given terrain and compared these pathways to those that cattle selected, as mapped with GPS collars. The results suggested cattle took shorter routes than the predicted 'least-effort' pathways, and these routes were upwards of 1% grade less steep than the 'least-effort' pathways predicted by GIS indicating that cattle establish efficient routes over time (Ganskopp et al. 2000).

Accelerometers may be used to determine amount of time spent grazing or time of day spent grazing, however they do not have the abilities to associate this activity with a spatial location (Robert et al. 2011). Accelerometers are small devices that continuously sample and collect data including mean acceleration of 3 axes (x-, y-, and z- axis) as well as vector magnitude mean and maximum (Robert et al. 2011). This data can be interpreted into lying, standing, and walking behaviors and based on accelerometer placement can be used for a variety of other behaviors (Robert et al. 2011). Accelerometers help to reduce the need for grazing observations by providing activity information. Accelerometers are often used in studies in confined areas (i.e. feedlots), whereas GPS collars are often used in studies in expansive field sites (Bailey et al. 2017). Some newer GPS collars have accelerometers built in and both data types can be collected and used to evaluate grazing behavior.

2.7.2 Plant selection

Multiple methods are available to measure forage preferences all of which require extensive sample collection or observations (Valentine 1990). Some methods include observing animal density indicating an area of preference within a pasture likely showing preference to the plants in the given area (Valentine 1990). Calculating a selectivity index is also valuable if an accurate measurement of intake is available. A selectivity index shows the proportion of the plant of interest in relationship with the proportion of the plant of interest in the total available forage (Valentine 1990).

As described earlier, the bite count method involving direct observation can provide excellent data on individual plant selection; however, it is labour intensive (Holechek et al. 1982). Rumen evacuation or fistulas may be used to collect samples of digesta for botanical analysis or nutrient analysis to compare to allocated forage (Holechek et al. 1982; Ortega et al. 1995). Rumen evacuations are quite laborious and may not be as accurate as esophageal fistulation, as animals during the rumen evacuation procedure are in an abnormal physiological state which may influence their grazing behavior (Holechek et al 1982). Esophageal fistulas allow researchers to collect samples selected naturally from the animal providing a "snap shot" of what their diet may entail (Holechek et al. 1982). Esophageal fistulas may become plugged or contaminated with regurgitated rumen contents (Holechek et al. 1982; Ortega et al. 1995).

Willms and Rode (1998) estimated forage disappearance by clipping randomly distributed plots (0.5 m^2) prior to and following grazing. They also studied disappearance of plant type by mapping out two plots per paddock where they mapped the plants within each grid and measured these plants basal area and height then returned to these plots to conduct the same measurements following grazing (Willms and Rode 1998). By monitoring plant disappearance, Willms and Rode (1998) established what plants the cattle selected for and potential factors that influenced the animal's selection pressure for that plant. These authors found that rough fescue was consumed in the highest amount compared to Parry oat grass and Idaho fescue likely due to its abundance which made it more accessible in the winter grazing portion of the study. Fernandez-Rivera and Klopfenstein (1989b) used a similar technique to monitor corn crop residue disappearance when grazed by beef calves. In the study they collected samples pre- and post-grazing and sorted the samples into leaf plus husk, stem, cob, and grain and calculated the forage utilization as the difference between availability pre- and post- grazing (Fernandez-Rivera and Klopfenstein 1989b). Corn leaves and husk were utilized in the greatest quantity when corn crop residue was grazed by beef calves in the fall and winter (Fernandez-Rivera and Klopfenstein 1989b). It should be noted in this study prior to grazing, the cob only accounted for 9.1 to 13.5 % of total DM, whereas the leaf and husk accounted for 43.9 to 53.0%, the stem accounted for 30.4 to 42.9 % and grain accounted for 3.0 to 4.9% of the total DM available. Both above methods allow researchers to observe what was available to the animal and what was left by the animal to estimate forage utilization and plant preference.

In continuous grazing systems, animals spend more time selecting feeding stations and less time grazing leading to more selective behaviors (Valentine 1990). In short duration grazing, where managers give large groups a few hours or day worth of feed, animals are more inclined to graze with minimal selection (Valentine 1990). When forage is abundant animals move more slowly through a landscape as they spend more time in one spot with high palatable plant material often with a high biting rate (Bailey et al. 1996).

2.8 Rumen Fermentation

Ruminants have developed a symbiotic relationship with microorganisms within in the rumen, allowing the animal to effectively use feedstuffs non-ruminants cannot such as plant cell wall biomass (Giuberti et al. 2014; NASEM 2016b). Through microbial fermentation low quality feeds are converted to energy for both the host and the microbial population and through microbial growth, amino acids and B vitamins are supplied to the host (Sutton 1968; NASEM 2016b). Fiber cannot be digested by mammalian enzymes; however, microbes can convert these carbohydrates into short chain fatty acids (SCFA), primarily acetate, propionate, and butyrate as well as methane (CH_4), carbon dioxide (CO_2) and microbial cells (Penner et al. 2009; Giuberti et al. 2014; NASEM 2016b). During ruminal fermentation upwards of 85% of the feed energy is converted to SCFA while the remainder is lost as CH_4 and heat (Sutton 1979; NASEM 2016b).

Feeding protein can be relatively inefficient with upwards of 80 to 90% of intake N being excreted in the feces and urine (NASEM 2016b). To mitigate these losses rations can be formulated to meet amino acid (AA) requirements of the animal and N requirements of rumen microorganisms as microorganisms are digested post-ruminally and provide high quality protein to the animal (NASEM 2016b). Feed CP is hydrolyzed into peptides and amino acids, by bacteria, protozoa and fungi, which can further be deaminated into ammonia (NH_3), CO_2, CH_4 and SCFAs within the rumen (NASEM 2016b). High concentrate diets often only have 20-30% forage in the diet with the remainder being highly fermentable carbohydrate sources such as grain. Shifts in proportions of individual SCFA occurs when the diet changes, as high forage diets encourage acetate production thus raising the acetate:propionate ratio near 3:1 (NASEM 2016b). Whereas when highly fermentable diets are fed, propionate production increases shifting the acetate:propionate ratio closer to 2:1 (NASEM 2016b).

Ruminal NH_3 varies depending on the animal's DMI as well as the degradable intake protein (DIP) content of the diet, use by microbes and absorption and passage of NH_3 (NASEM 2016b). Rumen bacteria source a large portion of their N from NH_3 often using NH_3 and carbon skeletons from branched-chain SCFAs for growth (NASEM 2016b). Highly fermentable diets, rich in starch and sugar, encourage NH_3 utilization as more substrates are available for microbial protein synthesis (NASEM 2016b). However, if the rumen pH decreases due to high amounts of readily fermentable carbohydrates, microbial growth may be hindered due to the shift in microbial population because of the unfavourable pH (NASEM 2016b). Diets low in DIP limit microbial growth resulting in reduced fermentability of the diet, however diets with excess DIP result in excess N which is excreted via the urea cycle, an energetically expensive process (NASEM 2016b).

Short chain fatty acids are often measured using gas chromatography as described by Khorasani et al. (1996). Ammonia-N determination is done using a phenol-hypochlorite reaction as described by Broderick and Kang (1980). Since absorption of SCFA and ammonia N across the rumen wall occurs rumen fluid samples can only provide a concentration measurement, not an indicator of total production of either constituent (Aschenbach et al. 2011). Through estimating the concentration of SCFA and NH3-N within the rumen researchers are able to better understand the fermentation process the diet provided undergoes as well as the variation in an animal's diet when measurements are taken over time. Limitations exist when taking daily samples as you cannot measure production or removal rates of rumen metabolites.

2.8.1 Diet and rumen pH interaction

Concentrations of SCFAs in the rumen are a result of production and removal rates through neutralization, absorption and passage across the rumen wall (NASEM 2016b). When the rate of production exceeds the rate of removal, this will result in a buildup of dissociated protons resulting in a decrease in pH (NASEM 2016b). Supplementation of highly digestible carbohydrates often leads to a decrease in ruminal pH as the rate of production of dissociated protons increases (Hess et al. 1994). When ruminal pH declines fiber digestion often decreases as a result of decreased cellulolytic bacterial growth and thus bacterial cell yields decline resulting in decreased microbial protein synthesis (Hess et al. 1994).

Many forms of acidosis occur in beef cattle ranging from acute acidosis, potentially resulting in death of the animal, to subacute ruminal acidosis which is more difficult to detect with subtle symptoms (Kleen et al. 2003). Subacute ruminal acidosis (SARA) involves a drop in rumen pH over a period of time, up to hours per d, and is commonly experienced by dairy and beef cattle consuming high concentrate diets (Nocek 1997; Plazier et al. 2009). Due to the highly fermentable diets an accumulation of short chain fatty acids (SCFA) occurs which leads to a drop in pH that is compounded when insufficient rumen buffering occurs (Kleen et al. 2003; Plazier et al. 2009). Mastication produces saliva which is an excellent source of inorganic buffers that work to neutralize the organic acids produced during rumen fermentation (Plazier et al. 2009). Since mastication stimulates the release of these buffers, fiber source within the diet and DMI plays a role on the amount of buffer supplied to the rumen (Plazier et al. 2009). The transport of SCFA across the rumen wall also provides pH buffering capacity within the rumen, nearly 50 to 85% or ruminally produced SCFA are absorbed across the rumen wall (Aschenbach et al. 2011). As dissociated SCFA pass through the rumen epithelium bicarbonate is excreted by the epithelium which provides further buffering to the rumen, often at more substantial level than buffering provided through saliva (Aschenbach et al. 2011).

Symptoms of SARA include DMI depression, decreased fiber digestion, laminitis, liver abscesses, among others (Silveira et al. 2007; Plazier et al. 2009). A likely cause for decreased DMI associated with SARA is the reduced rumen motility during periods of low pH (Kleen et al. 2003). The pH threshold of SARA varies depending on the study, the animal, and the diet. Thresholds of pH < 5.5 for longer than 3 hr per day is often considered for SARA in dairy production systems (Plazier et al. 2009). A pH <5.8 is considered an initial threshold for a shift away from cellulolytic bacterial fermentation in the rumen, as once pH <5.6 for >1 h an inflammatory response is likely to occur (Aschenbach et al. 2011). Furthermore, a second threshold near pH 5.0 exists where protozoa begin to die and fermentation shifts to lactic acid formation (Aschenbach et al. 2011). Smaller thresholds for SARA of 5.5 and 5.0 for acute ruminal acidosis seem appropriate when taking single samples however, when pH × duration is considered a slightly higher threshold is used for SARA and acute acidosis of 5.8 and 5.2, respectively (Aschenbach et al. 2011). For a gestating beef cow where the primary diet consists of forage with minimal concentrate in the diet, more moderate thresholds are appropriate. Animals may be better suited to digest highly fermentable diets if given an adaptation period to allow for microbes better suited to digest the carbohydrates to proliferate as well as proliferation of rumen papillae for better SCFA absorption (Kleen et al. 2003).

Jose (2015) compared corn grazing, barley swath grazing, and drylot feeding of barley greenfeed and monitored rumen parameters. Rumen pH was lowest on d1 of a 3 d grazing allocation for swath grazing barley and grazing corn (Jose 2015). Jose (2015) observed decreased minimum pH and increased duration of pH <5.8 in cattle grazing whole plant corn in yr 2 compared to yr 1 while the whole plant starch content was higher in yr 2. This study emphasized the risk of acidosis in corn grazing as well as the impact of kernel starch content on acidosis. Rosser et al. (2017) compared 1 or 3 d allocations of whole-crop oat forage on intake and rumen fermentation and found that the 3 d allocation markedly increased the risk for acidosis even though it did not increase intake.

Diets with rolled corn tended to have higher minimum pH and the duration of pH < 5.8 was shorter when compared to total mixed rations (TMR) diets with rolled barley fed to lactating

Holsteins (Chibisa et al. 2015). Since the fermentation of starch within corn is slower and less extensive compare to barley grain, these results were expected (Chibisa et al. 2015). In diets where high concentrates are fed, TMRs are used to prevent sorting and ensure a consistent diet. Moya et al. (2014) acceses the relationship between feeding behavior and gastrointestinal function found surprising results. Feedlot heifers were able to self-select diets without increasing the risk of sub-clinical acidosis (Moya et al. 2014). In this study, the heifers were offered the same ingredients present in the control TMR, corn silage, barley grain and corn distillers' and were able to self-select a diet (Moya et al. 2014). Heifers fed a TMR had greater (P = 0.01) DMI, than heifers on the self-select diets and also had the highest number of bouts with pH below 5.5 (Moya et al. 2014). In this same study, ADG and gain:feed, both economically important parameters, were greater in heifers fed TMR than those on self-selecting diets which indicates that animal selection behavior does not select for the most balanced diet.

2.8.2 Total Tract Starch Digestion

Post-ruminal starch digestion is a more efficient use of starch compared to rumen fermentation of starch; however, if post-ruminal digestion is relied on too heavily starch may flow through the small intestine and into the large intestine which is the least efficient digestion site for starch (Harmon et al. 2004). Ruminal starch fermentation may be less efficient from a starch digestion energy perspective but it also promotes microbial protein synthesis and N recycling (NASEM 2016b). Total tract starch digestion (TTSD) is essentially the sum of starch digestion in the rumen, small intestine and large intestine or the difference between intake and excretion of starch (total starch intake – fecal starch excretion; Guiberti et al. 2014). Zinn et al. (2007) found that fecal starch excretion can be used to assess starch digestion quite effectively alone or in combination with fecal nitrogen.

Fecal starch concentration collected in spot sampling was found to be closely and linearly related to TTSD (R^2 = 0.94) in a dairy study assessing on-farm collection of feces directly from cows or from pen floors (Fredin et al. 2014). Using fecal samples to determine total tract digestibility of other nutrients such as NDF, CP and fat have proven to be less accurate. Predictions of CP and fat total tract digestibility are underpredicted due to endogenous and microbial synthesis of these nutrients (Fredin et al. 2014). Fecal NDF and total-tract NDF digestibility also has a low correlation (R^2 = 0.18, n = 380; Fredin et al. 2014).

Using fecal pH to assess TTSD has been used with varying success. Experiments with low fecal starch (<3%) found fecal pH was not a reliable indicator in TTSD (Ferraretto et al. 2013; Fredin et al. 2014). Low fecal pH is often a result of hindgut acidosis caused by a large amount of starch flowing to the large intestine and its rate of fermentation (Gressley et al. 2011; Fredin et al. 2014). High forage diets with less grain is less likely to lead to hind-gut acidosis (Gressley et al. 2011).

In dairy cattle, TTSD ranges from 70 to100% and is affected by numerous factors including particle size, grain processing, harvest maturity, moisture content, and corn endosperm type (Fredin et al. 2014). Corn endosperm type greatly influences location, rate and extent of starch digestion, floury endosperm results in more ruminal starch digestion whereas vitreous endosperms result in starch digestion being diverted to post-ruminal digestion or excreted (Taylor and Allen 2005).Vitreous endosperm contains hard, densely packed starch granules, often resulting in lower ruminal starch availability and reduced total tract starch digestibility (Zinn et al. 2002; NASEM 2016b). Corn also contains zein prolamins, endosperm storage proteins, which are particularly insoluble in the rumen compared to the prolamins found in barley, wheat or oat grain (NASEM 2016b).

Fredin et al. (2014) compared 8 studies, 30 diets and 564 fecal starch samples from lactating dairy cattle and found fecal starch ranged from 0 to 5% and TTSD was >95% with a low co-efficient of variation. However, evaluating other nutrients using total-tract digestibility with fecal concentration as an indicator has not been as successful (Fredin et al. 2014). Fat and CP estimates would be high due to endogenous secretions and NDF has a low correlation because it is less readily digestible compared to starch (Fredin et al. 2014).

When whole plant corn is harvested and stored as silage crop maturity is often at the 2/3 milk line stage or black layer maturity (Bal et al. 1997). In the early stage of maturity, the corn plant is highly fibrous with low energy but as it matures, starch sets into the kernels, and the energy content increases while the fiber digestibility decreases (Bal et al. 1997). As whole plant corn matures the moisture content declines and when fed to lactating dairy cows the total tract starch digestion and total milk production were greater at 1/2 milk line versus black layer stage of maturity (Bal et al. 1997). The ideal maturity for whole-plant corn grazing is not as well defined as there are not any storage implications with standing corn related to maturity (Baron et al. 2003). As the plant matures the kernel virtuousness increases which decreases digestibility without mechanical disruption, so earlier maturity such as 1/2 milk line, for corn grazing may be better utilized by the animal.

2.9 Summary of Literature Review

As western Canadian cow-calf producers continue to grow herd numbers cost of production becomes more and more closely managed. To improve profitability producers will continue to implement extensive grazing practices. Before implementing an extensive grazing systems the effect on cow performance, nutritive value and yield, and whole-system costs should be evaluated. Grazing whole-plant corn is increasing in popularity in western Canada due to the crops high yielding potential, nutritive value and low-labor requirements. However, readily fermentable starch in the corn kernels increases the risk of acidosis for grazing beef cattle (Kleen et al. 2003). Management to limit access to feed is needed to mitigate the risk of acidosis and improve crop utilization (Volesky et al. 2002; Kelln et al. 2012; Jose 2015). The objectives of the following research are to assess the effects of 3- or 9- d allocation of whole plant corn with or without supplemental hay on animal performance, rumen dynamics, grazing behavior and whole-system economics. We hypothesized that fiber supplementation and grazing allocation length would have no effect on forage yield and quality, cow performance and DMI, forage utilization, rumen dynamics, and grazing behavior, rumen dynamics and system costs.

3.0 EFFECT OF 3- VS. 9-D ALLOCATION WITH OR WITHOUT FIBER ON FORAGE DRY MATTER INTAKE AND UTILIZATION, BEEF COW PERFORMANCE, GRAZING PREFERENCE AND BEHAVIOR, AND SYSTEM ECONOMICS

3.1 Introduction

Economic volatility often stimulates change in beef management practices to reduce risk or total production costs (Sheppard et al. 2015). Extensive winter grazing practices are becoming increasingly utilized for feed cost savings attributed to reduced machinery and fuel costs and reduced labour demands (McCartney et al. 2004; Baron et al. 2016). Extensive grazing practices, including whole-plant corn grazing, allow producers to eliminate the time and money needed to harvest, haul and deliver the feed as well as hauling the manure away (Jungnitsch 2008).

Current recommendations for whole plant corn grazing are derived from swath grazing and bale grazing recommendations, which are primarily targeted to reduce the risk of acidosis and mitigate waste (Volesky et al. 2002; SMA 2008). Recent work in western Canada has compared whole plant corn grazing to swath grazing annual cereals and drylot management for both pregnant beef cows (Jose 2015) and backgrounding calves (McMillan et al. 2018). These studies showed cost savings of using extensive grazing systems over traditional dry lot systems (Jose 2015; McMillan et al. 2018). Research comparing different management strategies within the whole-plant corn grazing system is lacking and necessary. Additionally, information regarding DMI, forage utilization, grazing behavior and plant selection, and system costs across different management strategies is required. This study was conducted to evaluate the effects of allocation length and supplemental hay on forage utilization, animal performance, grazing preference and behavior, and whole system economics in whole plant corn grazing systems.

3.2 Materials and methods

3.2.1 Location and crop management

A 2-yr field study was conducted at the Western Beef Development Center's Termuende Research Ranch, located 8 km east of Lanigan (latitude 51°51'N, longitude 105°02'W), Saskatchewan, Canada. Soil at the study site was Oxbow Orthic Black with a loam texture (Saskatchewan Soil Survey 1992). In spring of 2015 and 2016, two 15 ha fields were seeded at a rate of 80,000 seeds/ha, using a 75 cm row spacing, with a 2100 heat unit corn (*Zea mays* hybrid P7332R from Pioneer Hi-Bred Ltd., Chatham, Ontario)on June 3, 2015 and May 31, 2016. Field work prior to seeding included mechanical disturbance with a Summers ® vertical tillage implement (Summers Manufacturing Inc., Devils Lake, North Dakota) prior to seeding. Following soil testing recommendations, fertilizer was applied at a rate of 90 kg N/ha in yr 1 and yr 2 of actual N at the time of seeding. Glyphosate [N-(phosphonomethyl) glycine] was applied at 1.7 L ha^{-1} in both years at the 4- and 8-leaf stages for weed control. The study site was further sub-divided into 8 replicate paddocks, using high tensile electric fence, to accommodate the replicated grazing systems. The 5 yr cropping history of the study sight was corn grown for grazing.

3.2.2 Grazing systems

Each year, 96 beef cows were stratified by BW and randomly allocated to 1 of 4 replicated (n = 2) grazing systems in a 2 × 2 factorial treatment design: (i) 3-d allocation with supplemental fiber (**3DF**); (ii) 3-d allocation without supplemental fiber (**3DNF**); (iii) 9-d allocation with supplemental fiber (**9DF**); and (iv) 9-d allocation without supplemental fiber (**9DNF**). All cows were cared for in compliance with the Canadian Council on Animal Care guidelines (CCAC 2009) and approved by University of Saskatchewan Animal Care Committee (Protocol No. 20090107). Cows were allocated forage in each grazing system based on body weight, forage nutrient density, and environmental conditions in accordance with the NASEM (2016) beef model for nonlactating pregnant beef cows as predicted by CowBytes Ration Balancing Program (AAFRD 2011). Target forage allocation was 2.5% of BW as DMI while accounting for an additional 15% DM of waste. Hay bales were weighed and sampled using core sampling technique for chemical composition, prior to allocation to treatment (Volesky et al. 2002). The supplemental fiber source was alfalfa grass hay (yr 1, 62% TDN, 10.3% CP, 58.8% NDF; yr 2, 58% TDN, 15.5% CP, 57.8% NDF). Hay was offered to 3DF and 9DF treatments at a rate of 15% of total estimated dietary DMI and offered in addition to allocated forage. Hay was offered in a bale ring and was located near the bedding area within the grazing paddock. Forage was allocated to provide 3 (3.3 ± 0.53) or 9 (7.2 ± 0.95) days worth of feed for the cattle in each paddock in the 3d or 9d treatment (trt), respectively.

3.2.3 Weather data collection

Long term (1985-2015) total precipitation (mm) and monthly temperature averages (°C) were obtained from the Environment Canada Climate data website (www.climate.weatheroffice.gc.ca) for Leroy, Saskatchewan. This weather station was chosen, due to its close proximity to the study site and its complete data set for both current and 30-yr average temperatures and precipitation data. Daily mean temperatures and monthly precipitation were also collected from May 2015 to March 2017 using the same weather station (Leroy, Saskatchewan; Appendix B, Figures B.1 and B.2).

3.2.4 Estimation of crop dry matter yield and nutritive value

Each year in October, forage samples were collected to determine biomass yield and quality. Crop yield was estimated by measuring forage DM production per unit length of row for each corn treatment prior to the grazing period. Dry matter yield (DMY) was measured at 3 random areas in each replicate paddock by harvesting a 5.4 × 0.8 m length of row and following this 3 sub-samples were collected for DM estimate and forage nutritive value (Lauer 2002). The weight collected in 5.4 × 0.8 m length of row (17.ft of row on a 75 cm row spacing) is representative of 1/1000th of an acre (0.000405 hectare) in combination with DM content was used to calculate yield per hectare.

In addition, every 21 d during the study period, corn plants (n=3) from each replicate paddock were harvested at 5 cm stubble height and retained for quality determination. All forage samples were dried in a forced air oven at 55°C for 144 h to determine DM content and then ground to pass through a 1-mm screen using a Thomas-Wiley mill (Model 4, Thomas Scientific, Sweedesboro, New Jersey), and stored in air tight bags. Samples were sent to Cumberland Valley Analytical Services laboratory (CVAS; Waynesboro, Pennsylvania) and analyzed for crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, starch Ca and P. Near infrared spectroscopy (NIR) analysis was used for CP, NDF, ADF, and lignin determination using a corn silage calibration curve. If samples did not fall within the calibration curve available at CVAS they were analyzed using wet chemistry analysis. Wet chemistry methods were used for starch (Hall 2009; 920.40 AOAC 2012), Ca and P determination (968.08, AOAC 2012).

3.2.5 Estimation of dry matter intake and forage utilization

A modified pre- and post-grazing technique as described by Jasmer and Holechek (1984) was used to determine DMI as a percentage of forage disappearance by weighing several random predetermined areas of corn forage pre-grazing, then following grazing weighing the same given area (Jasmer and Holechek 1984). Average DM weight pre-grazing was determined by weighing 3, 5.4 × 0.8-m lengths of row per replicate paddock, as previously described in Section 3.2.3. Residue, or post-grazing DM weight was determined in each replicate paddock by weighing 30, 1.0 m^2 quadrat samples in addition to taking 3 subsamples for residue DM and quality from each paddock (Volesky et al. 2002). Shears were used to cut the forage that fell outside of the quadrat so that an accurate weights could be collected for residue yield. Supplemental hay DMI was estimated by weighing the round bales prior to feeding using a portable platform scale and weighing the residue as described by Kelln et al. (2011). Corn and supplement hay DMI were calculated according to the following equations (Jasmer and Holechek 1984; Kelln et al. 2011; Jose 2015).

Equation 3.1 DMI estimation equation.

Forage DMI (kg/cow/d) = (kg of DM allocated - kg of DM residual)/(n/P)

Where, P = grazing allocation length, n = 14 (number of cows per experimental unit)

Equation 3.2 Forage utilization equation.

Residue (%) = (Post-graze weight/Pre-graze weight) × 100

3.2.6 Animal Management

Each replicate (n=2) group in each of the four grazing systems had 12 intact cows and 2 cannulated cows for the duration of the study period for a total of 96 dry pregnant beef cows and 16 open cannulated cows. Cannulated cows were used to collect rumen fermentation data as described in section 4.0. All cows were cared for in compliance with the Canadian Council on Animal Care guidelines (CCAC 2009) and approved by University of Saskatchewan Animal Care Committee (Protocol No. 20090107). Cows were managed on the grazing systems for 84 d (11 December 2015 to 3 March 2016) in yr 1 and 88 d (9 November 2016 to 2 February 2017) in yr two.

The cows were allocated forage for either a 3 d or 9 d period using portable electric fence to limit access and control utilization of the forage. Animals could back-graze; however, most of the grazing observed occurred in areas with new allocations of forage. Each paddock was equipped with an insulated portable water trough to provide access to water and two (3 × 10 m) free-standing portable wind breaks to provide shelter. All cattle were bedded with straw as determined by staff and weather conditions. Cows had *ad libitum* access to a commercial 2:1 mineral supplement (15.5% Ca, 7% P, 2.5% Mg, 5.8% Na, 200 ppm I, 3000 ppm Fe, 1500 ppm Cu, 5000 ppm Mn, 46 ppm Co, 50 ppm Fl (max), 500000 IU/kg Vitamin A (min), 50000 IU/kg Vitamin D3(Min), 2500 IU/kg (Min) (Right Now ® Emerald, Cargill Nutrition) and cobalt iodized salt blocks.

Prior to study start, all cows were diagnosed for pregnancy via rectal palpation to ensure all cows were pregnant. Mature cows (7^{th} parity ± 2.62) grazed the corn for during the 2^{nd} trimester calving in late April to early May both years. Cow performance was determined by measuring body weight (BW), body condition score (BCS), and subcutaneous body fat. Body weight was measured at the start and end of study over 2 consecutive d, prior to feeding to limit the variation caused by rumen fill. Body weight was also measured every 21 d to monitor BW over the course of the study. Body weight was adjusted for conceptus weight using the following equation (NASEM 2016b).

Equation.3.3 Body weight correction for conceptus weight equation.

$$\text{Conceptus weight (kg)} = (\text{CBW} \times 0.01828) \times e^{[0.02 \times d) - (0.0000143 \times d \times d)]}$$

Where, CBW=calf birth body weight and d=days of pregnancy

Body condition score and subcutaneous fat measurements were collected at the start and end of study by an experienced technician, using the Scottish five point scale where 1 is emaciated and 5 is grossly fat (Lowman et al. 1976; Marx 2004; AAFRD 2006). Subcutaneous fat measurements were taken using real-time ultrasound (Echo Camera SSD-500, Overseas Monitor Corporation Ltd., Richmond, BC, Canada) equipped with a UST 5044-17 cm, 3.5 MHz linear array transducer, between the 12^{th} and 13^{th} rib to measure rib fat, and at the hip or thurl to measure rump fat as these measurements correlate well with total body fat (Schroder and Staufenbiel 2006).

3.2.7 Grazing behavior and preference data collection

Each yr, the study had 3 sampling periods lasting 9 d each, with each sampling period starting on d 1, d 36 and d 74, respectively. During these sampling periods animal plant preference and grazing behavior data was collected. The sampling periods ran the duration of the grazing allocation resulting in 3 d or 9 d of data collection for 3D and 9D treatments, respectively.

3.2.7.1 Plant preference estimation

The disappearance of plant structures (leaf, cob, husk and stem) was conducted to gain an understanding of animal grazing preference. Prior to grazing, corn plants in the allocated area for grazing were marked as described by Lardner et al. (2002) and whole plants and plant structures were collected. Lardner et al. (2002) marked individual plant parts in the field and returned to measure these plant structures to monitor disappearance after grazing occurred. Each day during each sample period, plants were collected from each replicate (*n*=10 in 3D trts, *n*=15 in 9D trts) and separated into the cob, husk, leaf, and stem plant structures. Total plant and individual plant structure weights were determined at this time, and all individual plant structure weights were reported as a percent of total plant weight.

Equation 3.4 Plant structure percentage equation.

$$\text{Plant structure percentage (\%)} = (PSW/TPW) \times 100$$

Where PSW =individual plant structure (stem, husk, leaf or cob) weight and TPW = total plant weight collected

3.2.7.2 Predicting animal grazing behavior

One cow from each replicate (n=2) group was randomly selected and fitted with a Lotek ® 3300LR GPS collar (Lotek Wireless, Newmarket, Ontario), for a total of 8 animals. The GPS collars were programmed to record data every 5 min starting at 0700 h on d 1 in each of the three sampling periods and conclude at 0700 h on d 4 or d 10 in 3D and 9D treatments, respectively. The duration of data collection spanned over the length of each sampling period to monitor animal movement from initial turnout on d 1, until initial turnout for the next grazing allocation. Collars were placed on the cows, 1 d prior to turnout to allow for adaptation to wearing the collar. The schedule generated 288 records d^{-1} resulting in 864 locations and 2592 locations for 3D and 9D treatments, respectively. In yr 1, all 8 collars worked without issue with 100% success in data recording, however in yr 2, all 8 collars failed due to a scheduling error in period 3, resulting in data collection for only periods one and two. Additionally, in yr 2, 4 of the collars failed for 1 d during period 2, for cows in 9DF and 9DNF treatments. In each paddock during each sampling period, features of interest were marked with a handheld Garmen eTrex GPS (Garmin International, Inc., Olathe, Kansas) to later validate and compare with GPS collar coordinates. The features marked included water troughs, bale feeders, and bedding sites.

The GPS data from the collars and marked features were mapped on ArcMAP 10.3© (Environmental Systems Research Institute, Inc., Redlands, California). The map was used to sort data based on physical location. The GPS fixes found within the features of interest were determined to be associated with the grazing activity. For example, GPS fixes within 5 m of the water trough were recorded as the animal drinking water, fixes within 10 m radius of the hay bale (fiber source) were recorded as consuming hay. These buffer radius around these attributes is relative to the size of the physical attribute within the paddock. Fixes not within the bounds of any of the three features, water, hay, or bedding area, were designated as corn grazing activity. Because the GPS fixes were collected every 5 min it was assumed the behavior lasted 5 minutes. The following equation shows how the duration in hr d^{-1} for an activity was calculated.

Equation 3.5 Activity duration estimation.

Duration of activity Z (hr d^{-1}) = [(no. of fixes Z x 5 min)/60 min] /p

Where no. fixes of Z = no. of fixes of activity Z over the grazing period and p=grazing allocation length.

3.2.8 Economic analysis

Agronomic inpute, yield measures and feeding records were combined with invoices for actual expenses incurred as well as reasonable estimates (e.g., for labour, owned equipment use, infrastructure depreciation) for non-cash expenses to determine total winter feeding costs reported as $/hd/d to compare among grazing systems (treatments). Crop production costs considered inputs (seed, fertilizer, herbicide) and equipment to grow and prepare the crop for extensive feeding. The total crop production costs per ha, were divided by the DM yield per ha to determine a cost per kg of dry matter. Feeding records included metre of row allocated to the replicate every 3 or 9 d. Yield measures included DM forage weight per 5.3 m (17.5 ft) of row. These measures were combined and divided by the number of cows in the replicate to determine the cost of corn per cow per day. Crop production costs included costs incurred, suggested retail costs and published custom rates from the Saskatchewan Ministry of Agriculture's Farm Machinery Custom and Rental Rate Guide (SMA 2010, 2016-2017). The cost of corn production included a land rental rate of $98.80/ha ($40/acre; SMA 2017). Labour to feed, check, bed and water the cattle was valued at $20/hour. The research ranch staff were consulted to establish fair estimates of the time required for each activity. Equipment used to feed and water the cattle was assigned an hourly rate in line with the *Farm Equipment Custom and Rental Rate Guide* (truck $30.60/hr, tractor $66.74/hr, and bale processor $17.22/hr; SMA 2010, 2016-2017). Supplemented hay was valued at the purchase price of $88.20 per tonne. Bedding straw was valued at the purchase price of $0.04 per kilogram. Infrastructure depreciation was based on an initial investment of $3,000 for the infrastructure (portable windbreak panels, fence posts, rebar, polywire, energizer, battery) required to field feed and the assumption it would be used for 10 years and would have a $1000 salvage value, for an annual depreciation of $200 which was divided by the number of cows and divided by 180 d, the typical winter feeding length for cow calf operations.

3.2.9 Statistical analysis

Statistical analysis was conducted using the mixed procedure of SAS (SAS version 9.4, SAS Inc., Cary, North Carolina). Experimental design was a 2 × 2 factorial arrangement in a completely randomized design. The fixed effects were fiber supplement (F vs. NF), allocation (3D vs. 9D). Timing within allocation was treated as a repeated measure and replicates within each year were treated as random effects. Interaction of the main effects (fiber × allocation, timing × fiber, timing × allocation, timing × fiber × allocation) were also reported. Each replicate paddock (n=2) within each treatment each yr and period was the experimental unit. To determine if data was normally, identically and independently distributed (NIID), the UNIVARIATE procedure of SAS was used. Tukey's multi-treatment comparison was applied to determine whether the treatment means were different, and differences were considered significant when $P \leq 0.05$ and trends discussed when $P < 0.10$.

3.3 Results and Discussion

3.3.1 Weather data

Mean monthly temperature averages from May to July in both yr 1 and 2 were slightly warmer compared to the 30 yr average, however August temperatures in yrs 1 and 2 were lower than the 30-yr average (Figures B.1 and B.2). Night time temperatures remained above freezing during the summer months for yr 1 and yr 2. The first dates with temperature below 0°C occurred on September 10, 2015 and October 5, 2016, however the duration of the low temperature is unknown (Figure B.1). A temperature of -3°C occurred on October 15, 2015 and October 8, 2016 (Figure B.1) and was used as the end point (killing frost) for calculating corn heat units (CHU) for each growing season while the starting point for calculating CHUs was the seeding date. The growing seasons accumulated 2132 and 2185 CHU, respectively in yr 1 and 2, respectively (Appendix A Table A.1.).

Total precipitation for the growing season (May to August) for yr 1 was 166 mm, which was well below the 30-yr average of 280 mm, while yr 2 precipitation (340 mm) was 33% higher than the 30-yr average. In yr 1, very little rainfall occurred during May (3 mm) compared to yr 2 (42 mm) which was comparable to the 30 yr average of 44 mm (Figure B.2). In yr 2, July rain fall was more than twice the average with 183 mm compared to yr 1 of 72 mm (Figure B.2). Cambouris et al. (2016) found that soil texture and amount and frequency of rainfall around N fertilizer application had a greater impact on corn yield than N fertilizer rates. The reduced rainfall in combination with the reduced CHU may have resulted in the lower corn yield in yr 1 compared to yr 2 (Appendix A, Table A.1; Appendix B, Figure B.2).

3.3.2 Forage yield, quality and estimated forage utilization

Water, nutrient availability and temperature are factors that can impact a crops potential yield (NASEM 2016a). Corn can often achieve a much higher yield compared to cereal grain crops used for winter grazing such as oat and barley (May et al. 2007). Yields of 11.69 and 13.16 T DM/ha were observed in yr 1 and 2, respectively (Appendix A. Table A.1.). As indicated, rainfall and low CHU's may have contributed to the reduced yield in the first yr of study. Recent work by Lardner et al. (2017), compared the yield and nutritive value of short-season corn hybrids and barley at different regions in western Canada. Corn hybrids had approximately 40% greater DM yield than barley across all regions, ranging from 31 to 78% greater biomass (Lardner et al. 2017). Corn yields in the same study were similar to yields in the current study which ranged from 12.0 to 13.2 T DM/ha over 3 yr (Lardner et al. 2017). After a frost event, NDF concentration may increase as soluble carbohydrates leach from corn stalks and leaves (Baron et al. 2003). Following a killing frost, many standing forages decline in quality quickly as the leaves fall off, however corn plants maintain their structure with minimal leaf loss throughout the winter (Baron et al. 2003; Billigetu et al. 2014). Samples collected in the current study were collected following the killing frost so nutritive value change prior to and following the killing frost cannot be commented on.

Forage biomass and nutrient composition are highly dependent on species, variety, growth stage, and environmental conditions (McCartney et al. 2008). Forage chemical composition, biomass and residue estimates are summarized in Table 3.1. All corn forage in the current study was grown under similar agronomic and environmental conditions, which resulted in similar nutritive value across all treatments. Forage residue was numerically higher in 9DF and 9DNF with 48.0 and 45.8% of forage biomass remaining in the field, respectively while 42.4 and 42.5% remained in 3DF and 3DNF, respectively.

Table 3.1 Forage nutritive value pre-graze, forage biomass and estimated residue of corn forage over 2 yr.

	Treatment					
Item[1]	3DF	9DF	3DNF	9DNF	SEM	*P*-value
DM	48.8	50.7	50.2	52.9	2.65	0.77
CP, % DM	7.9	7.8	7.6	7.7	0.23	0.23
ADF, % DM	31.6	31.7	32.1	31.1	0.89	0.25
NDF, % DM	52.2	52.3	52.7	51.5	1.22	0.32
TDN, % DM	67.7	67.6	67.4	68.1	0.58	0.27
Starch, % DM	19.6	20.1	19.5	20.4	1.79	0.84
Lignin, % DM	4.0	4.0	4.1	4.0	0.09	0.43
Ca, % DM	0.2	0.2	0.2	0.1	0.01	0.84
P, % DM	0.2	0.2	0.2	0.2	0.01	0.11
NEg, MCal kg^{-1}	0.9	0.9	0.9	0.9	0.02	0.27
Available forage, T DM/ha	13.3	13.0	13.6	13.3	1.13	0.94
Residual forage, T DM/ha	5.2	5.7	5.4	5.5	0.44	0.73
Resiude[2], %	42.4	48.0	42.5	45.8	3.64	0.76

[1] DM= dry matter, CP= crude protein, ADF= acid detergent fiber, NDF= neutral detergent fiber, TDN= total digestible nutrients, Ca= calcium, P= phosphorus NEg= net energy for gain.
[2]Residue %= (residual forage/available forage) × 100.

Nutritive value of corn forage, including DM, CP, fiber and starch, did not differ (*P* = 0.84) across treatments (Table 3.1). Across all treatments, CP content ranged from 7.6 to 7.9% (DM), which is comparable to results from Lardner et al. (2017) and slightly less than results reported by Jose et al. (2017) and McMillan et al. (2017). The NE_g was 0.9 MCal kg^{-1} of DM across all trt. The TDN content ranged from 67.4 to 68.1% (DM), which is similar to results reported by Lardner et al. (2017), Jose et al. (2017), and McMillan et al. (2017). Corn yield, TDN and CP content of the forage available in the current study are similar with previous studies suggesting corn is a suitable crop to meet requirements for dry, pregnant beef cows in early to mid-gestation but, corn protein levels may fall short for late gestation and lactating beef cows (Baron et al. 2003; May et al. 2007; NASEM 2016b; Lardner et al. 2017). Calcium and P levels in the current study are consistent with other study corn samples, yet do not meet the nutritional requirements of lactating beef cows and require the supplementation of Ca and P in the diet (NASEM 2016b; Lardner et al. 2017).

Weathering can impact nutritive value of forage as leaching and wind damage can occur causing nutrient losses (Volesky et al. 2002; Baron et al. 2003). The change in corn nutrient composition over the grazing study is presented in Table 3.2 where sample collection time was treated as a repeated measure. Treatment did not impact forage nutritive quality ($P > 0.05$). Residue samples were different from pre-graze samples collected throughout the study ($P < 0.01$) for all components except % DM. Residue (refused) forage samples had greater ($P < 0.01$) fiber content and lower ($P < 0.01$) TDN and CP content compared to samples from fresh (ungrazed) allocated corn (Table 3.2). The NDF, ADF and lignin concentration were highest ($P < 0.01$) in the residue sample compared to samples collected during the grazing study. Whereas, the starch and TDN content were the least ($P < 0.01$) in residue samples compared to grazing samples.

Crude protein was greatest at the start of the study and least in the residue samples (8.9 and 5.5%, respectively).

Earlier studies have observed large losses due to the weathering effects of frost, snow, and wind during the fall and winter resulting in up to 70% of DM disappearance in corn stover (Lamm and Ward 1981; Willms et al. 1993). In the current study all samples were taken following the killing frost so weathering effects related to freezing cannot be observed. Recent research by Baron et al. (2003), discovered weathering effects ranged from 18 to 38% on conventional grain corn and recent grazing corn varieties, respectively from September to January (Baron et al. 2003). These authors collected quality samples prior to frost as well as throughout the grazing trial as well as yield samples throughout. In the current study samples were only collected following the killing frost and no yield estimates were collected during the study. In the future, yield measurements every 21 d alongside quality measurements may better predict the affect of weathering.

Table 3.2 Nutritive value of corn forage over the grazing study duration over 2 yr.

	Forage sample collection time[1]							
Item[2]	Start of Study	d-21	d-42	d-63	End of Trial	Residue	SEM	*P*-value
DM	41.2*a*	48.4*b*	50.9*ab*	52.9*ab*	53.7*ab*	56.8*a*	2.82	<0.01
CP, % DM	8.9*a*	7.9*b*	8.0*b*	8.2*b*	8.0*b*	5.5*c*	0.24	<0.01
ADF, % DM	27.5*b*	28.4*b*	28.2*b*	28.2*b*	28.3*b*	49.0*a*	0.96	<0.01
NDF, % DM	46.2*b*	48.1*b*	47.6*b*	48.3*b*	48.2*b*	74.8*a*	1.31	<0.01
TDN, % DM	70.7*a*	70.2*a*	70.2*a*	70.3*a*	70.2*a*	54.6*b*	0.63	<0.01
Starch, % DM	21.2*a*	24.1*a*	24.8*a*	23.4*a*	23.5*a*	2.4*b*	1.92	<0.01
Lignin, % DM	3.5*b*	3.5*b*	3.5*b*	3.5*b*	3.6*b*	6.7*a*	0.11	<0.01
Ca, % DM	0.1*b*	0.1*b*	0.1*b*	0.1*b*	0.1*b*	0.4a	0.01	<0.01
P, % DM	0.2*a*	0.2*a*	0.2*a*	0.2*a*	0.2*a*	0.1*b*	0.02	<0.01
NEg, Mcal kg^{-1}	1.0*a*	1.0*a*	1.0*a*	1.0*a*	1.0*a*	0.5*b*	0.02	<0.01

[a-b]Means within a factor, within a row with different letters differ ($P < 0.05$).

[1]Timing denotes the timing within the study that forage samples (*n*=3) were collected over the grazing study. Residue= post-graze forage.

[2] DM= dry matter, CP= crude protein, TDN= total digestible nutrients, Ca= calcium, P= phosphorus NE= net energy for maintenance and gain.

Corn residue biomass following grazing did not differ (*P* = 0.73) among grazing systems (Table 3.1). Residues following grazing ranged from 4.9 to 6.2 T DM ha^{-1} over the 2 yr study period, which is comparable to recent work by Jose et al. (2015) where corn residue following grazing averaged 5.4 T DM per hectare. In the current study, utilization of corn did not differ (*P* = 0.76) across treatments and ranged from 42.4 to 48.0% residue remaining in the field (Table 3.1). The lower quality residue remaining in the paddock post-graze in combination with manure nutrient deposition can provide a valuable source of organic matter and nutrients when incorporated into the soil (Kelln et al. 2012).

3.3.3 Cow performance

Cow BW, rib and rump fat, BCS, and ADG a not affected by grazing system over the 2 yr study (*P* = 0.93) (Table 3.3 and 3.4). Cow BW was adjusted for conceptus weight and resulted in cattle gaining or maintaining BW throughout the study (Table 3.4). The objective of a winter grazing system is for cattle to maintain body condition, which was observed for all cows in all grazing systems in the current study (Table 3.4). Body condition score change did not differ (*P* = 0.77) between grazing systems, ranging 2.5 to 3.0 across all treatments pre- and post-grazing. Energy and protein content of whole plant corn (65.6% TDN; 7.7% CP) was adequate to meet requirements for non-lactating beef cows in mid gestation which was reflected in the performance data as weight loss was not observed (Baron et al. 2003; NASEM 2016b).

Table 3.3 Descriptive statistics on DMI in grazing systems over 2 yr.

	Fiber[1]		No Fiber		
Item	3D	9D	3D	9D	SEM
DMI[4], kg/d	10.9	12.6	10.5	13.4	1.51
Corn DMI, kg/d	9.5	11.3	10.5	13.4	1.44
Hay DMI, kg/d	1.4	1.3	-	-	0.18

[1]Fiber= with supplemental fiber, No Fiber = without supplemental fiber; 3D=3d allocation length; 9d allocation length.

Table 3.4 Effect of grazing system on beef cow performance over 2 yr.

	Fiber[1]		No Fiber			*P*-value[5]		
Item	3D	9D	3D	9D	SEM	Alloc	Fiber	Alloc × Fiber
Cow BW[2], kg								
Initial	655.6	655.4	655.7	656.8	6.46	0.88	0.84	0.85
Final	694.8	698.5	695.8	691.0	11.69	0.93	0.62	0.52
Change	36.8	40.6	37.7	31.8	4.68	0.80	0.36	0.27
Rib Fat, mm								
Initial	4.3	4.2	4.1	4.0	0.51	0.79	0.59	0.93
Final	4.3	4.5	4.8	4.6	0.36	0.53	0.07	0.71
Change	0.0	0.3	0.6	0.8	0.55	0.56	0.13	0.93
Rump Fat, mm								
Initial	4.3	5.4	5.0	4.8	0.50	0.12	0.85	0.56
Final	4.6	5.0	5.3	5.3	0.59	0.58	0.15	0.43
Change	0.5	-0.1	0.6	0.7	0.65	0.58	0.41	0.51
BCS								
Initial	2.7	2.7	2.6	2.6	0.07	0.34	0.49	0.68
Final	2.6	2.6	2.6	2.6	0.07	0.24	0.63	0.45
Change	-0.1	0.0	0.0	0.0	0.07	0.62	0.29	0.77
ADG[3], kg/d	0.7	0.8	0.7	0.7	0.12	0.91	0.43	0.55

[1]Fiber= with supplemental fiber, No Fiber = without supplemental fiber; 3D=3d allocation length; 9d allocation length.
[2]Cow BW was adjusted for conceptus weight gain.
[3]ADG= average daily gain.
[4]DMI= dry matter intake.
[5]AFixed effects of allocation, fiber and fiber × allocation.

Table 3.5 Effect of allocation and fiber on forage DMI over 2 yr.

	Allocation		Fiber			*P*-value	
Forage DMI[1]	3D	9D	Fiber	No Fiber	SEM	Allocation	Fiber
	……..…….kg/d……………						
Corn	9.9	12.4	10.4	11.9	1.34	<0.01	NS
Hay	0.7	0.7	1.3	0	0.17	0.92	NS
Total	10.6	13.1	11.7	11.9	1.41	0.01	NS

[a-b]Means within a factor, within a row with different letters differ ($P < 0.05$).

[1] DMI = Dry matter intake collected over 2 year using pre- and post graze yield data.

Total DMI (corn + hay) did not differ among grazing systems (Table 3.3). Corn and supplement hay intake was not affected by treatment. However, allocation length affected (*P* = 0.01) total DMI (Table 3.5). Total DMI was 23% greater (*P* = 0.01) in 9D grazing allocations compared to 3D, 13.1 and 10.6 kg/d, respectively (Table 3.5). When hay was offered, corn and DMI was numerically lower. This suggests supplemental hay may be substituted in place of corn forage when available. Feed intake is a function of forage availability, palatability and nutritive value (Valentine 1990; NASEM 2016b). When forage is scarce a substitution effect is favourable and is often achieved by providing an energy or protein supplement (Mathis and Sawyer 2007). The supplemental hay may have provided a more palatable option for the cattle once the cobs were consumed and only leaf, husk and stem remained, resulting in the lower corn DMI observed in those treatments with hay offered. Although total corn consumed was higher in 9D trt no affect on animal performance was observed. Numerical utilization data shows higher residual forage in 9D trt which may indicate more forage was being wasted in these trt. It should be noted that snow accumulation in yr 1 and 2 was well below the 30 yr average of 20.15 cm of snow cover (December to March average) with only 7.3 and 6.4 cm in yr 1 and 2, respectively. Snow cover in the current study likely had little to no affect on cow access to forage.

3.3.4 Grazing preference

During each sampling period, corn plants were collected from each replicated paddock to monitor plant part consumption. Stem, husk, leaf and cob structures were separated and weighed to record the representative proportions of total plant weight (Table 3.6). When supplemental hay was not offered there was a higher proportion of stem (*P* < 0.01) remaining while a lower proportion of husk (*P* = 0.02) and leaf (*P* < 0.01) which may indicate cattle were selecting for the more palatable structures (husk and leaf) compared to the stem when they were not offered hay.The proportion of cobs did not differ (*P* = 0.22), between groups with or without supplemental hay. This suggests that the animals were selecting more aggressively for palatable plant structures including the husk and leaf when no hay was available, while both treatments consumed cobs at a similar rate regardless of hay supplementation (Table 3.6). Allocation length did not affect the proportion of stem ($P = 0.30$), leaf ($P = 0.38$), or cob ($P = 0.78$) selected, but indicated a greater ($P < 0.01$) proportion of husk for the 9D compared to 3D allocation length.

Over the 2 yr, as days within a grazing allocation progressed the proportion of each plant structure remaining differed ($P = 0.01$; Table 3.6). From the start to end of a grazing period the proportion of stem increased ($P = 0.01$) while the proportion of husk, leaf and cob all decreased ($P = 0.01$; Table 3.6). The difference in nutritive value of residue forage samples compared to allocated corn samples likely reflects the change in available forage post grazing and animal selection of more palatable plant parts. During sampling of residue material, there were observed to be few to no corn kernels present, which is reflected by the lower starch and energy content compared to samples taken from new allocated corn forage (Table 3.2). In the current study there were no 2-way trt interactions (fiber × allocation) for the stem, husk or cob proportions, however a 3-way interaction (fiber × allocation × timing; $P = 0.03$) for the leaf proportion occurred (Figure 3.1). The leaf proportion was greater at the beginning of allocation for the 3DF and 9DNF groups, and lowest at the end of allocation for the 9DNF groups, suggesting the cows in the 9DNF group selected the greatest for leaves compared to the other treatments (Figure 3.1).

Current study results indicate that the cow diets were changing throughout the grazing allocation with more cobs consumed at the start and fewer cobs near the end of the forage allocation (Table 3.6). The cows were not selecting for the stem, as the proportion of this structure increased from start to end of allocation period (Table 3.6). Similar results were reported in a study where corn stover (forage remaining in a corn field following harvesting) was grazed by beef cattle (Lamm and Ward 1981). The authors observed over the 86 d grazing study that animals selected for plant parts in descending order of corn grain, husk and leaves, cobs, and stalks. Researchers were able to achieve these findings by collecting samples of forage pre-grazing and near the end of the grazing study, then comparing results to an ungrazed control area to ensure the increased disappearance of husk, leaves and corn grain was truly due to animal selection and not an effect of weathering factors (Lamm and Ward 1981). Similar work by Fernandez-Rivera and Klopfenstein (1989a) found that when grazing stover, cattle selected leaf and husk proportions in the greatest quantity (Fernandez-Rivera and Klopfenstein 1989a). The authors also evaluated the nutritive value of the leaf blade and husk and found leaf blade CP content ranged from 3.7 to 6.4% while the stem mean CP content was 2.6 to 4.6% (Fernandez-Rivera and Klopfenstein 1989b). Nutritive value of stover plant portions was also determined for irrigated and dryland corn crops. The irrigated forage had a mean CP content of 3.7 and 3.0%, and a mean NDF content of 85 and 84.4% in the leaves and stems, respectively. Fernandez-Rivera and Klopfenstein (1989b) also suggests that corn hybrid and irrigation level will impact both corn stover quantity and quality. Corn crops planted for grazing are often not as mature at the time of grazing, compared to stover remaining after grain harvest which may influence the selection behavior of the animal. As maturity increases, sugars in the plant are converted to starch making the stem and leaves less sweet which makes them less palatable to the animal (Goatcher and Church 1970; Klopfenstein et al. 1987).

Table 3.6 Main effects of fiber, allocation, and timing on grazing preference of corn plant structures over 2 yr.

	Treatment													
	Fiber			Allocation			Timing					*P*-value[2]		
Plant structure[1]	Fiber	No Fiber	SEM	3D	9D	SEM	Pre-graze	Start	Mid	End	SEM	Fiber	Allocation	Timing
Stem	67.6*a*	70.7*b*	0.82	69.8	68.5	1.8	48.6*d*	61.0*c*	79.6*b*	87.4*a*	2.03	<0.01	0.30	<0.01
Husk	8.3*a*	7.6*b*	0.69	7.4*b*	8.5*a*	0.71	9.2*a*	8.3*a*	7.8*ab*	6.4*b*	0.78	0.02	<0.01	<0.01
Leaf	7.4*a*	5.9*b*	0.36	6.5	6.8	0.37	8.1*a*	7.1*ab*	6.2*bc*	5.3*c*	0.44	<0.01	0.38	<0.01
Cob	16.8	15.6	1.02	16.3	16.1	1.01	34.2*a*	23.5*b*	6.2*c*	1.1*d*	1.18	0.22	0.78	<0.01

[a-c]Means within a factor, within a row with different letters differ ($P < 0.05$).

[1]plant structure = % of total plant weight. 10 plants weighed daily for 3D treatments and 15 plants weighed daily for 9D treatments. Stem = stalk 10 cm from base to tip with all leaves, husk and cobs removed, Husk = husk of cob; Leaf = leaf material pulled from plant, Cob = cob with corn kernels intact.

[2]Fiber= fiber supplement effects; Allocation= allocation length effects; Timing= timing within allocation effects.

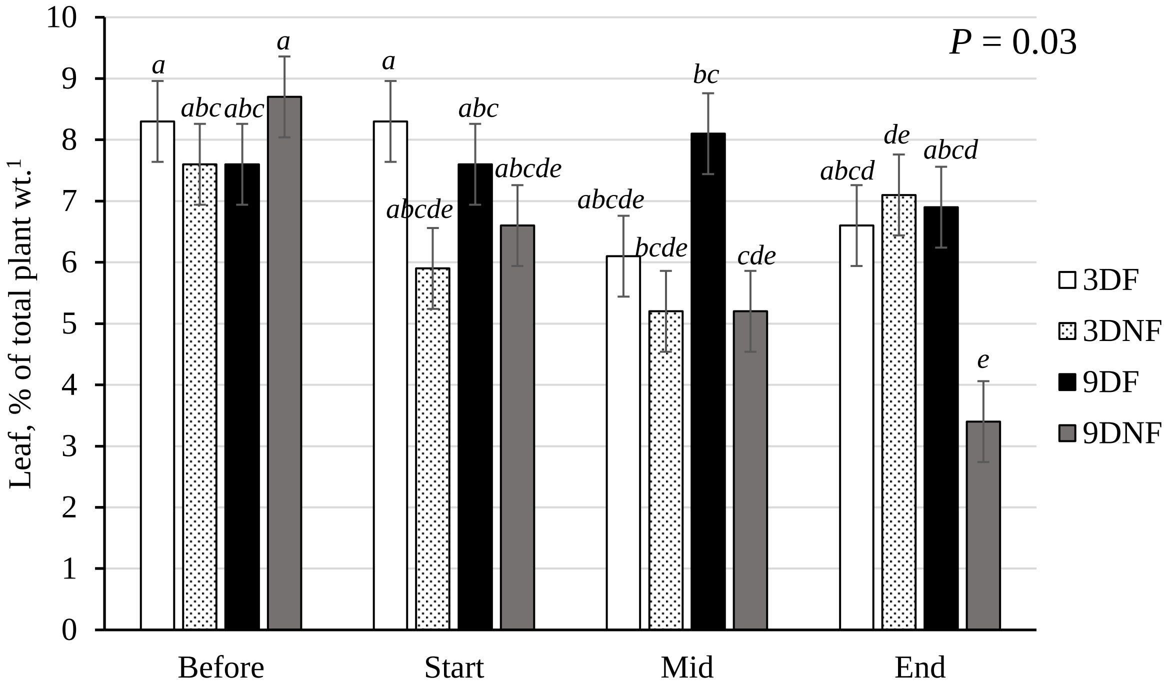

Figure 3.1 Effect of grazing system on disappearance of leaves over 2 yr.

Vertical bars within treatment with different letters differ ($P < 0.05$). Measurements from plant structures collected at the start (3D= d 1; 9D= d 1-2), middle (3D=d 2; 9D= d 5-6) and end (3D=d 3; 9D= d 7-8) of allocation. Leaf % of total plant weight. 10 plants weighed daily for 3D treatments and 15 plants weighed daily for 9D treatments.

3.3.5 Grazing activity

Figure D.3 (Appendix D) is a diagram of how the GPS data was mapped using ArcGIS 10.3.1 (ESRI, Redlands, CA) and then used to predict grazing activity. Data were analyzed using the mapping tool and are summarized in Figure 3.2 and Table 3.7. Fiber allocation resulted in decreased (P = 0.03) time spend grazing corn likely due to the additional time spent consuming the supplemental hay (Table 3.7). The data also suggests cattle on the 3D allocation systems spent more time (P = 0.01) at the water trough than cattle on the 9D forage allocation system 0.2 vs 0.1 hr/d, respectively. Since the GPS data was collected on 5-min intervals, a deficiency should be noted that watering events could have been missed if the animal went to the water trough and left within the 5 min time frame, thus resulting in no GPS fix representing the watering event.

Main effect interactions over time were also analyzed with no significance observed (P = 0.52). Figure 3.2 shows the average time spent in the corn over a grazing allocation. While the data indicates no significant (P = 0.52) treatment effect, it draws attention to the animal's likely change in grazing behavior as the available forage structures changed. This preference change was observed in the grazing preference data (Tables 3.4 and 3.5), where the cattle consumed the corn cobs at the start of the forage allocation.

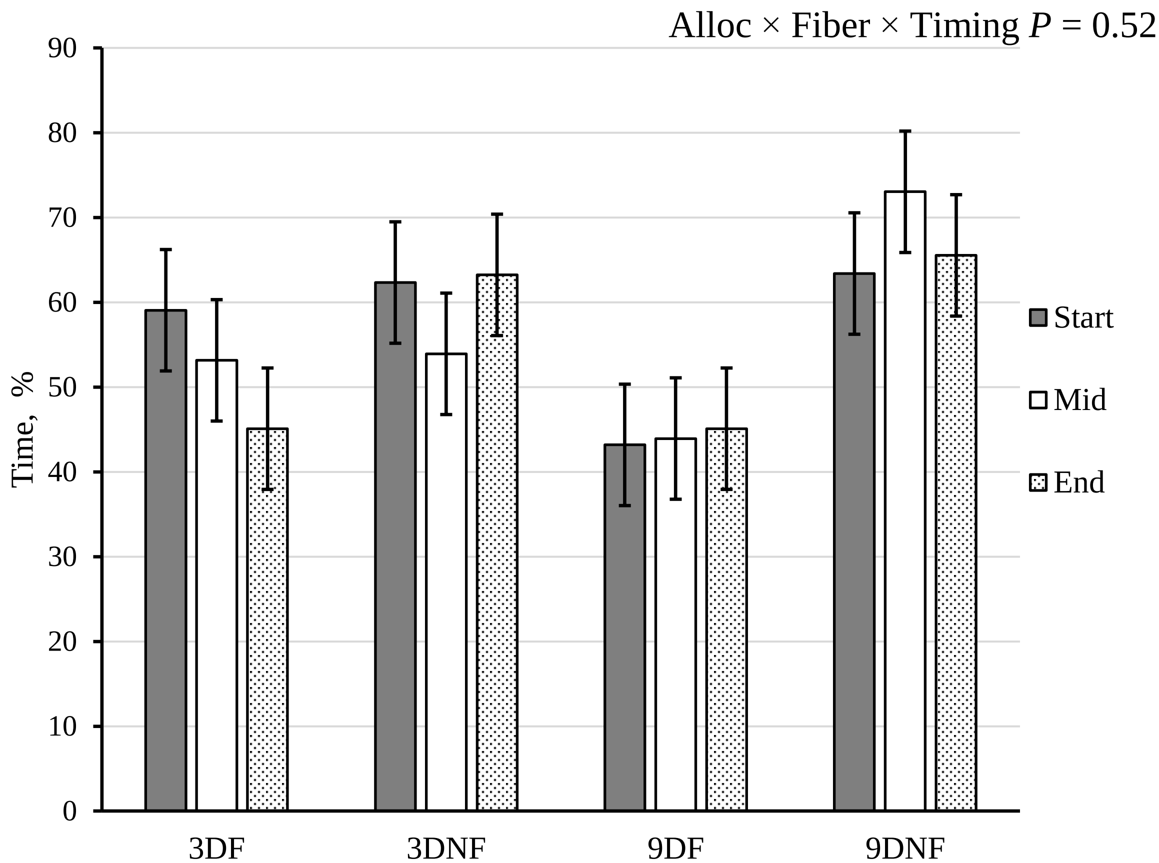

Figure 3.2 Effect of grazing system on time spent grazing corn within a grazing allocation over 2 yr.

Vertical bars within treatment with different letters differ ($P < 0.05$). Data from GPS collars summarized by timing within allocation with start (3D= d 1; 9D= d 1-2), middle (3D=d 2; 9D= d 5-6) and end (3D=d 3; 9D= d 7-8) of allocation using 0700 h as the starting point of each day.

Similar grazing activity analysis was used by Bailey and Jensen (2008), where supplements were offered to cattle grazing rangeland, and GPS collars were used to estimate the amount of time spent grazing within a 100 m radius of locations where supplements were offered. In the study, protein cake was fed 3 times per week in low lying and more accessible terrain while low moisture blocks were continuously available on steeper terrain (Bailey and Jensen 2008). The study reported that within 60 min after range cakes were offered, cattle had consumed the cubes and were not enticed to remain and graze in the area; whereas the low moisture blocks encouraged grazing in less desirable areas over a longer period of time, an increase of 200 to 300 min per day (Bailey and Jensen 2008). This data agrees with current study findings (Table 3.7), when hay was offered, cattle adjusted their grazing area and spent less time in the corn once the cobs are consumed.

In another study, Ganskopp and Bohnert (2009) monitored grazing cattle using GPS collars in large range pastures (329 and 258 ha) and compared the data to extensive forage sampling across the landscape. Free-ranging cattle spent more time in locations where forage had greater than average *in situ* DM disappearance and CP content, and lower than average NDF content. These authors also suggest that cattle respond to a combination of nutritional characteristics when selecting an area to graze such that they may not always seek the area with the highest CP forage, but select an area with moderate CP and more palatable plants. In addition, paddock size has been shown to effect animal grazing behavior (Turner et al. 2000; Bailey and Jensen 2008), explaining why current study paddock size was kept similar (1.2 ± 0.38 ha).

Table 3.7 Main effect of allocation and fiber on time spent in the corn, at the water trough, bedding area or fiber supplement over 2 yr.

	Allocation			Fiber			*P*-value		
Item	3D	9D	SEM	Fiber	No Fiber	SEM	Allocation	Fiber	Alloc × Fiber
Corn[1,2]									
% of time[3]	56.5	55.7	4.70	48.6*b*	63.6	4.70	0.90	NS	NS
hr/d[4]	13.6	13.4	1.13	11.7*b*	15.3	1.13	0.90	NS	NS
Fiber Supplement								NS	NS
% of time	10.1	9.8	3.14	19.7*a*	0	3.14	0.91		
hr/d	2.4	2.3	0.75	4.7*a*	0	0.75	0.90	NS	NS
Bedding Area								NS	NS
% of time	32.5	34.3	4.50	31.2	35.6	4.50	0.77		
hr/d	7.8	8.2	1.08	7.5	8.5	1.08	0.78	NS	NS
Water								NS	NS
% time	0.9*a*	0.2*b*	0.35	0.5	0.6	0.35	0.01		
hr/d	0.2*a*	0.1*b*	0.09	0.1	0.1	0.09	0.01	NS	NS

[a-b]Means within a factor, within a row with different letters differ ($P < 0.05$).
[1]Data collected with 5-min GPS fixes for 24 hr/d; 3D trt = 3 consecutive d or 864 fixes. 9D trt = 9 consecutive d or 2592 fixes.
[2]Feature locations determined by handheld GPS and compared to GPS fixes using ArcGIS 10.3.
[3]Percent of time at feature = no. fixes within feature/total no. fixes.
[4]hr/d= [(no. fixes*5 min)/60min]/no. of days.

3.3.6 Economic Analysis

Land preparation costs, crop input costs and total production costs each yr are outlined in Table 3.8. Fixed costs included labour, equipment, and infrastructure depreciation while variable costs included crop inputs, supplemental hay, bedding, salt and mineral (Kelln et al. 2010; Jose 2015). Crop production expenses are reported on a cost per ha basis (Table 3.8). Crop production costs were the same across all treatments and were similar for each year of the study. Crop production expenses will vary slightly year to year based on the extent of land preparation needed, level of fertilizer needed, and changes in crop input and custom rates (SMA 2016-2017). Compared to annual small grain cereals, corn is often the highest input cost crop (Jose 2015; McMillan et al. 2018). Crop production costs in the current study of \$774.26 ha^{-1} are comparable to \$746.00 ha^{-1} as reported by McMillan et al. (2018). In the same study, crop production costs for barley greenfeed or swath-grazing barley amounted to \$529.25 and \$477.73 ha^{-1}, respectively. High corn production costs seldom result in the highest cost per hd per d basis, but often discourage risk adverse producers.

Table 3.8 Crop production costs.

Crop Production Expenses[1]	2015	2016	2 Yr Average
	………..……$/ha……………...…..		
A. Land Preparation Costs			
Sommers Machine	44.46	88.92	66.69
Rogator	19.64	19.64	19.64
Cultivator	22.48	0	11.24
Heavy Harrows	11.73	0	5.87
B. Crop Input costs			
Seed	251.85	268.64	260.24
Seeding	38.29	38.29	38.29
Land Rolling	14.10		7.05
Fertilizer	101.41	132.28	116.85
Herbicide	59.28	58.37	58.83
Herbicide Application	88.92	92.63	90.77
C. Land Rent	98.80	98.80	98.80
Total Crop Production Expenses (A+B+C)	750.96	797.55	774.26

[1]All system costs are calculated similarly.

System costs are reported on a cow per day basis and extensive feeding records were used to estimate costs for yr 1 and 2. Corn crop production costs were divided by the total DM yield in each grazing system to calculate the cost of corn on a price per kg DM basis. Cost per kg of DM was then multiplied by the estimated feed allocated over the course of the study based on feed records of length of row offered and row weights recorded during yield assessment. The cost of the corn was $64.92 and $62.68/MT of DM in yr 1 and 2, respectively. The total hay offered in each 3DF and 9DF treatment replicate was multiplied by the purchase price ($0.09/kg) for the hay and divided by the total cow days to calculate cost per cow per day for hay supplementation. Mineral ($32.13/25 kg bag) and salt ($5.33/25 kg block) retail costs and records of amounts offered were used to calculate cost per cow per day. Feed costs over 2 yr were $1.36, $1.21, $1.62, and $1.56 /cow/d for 3DF, 3DNF, 9DF, and 9DNF, respectively (Table 3.9). Total feed costs were numerically greater ($P > 0.05$) for the fiber supplemented systems (3DF, 9DF) compared to no fiber systems (3DNF, 9DNF), which can be attributed to the additional cost of supplying supplemental hay (Table 3.9).

Table 3.9 Economics of forage allocation length and supplemental fiber when grazing corn over 2 yr.

System Expenses	Treatment				SEM	*P*-value
	3DF	3DNF	9DF	9DNF		Allocation*Fiber
	………...$ cow/d………...					
A. Field Feeding Costs						
Corn	1.04	1.14	1.26	1.49	0.171	0.61
Hay	0.25	-	0.30	-	0.051	0.58
Mineral & Salt	0.07	0.07	0.06	0.07	0.004	0.14
Total Feed Costs	1.36	1.21	1.62	1.56	0.141	0.70
B. Total Other Direct Costs						
Bedding	0.06	0.06	0.06	0.06	0.005	0.38
C. Yardage Costs						
Machinery Cost[1]	0.15	0.16	0.09	0.09	0.012	1.00
Labour	0.09	0.09	0.05	0.05	0.006	0.84
Infrastructure Depreciation	0.08	0.08	0.08	0.08	0.004	0.85
Total Yardage Costs	0.32	0.33	0.22	0.22	0.021	0.85
Total Production Costs (A+B+C)	1.74	1.60	1.90	1.84	0.164	0.73

[1] Machinery costs include fuel cost.
SEM= pooled standard error of the mean.

Figures 3.2 and 3.3 demonstrate the individual effects of fiber and allocation on production costs. Total feed costs were numerically greater for 9D allocations which is likely a reflection of the numerically greater DMI over the 2 yr study. The average production costs over 2 yr were \$1.74, \$1.60, \$1.90 and \$1.84/cow/d for 3DF, 3DNF, 9DF and 9DNF systems, respectively (Table 3.9). Total production costs did not differ ($P = 0.73$) among grazing treatments (Table 3.9). Costs were expected to be lower for 9D allocation lengths due to the reduced labour needed to move fence and cows every 9 d compared to every 3 d; however, the cost savings in labour was outweighed by the increased feed costs. In both 9DF and 9DNF systems, the total yardage costs were \$0.11 lower ($P = 0.85$) than 3DF and 3DNF grazing systems likely due to the reduced machinery and labour costs as a result of fewer fence and animal movements (28 and 12 moves, 3 and 9 d respectively). Total feed costs were higher ($P = 0.04$) in 9D trt compared to 3D at \$1.59 and \$1.29/hd/d, respectively likely due to the higher ($P < 0.01$) corn costs of \$1.40 and \$1.12/hd/d for 9D and 3D, respectively. Corn residue which was numerically greater ($P = 0.76$) in 9DF and 9DNF (48 and 45%, respectively) compared to 3DF and 3DNF (42.4 and 42.5%, respectively) meaning it was utilized more poorly in 9d allocations (Table 3.1). These greater feed cost outweighed any savings observed in yardage costs, resulting in total production costs being numerically greater for the 9d grazing systems in this study. Total production costs were 18% higher for 9DF compared to 3DNF, suggesting the increase was due to increased feed costs associated with the hay and increased corn consumed in 9DF compared to 3DNF.

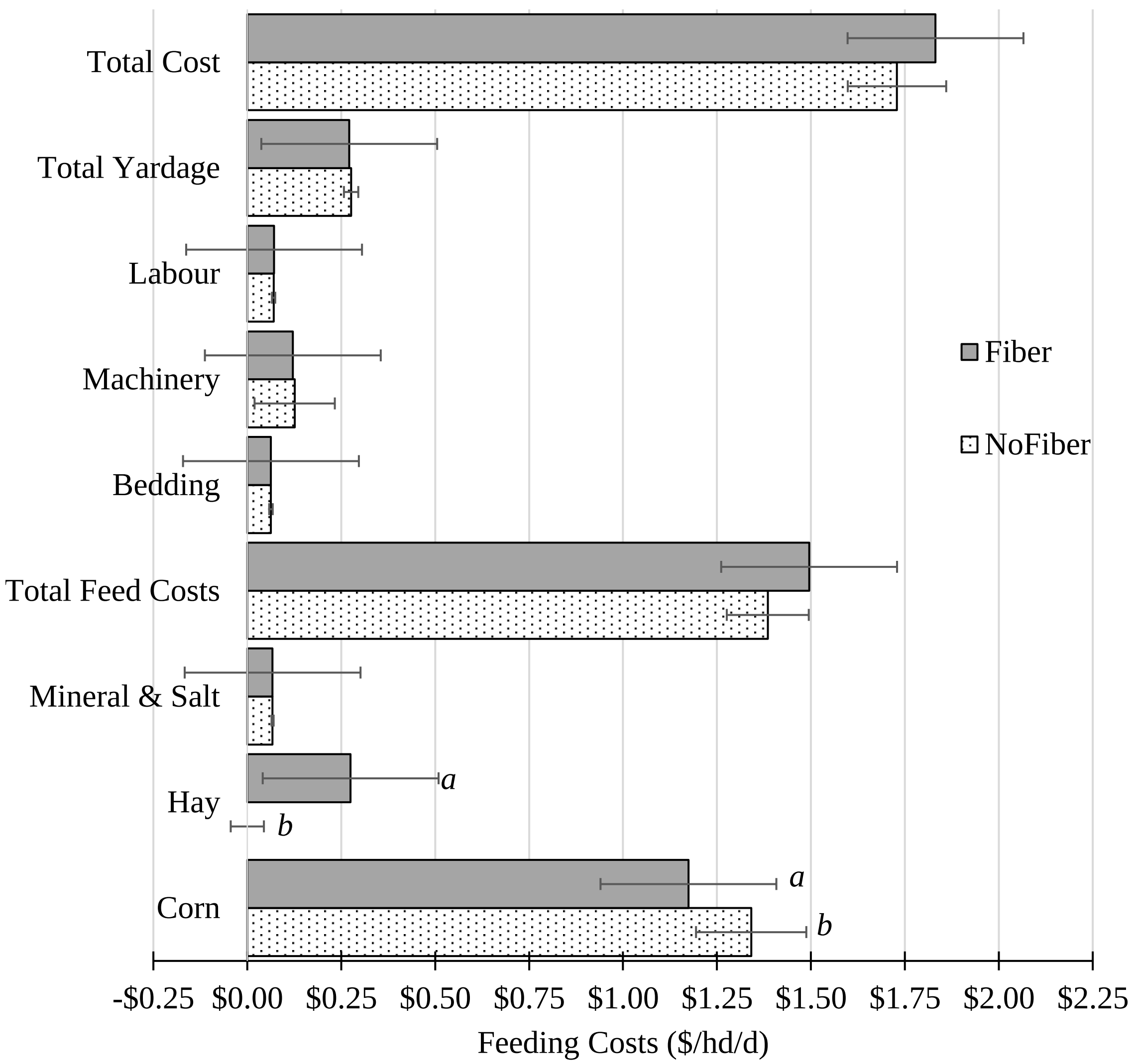

Figure 3.3 Effect of fiber supplementation on economic costs over 2 yr. Horizontal bars within treatment with different letters differ (*P* < 0.05).

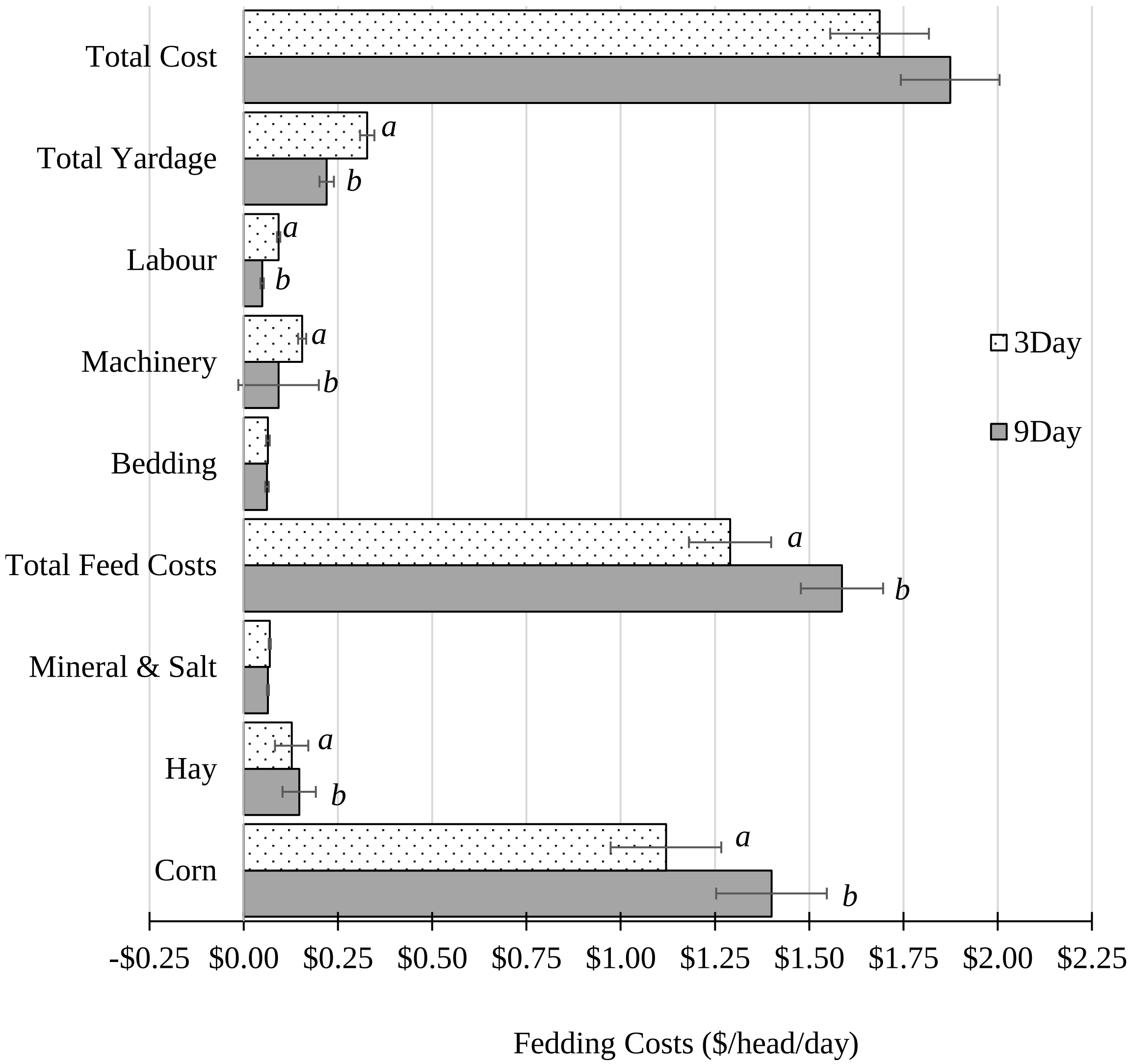

Figure 3.4 Effect of allocation length on economic costs over 2 yr.

Horizontal bars within treatment with different letters differ (*P* < 0.05).

3.3.7 Conclusion

In the current study, corn yield, energy and CP content were comparable for corn grown in other research studies conducted in western Canada (Jose et al. 2017; Lardner et al. 2017). Cow performance was not affected by grazing system suggesting corn quality met the nutritional requirements of the cows during second trimester, which agrees with previous findings (Baron et al. 2003; May et al. 2007; NASEM 2016b). Grazing preference and behavior data suggest that cattle preferentially graze the nutrient dense structures, such as cobs at the start of a grazing allocation. Data suggests that as grazing progresses within a grazing allocation period, the diet composition also changes. As cobs are consumed, less nutrient dense plant structures like husk, leaf and stem, make up a larger portion of the animal's diet.

Allocation length affected corn ($P < 0.01$) and total forage ($P = 0.01$) DMI suggesting that as allocation length increases more forage is consumed. However, forage utilization results suggest that the cows left more residue in 9D allocation systems outweighing the cost benefits of reduced labour in the 3D systems. Study results suggests that a 3D allocation system may provide a more nutritionally consistent diet for the cow and a more cost-effective strategy for the producer. Fiber supplementation does not reduce the grazing selection of corn cobs or improve forage utilization. Furthermore, fiber supplementation did not reduce overall feed costs in the current study. The cost effectiveness of fiber supplementation will vary across farms due to the feed costs on farm.

4.0 EFFECT OF 3- VS. 9-D ALLOCATION WITH OR WITHOUT FIBER SUPPLEMENTATION ON RUMEN FERMENTATION DYNAMICS

4.1 Introduction

Swath-grazing, bale grazing, and stockpiled forages are commonly used for extensive grazing, however grazing whole plant corn is growing in popularity due to the high yield potential, nutritive value and the crop's erect structure (Baron et al. 2003; Sheppard et al. 2015). Recent improvements in corn hybrids make it more suitable for northern areas of western Canada (Lardner et al. 2017; McMillan et al. 2017). Although corn grain is typically less readily fermentable than barley grain, the risk for acidosis is still quite high (Chibisa et al. 2015; Silveira et al. 2007). Mitigating the risk of acidosis in feedlot or dairy rations usually involves feeding a TMR to provide fiber and prevent sorting for the highly fermentable portion, such as the corn grain (Krause and Oetzel 2006). In a grazing scenario cattle are left to select their own diet so when highly fermentable grain is readily available, the risk of acidosis is increased (Jose 2015). Previous work by Jose et al. (2015), studied the effect of corn grazing and swath grazing on rumen fermentation dynamics on 2- to 3-d allocation lengths. Further evaluation of the effects of extensive grazing systems on rumen fermentation may lead to alterations in management practices can help mitigate the risks of acidosis in grazing systems utilizing whole plant corn.

4.2 Materials and Methods

4.2.1 Animals, crop management and experimental design

Sixteen ruminally cannulated beef cows were allocated to 1 of 4 replicated (*n*=2) grazing systems which included i) 3 d corn allocation with supplemental fiber (**3DF**); ii) 3 d corn allocation without supplemental fiber (**3DNF**); iii) 9 d allocation with supplemental fiber (**9DF**); or iv) 9 d allocation without supplemental fiber (**9DNF**). A completely randomized design with a 2 × 2 factorial arrangement design was used to evaluate the effects of the grazing systems.

Throughout the study, all the cannulated cows grazed in replicate paddocks with intact cows and were managed similarly as described in Section 3.0.

4.2.2 Data collection

Each year, the rumen fermentation study was divided into 3 sampling periods at the start, middle and end of the grazing study starting on d 1, d 36 and d 74, respectively. The sampling periods ran the duration of the grazing allocation resulting in 3 d or 9 d of data collection for 3D and 9D treatments, respectively.

4.2.2.1 Rumen fluid collection

Rumen fluid was collected on d 1 (start), 2 (middle), and 3 (end) for 3DNF and 3DF treatments, and d 1 and 2 (start), 5 and 6 (middle), and 8 and 9 (end) in the 9DNF and 9DF treatments. For 9DNF, 9DF treatments, rumen samples were composited at the time of analysis based on d of sample collection to better represent the start, middle and end of grazing allocation. Rumen fluid was strained through 2 layers of cheesecloth and 3, 10-mL aliquots were transferred into 12-mL centrifuge tubes (Thermo Fisher Scientific, Watham, MA) . One sample was stored as a spare sample. One sample was preserved with 2 mL of 25% (v/v) metaphosphoric acid (H_3PO_4) to be used for SCFA analysis. The final sample was preserved with 2mL of 1% sulfuric acid (H_2SO_4) to be used for ammonia-N determination. All samples were stored at -20°C until further lab analysis was completed.

4.2.2.2 Indwelling rumen pH measurement

To monitor fluctuations in rumen pH, Lethbridge Research Centre pH measurement systems were used (LRCpH; Dascor Inc., Escondido, CA) as described by Penner et al. (2006). Two cows per replicate (n = 2) had LRC pH system probes inserted into the ventral sac of their rumen during all three sampling periods. The LRCpH probes were set to collect pH measurements in millivolts (mV) at 5 min intervals over the duration of the sampling period from 0700 h on d 1 to d 4, or d 1 to d 10, for 3 d and 9 d trt, respectively. Prior to and following each sampling period, the LRCpH probes were standardized using a buffer solution at pH of 4 and 7 in a 39°C water bath. The drift between initial and final standardization was considered linear and the mV data was converted to pH values (Jose 2015). A ruminal pH of 5.8 was the threshold for mild ruminal acidosis used in this study (Maekawa et al. 2002). From the data collected daily minimum, mean, maximum pH, duration (min/d) and total area (pH × min) pH ≤ 5.8 was calculated for each replicate, by period across 2 yr as described by Penner et al. (2006) and Chibisa et al. (2015).

4.2.2.3. Short chain fatty acid determination

Rumen fluid samples were collected as described in Section 4.2.2.1. Samples were thawed at room temperature, inverted several times then centrifuged at 12,000 × *g* for 10 min at 4°C. Samples were then sub-sampled into micro-centrifuge tubes and centrifuged again at 16,000 × *g* for 10 min at 4°C. An internal standard, isocaproic acid, was added to each duplicate sample and loaded into Agilent GC vials. The samples were analyzed using an Agilent 6890 Series Gas Chromatography auto sampling system equipped with a Agilent 7683 Series Injector (Agilent Technology Inc., Mississauga, ON; Khorasani et al. 1996). A mixed standard was also included in the analysis and consisted of known amounts of acetic, propionic, butyric, isobutyric, valeric, isovaleric, caproic and isocaproic acids to set up the calibration curve.

4.2.2.4 Rumen ammonia-N estimation

The rumen fluid samples were thawed at room temperature, inverted to mix the contents, and centrifuged at 12,000 × *g* for 10 min at 4°Celcius. Samples were then subsampled and duplicate micro centrifuge tubes were centrifuged at 14,000 × *g* for 10 min at 4°C, the supernatant was then placed on ice and subsampled into glass test tubes. These samples were then prepared using the phenol-hypochlorite method described by Broderick and Kang (1980). All the prepared samples, including blanks and calibration samples (5, 10, 15, 20, and 25 mg/dL of NH_3) were read using atomic absorption spectrometry. The concentration of NH_3 was read using a Pharmacia LKB Ultrospec III spectrophotometer at 630 nm (LKB Biochrom Ltd., Cambridge, EN).

4.2.2.5 Fecal sample collection

At 1000 h each day during each sampling period ≥ 200 g of fresh manure was collected from 5 manure pats on the ground as described by Jancewicz et al. (2017). All manure samples were then frozen at -20°C until samples could be dried in a forced air oven at 55°C for 4 days. Dried samples were then ground to 1 mm with a Retsch grinder (Verder Scientific, Inc., Newton, PA). All ground fecal samples were sent to Cumberland Valley Analytical Services (Waynesboro, PA) where they were analyzed for starch using the AOAC Official Method 920.40 (Direct Acid Hydrolysis) recommended technique modified with corrections for glucose from Hall (2009).

4.2.3 Statistical analysis

Data was analyzed using the mixed model procedure of SAS (Version 9.4, SAS, Cary, NC). The experimental design was a completely randomized with a replicated 2 × 2 factorial arrangement in a completely randomized design. Each replicate paddock (n=2) within each treatment each yr and period was the experimental unit. The fixed effects were fiber supplement and allocation length. Timing within allocation was treated as a repeated measure and replicates within each year were treated as random effects. Interaction of the main effects (fiber × allocation, timing × fiber, timing × allocation, timing × fiber × allocation) were also reported.

To determine if data was normally, identically and independently distributed (NIID), the UNIVARIATE procedure of SAS was used. Tukey's multi-treatment comparison was applied to determine whether the treatment means were different, and differences were considered significant when $P \leq 0.05$ and trends discussed when $P < 0.10$.

4.3 RESULTS AND DISCUSSION

4.3.1 Rumen pH

Main effects on rumen pH are shown in Table 4.1. No significant effect ($P = 0.59$) of fiber or allocation ($P = 0.11$) on main effects were observed in the 2 yr study except for the effect of allocation ($P = 0.05$) on maximum pH level. The maximum ruminal pH was greater ($P = 0.05$) and the minimum ruminal pH tended ($P = 0.08$) to be greater in the 9D allocation treatments (Table 4.1). It was surprising that allocation length did not affect ($P = 0.92$) the time rumen pH < 5.8 considering the 9D cattle had access to 3 fold the amount of forage and therefore potentially more corn cobs compared to 3D allocation cattle. Intake limitations may explain this as even though 9D cows had access to more plant structures including cobs, they could not consume any more than the 3D groups in a 24 h period. Mean and minimum pH was numerically lower in groups without supplemental hay and the duration of time spent pH < 5.8 was 74.9 compared to 36.1 min per day in the no fiber and fiber groups, respectively (Table 4.1).

All rumen pH parameters were affected ($P = 0.01$) by timing within allocation. As timing progressed within a grazing allocation the minimum and maximum pH increased ($P = 0.01$; Table 4.1). These findings in the current study agree with Jose et al. (2015), where the first day of allocation resulted in the lowest minimum pH in both barley swath grazing and corn grazing systems. In the current study, the duration ($P = 0.01$) and area ($P = 0.01$) of ruminal pH < 5.8 was higher at the start of a grazing allocation (Table 4.1). Similar results were observed by Jose et al. (2015), where the duration ($P = 0.01$) and area ($P = 0.01$) of ruminal pH < 5.8 was greatest on d 1 in both corn and swathed barley grazing. Rosser et al. (2017) observed the 735.7, 361.7, and 65.8 min/d of pH <5.8 on d1, d2 and d3 of 3D allocation of forage while only 5 to 79 min/d of pH < 5.8 in 1D allocations. Rosser et al. (2017) concluded that more frequent feeding of whole crop forages would minimize the risk of low ruminal pH.

Table 4.1 Effect of fiber, allocation, and timing within allocation on rumen pH over 2 yr.

	Treatment												
	Fiber			Allocation			Timing				*P*-value[2]		
Item	Fiber	No Fiber	SEM	3D	9D	SEM	Start	Mid	End	SEM	Fiber	Allocation	Timing
Ruminal pH													
Minimum[1]	6.32	6.20	0.133	6.19	6.34	0.133	5.93*c*	6.25*b*	6.61*a*	0.130	0.14	0.11	<0.01
Mean	6.68	6.63	0.107	6.58	6.73	0.107	6.45*b*	6.65*a*	6.86*a*	0.101	0.59	0.08	<0.01
Maximum	7.03	7.03	0.055	6.95	7.10	0.055	6.93*c*	7.03*b*	7.12*a*	0.042	0.98	0.05	<0.01
Duration <5.8, min/d	36.10	74.90	26.698	54.23	56.78	26.698	143.18*a*	26.32*b*	0*b*	29.074	0.14	0.92	<0.01
Area <5.8, pH × min	4.13	20.34	14.695	10.63	16.83	14.69	37.44*a*	2.39*b*	0*b*	15.475	0.13	0.76	0.02

[a-c]Means within a factor, within a row with different letters differ ($P < 0.05$).

[1]Continuous indwelling pH measurement; 3 d in 3D trt and 9 d in 9D trt.

[2]Fiber= fiber supplement effects; Allocation= allocation length effects; Timing= timing within allocation effects.

4.3.2 Rumen fermentation

Rumen fermentation data were analyzed with main effects as shown in Table 4.2. Grazing systems with supplemental hay had greater (P = 0.03) propionate concentrations compared to those without hay, 17.5 and 16.7% of total SCFA concentration, respectively (Table 4.2). Total SCFA concentration was greater (P = 0.01) at the start and mid of each grazing allocation compared to the end, 102.1, 99.1, and 86.8 mM, respectively. Propionate concentrations were numerically greater (P =0.19) at the start of a grazing allocation compared to the end while acetate concentrations were highest (P = 0.01) at the end of the grazing allocation. More readily fermentable plant structures, such as corn cobs, were available at the start of the grazing allocation compared to the end (Table 3.6), which provides more substrate to the microbes for SCFA production which may account for the higher concentration observed and the slight change in acetate concentration (Table 4.2). Isovalerate concentration was greater (P = 0.01) in 9 d allocations compared to 3 d and was greater (P = 0.01) when hay was offered. Total SCFA concentration or the concentration of acetate, butyrate, isobutyrate and valerate were not affected (P > 0.05) by fiber or allocation main effects.

In a high forage diet, cellulolytic bacteria are imperative to ensure maximum forage utilization is achieved, and in high forage rations when rumen pH drops, so does the proteolytic activity within the rumen (Bach et al. 2005). Rumen ammonia-N concentration was observed to be quite low overall, but comparable to results reported by Jose et al. (2015). The low Rumen ammonia-N concentration would indicated that the whole plant corn is not providing any excess protein, although it may be adequate for mid-gestating cattle it may be deficient depending on the growing conditions so producers should feed test and supplement accordingly. Rumen ammonia-N was greater (P < 0.01; Table 4.2) at the end of a grazing allocation and lowest at the middle of allocation (2.9 and 1.7 mg dl^{-1}, respectively; Figure 4.1). Near the end of the grazing allocation corn cobs had already been consumed leaving a diet consisting primarily of leaves and corn stems (Table 3.6). The increased ammonia-N near the end of the grazing allocation may be due to the increased rumen pH and lack of readily fermentable substrate in the diet.

Table 4.2 The effect of fiber supplementation, allocation length, and timing within grazing allocation on ruminal fermentation parameters in grazing beef cows over 2 yr.

	Treatment										*P*-value[1]				
	Fiber			Allocation			Timing								
Item	Fiber	No Fiber	SEM	3D	9D	SEM	Start	Mid	End	SEM	Fiber	Alloc	Timing	Alloc× Fiber	Alloc× Fiber× Timing
Ruminal SCFA, m*M*															
Total[3]	97.98	94.03	3.832	97.53	94.48	3.832	102.12*a*	99.13*a*	86.77*b*	3.832	0.18	0.30	<0.01	0.28	0.50
Acetate[4]	65.73	64.43	0.572	65.35	64.81	0.572	64.88*ab*	64.11*b*	66.25*a*	0.582	0.11	0.51	0.01	0.36	0.49
Propionate	16.73*b*	17.54a	0.375	16.88	17.39	0.375	17.55	16.97	16.88	0.397	0.03	0.16	0.19	0.88	0.97
Butyrate	13.12	12.92	0.422	13.09	12.95	0.422	13.41*a*	14.17*a*	11.49*b*	0.441	0.74	0.80	<0.01	0.60	0.80
Isobutyrate	0.80	0.84	0.019	0.81	0.84	0.019	0.77*b*	0.84*a*	0.86*a*	0.019	0.19	0.28	<0.01	0.25	0.60
Isovalerate	1.21*b*	1.42*a*	0.084	1.23*b*	1.38*a*	0.084	1.16*b*	1.44*a*	1.34*a*	0.086	<0.01	0.04	<0.01	0.29	0.39
Valerate	0.91	0.98	0.042	0.95	0.94	0.042	0.92	1.03	0.89	0.041	0.22	0.91	0.02	0.06	0.27
Ammonia, mg dl^{-1}	2.5	2.1	0.28	2.6	2.1	0.28	2.5*ab*	1.7*b*	2.9*a*	0.28	0.31	0.26	<0.01	0.75	0.27

[a-c] Means within a factor, within a row with different letters differ ($P < 0.05$).
[1]Fiber= fiber supplement effects; Allocation=allocation length effects; Timing=timing within allocation effects.
[3] Measurements from rumen fluid samples collected at the start (3D= d 1; 9D= d 1-2), middle (3D=d 2; 9D= d 5-6) and end (3D=d 3; 9D= d 7-8) of allocation.
[6]Individual SCFA reported as % of total SCFA concentration.

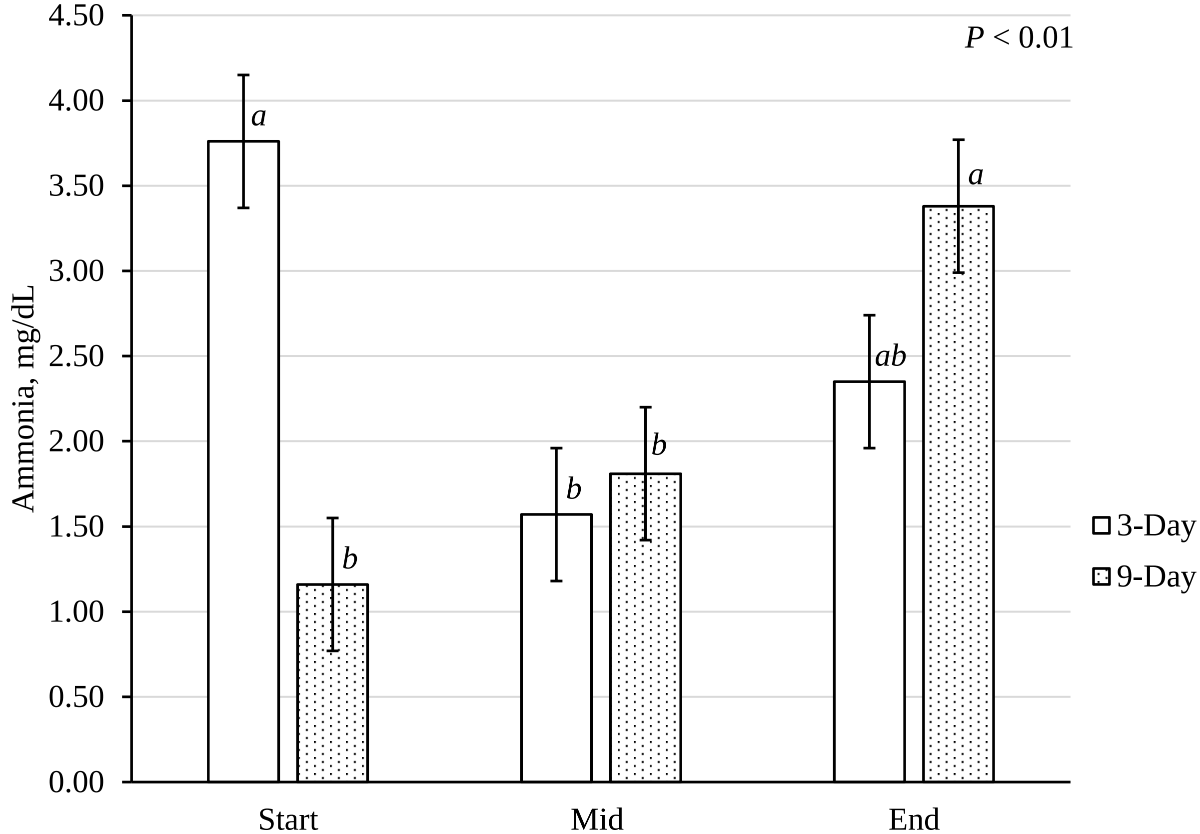

Figure 4.1 Effectof allocation and timing within allocation on rumen ammonia concentration over 2 yr.

Vertical bars within treatment with different letters differ ($P < 0.05$).

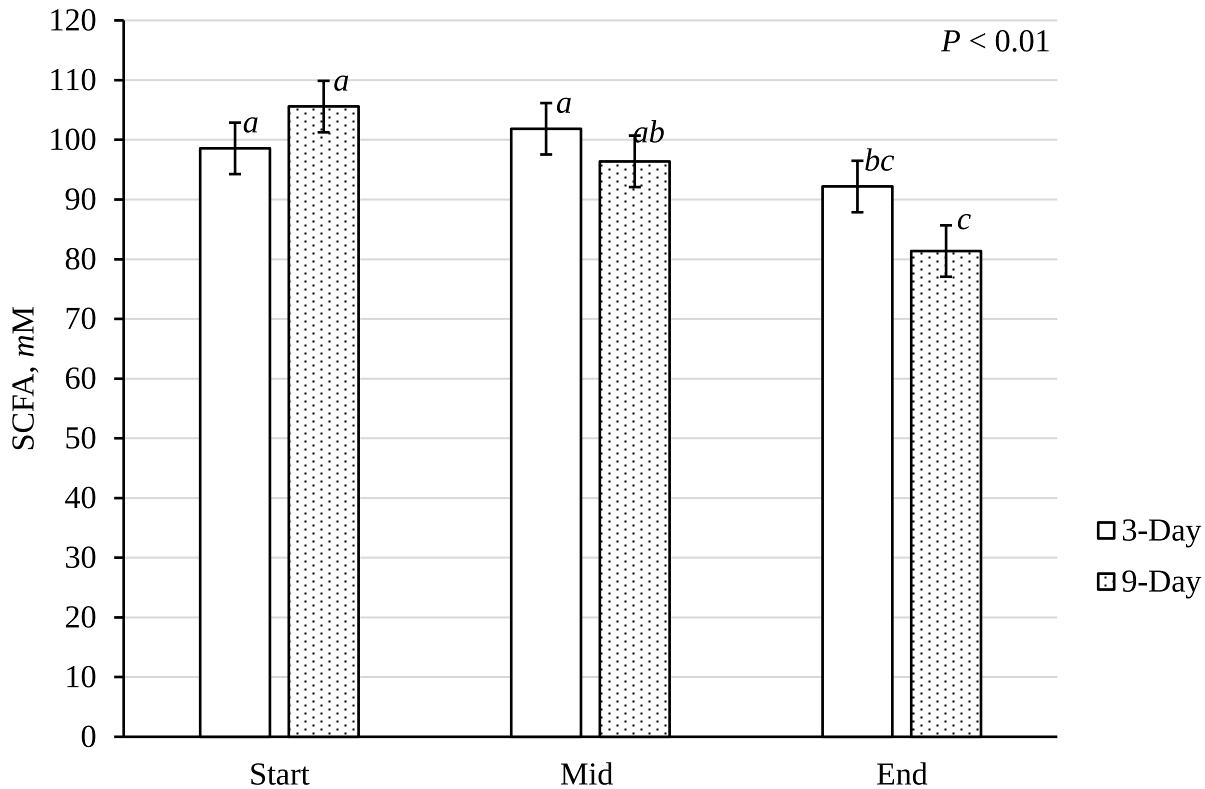

Figure 4.2 Effect of allocation and timing within allocation on rumen total SCFA concentration over 2 yr.

Vertical bars within treatment with different letters differ ($P < 0.05$).

4.3.3 Total tract starch digestibility

Fecal starch concentration was greater (P = 0.01; 2.7 vs. 1.4%) when no hay was offered compared to when supplement hay was available (Figure 4.3). Fecal starch tended (P = 0.07) to be lower at the end of a grazing allocation. Fecal starch tended (P = 0.07) to increase over the grazing allocation (Figure 4.3). Two-way interactions were observed (allocation × timing; P = 0.01) where fecal starch decreased over the grazing period in 9 d allocations (3.0, 2.1, and 1.1 % for start, mid and end, respectively; Figure 4.3). In 3 d allocations, fecal starch was lowest at the start of allocation and highest at mid allocation (1.1 and 2.7%, respectively) (Figure 4.3).

Timing of sample collection may have affected fecal starch results in the current study. Samples collected at start, were from d 1 in the 3D treatments, and the average from d 1 to d 3 in the 9D treatments were taken before 12:00 h on those given days so may not be representative of the respective day since the fresh fecal sample would likely not represent the current mornings diet. In work by Fredin et al. (2014) where lactating dairy cattle had fecal starch samples taken, the authors observed a time and day of sampling effect on fecal starch concentration, however because the fecal starch values were low and the total tract digestibility of starch (TTSD) was high, the numerical differences were small (P < 0.01). Fredin et al. (2014) suggests that in diets with lower TTSD, higher sample fecal starch concentration variability may exist. In future studies, a staggered sample day protocol may offer a more representative sample (i.e. sample on d 2 of allocation to better represent the effect of the d 1 diet or sample later in the day to allow for adequate time to see results of that day's diet).

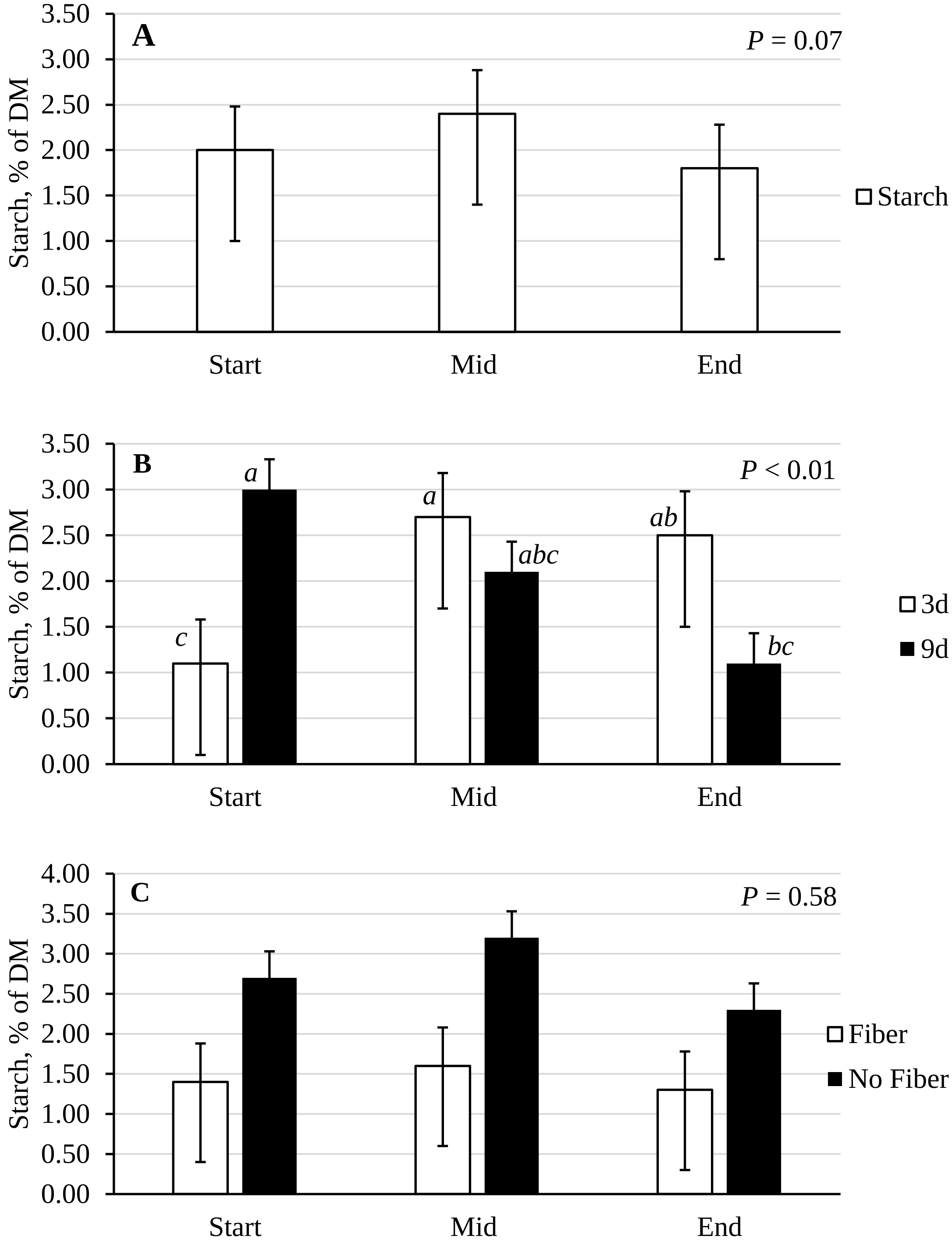

Figure 4.3 Effect of timing (A) and timing interactions with allocation length (B) and fiber supplementation (C) on fecal starch concentration over 2 yr.

Vertical bars within treatment with different letters differ ($P < 0.05$).

Previous work found that fecal starch content explained 68 and 91% of the variation in ruminal and total tract starch digestion, respectively (Zinn et al. 2002). Other work reports that fecal starch concentration explained 94 or 96% of the variation in TTSD (Fredin et al. (2014) and Zinn et al. (2007), respectively). Fecal starch can be used as a spot test to access feedlot cattle performance and grain processing performance. Zinn et al. (2002) suggests a target of 2 to 3% fecal starch as the goal for steam flaking corn, processing beyond this may lead to digestive upset if rumen degradability increases (2002).

4.3.4 Summary

Ruminal pH and fermentation data can provide valuable insight on the effect of changing diet the cow selects in a field crop grazing system. When grazing whole-plant corn, cows were offered a large amount of corn forage with plant structures varying in palatability and nutrient density. The ruminal pH and fermentation data in the current study, reflects how grazing selection and preference data along with grazing allocation length, can change the content of a grazing animal's diet over time. At the start of grazing, the diet primarily consists of cobs, which provides rapidly fermentable starch to the rumen microbes. Rumen concentration of SCFA was highest at the start likely due to this increase in fermentable starch available. As grazing progresses and cob availability decreases, the diet consists mainly of fibrous stalk, leaf and husk material. In the current study, allocation length and fiber supplementation did not affect rumen pH parameters, yet fecal starch results showed that as grazing progressed within an allocation the percent of starch in the feces decreased. This decrease in fecal starch could be a reflection of more starch being absorbed throughout the digestive tract or less starch being consumed. Less starch being consumed fits with grazing preference data showing little to no cobs were available near the end of grazing allocations.

5.0 GENERAL DISCUSSION AND CONCLUSION

Beef producers continue to adopt cost saving strategies to ensure the profitability of their operations. Drylot or confined feeding has been widely accepted as a costly method to over winter beef cows (Sheppard et al. 2015). For extensive winter grazing strategies to be successful, the system must provide the beef cow with adequate nutrition to maintain body condition while providing required nutrients for the growing fetus. In western Canada, the winter environment can pose considerable challenges as wind and cold temperatures can increase animal maintenance requirements and influence grazing behavior of the cow. Grazing whole plant corn is one wintering strategy that can meet nutrient requirements of a mid-gestation beef cow under most environmental conditions. However, growing corn for grazing is not without risk as the crop requires high input costs, including seed, and high N, P and K requirements. If growing conditions are favourable, corn has the potential to supply greater biomass yield, compared to annual small grain cereal crops in western Canada. However, in years with low CHU accumulation, low precipitation, or early frost, cob maturity may be limited resulting in decreased energy density of the whole plant.

Whole plant corn grazing is becoming more adapted in beef cow wintering programs in western Canada, however little data has been collected on the various management strategies. The current recommended practice of a 2 to 3 d grazing allocation is founded on swath-grazing recommendations to improve forage utilization and reduce the risk of acidosis. Current recommendations are often challenged by producers wanting to reduce labour and may result in cows being provided allocations between 7 and 30 d in length. Anecdotal evidence of digestive upset resulting in widespread morbidity and mortality raises questions on the importance of properly managing extensive grazing systems. In the current study, the objectives were to assess the effect of allocation length and provision of supplemental fiber (hay) on cow performance, DMI, preference, behaviour and rumen dynamics.

Environmental factors including temperature, wind chill and snow accumulation can impact animal performance in whole-plant corn grazing. Adequate shelter, protection from wind and available DM must be provided for cows to maintain body condition during periods of cold stress. In the current study, all cows maintained body condition and had positive body weight change during the grazing study. Cow BCS, BW, ADG, and rib and rump fat were not affected by the different grazing systems (3DNF, 3DF, 9DNF, 9DF). Dry matter intake was greater for cows in 9 d systems (9DNF, 9DF) compared to 3 d systems (3DNF, 3DF) (12.8 vs. 10.4 kg/d, respectively) but system (treatment) did not affect supplemental hay intake. Cattle spent less time in the corn and corn intake decreased when hay was offered, supporting the theory that substitution may occur when a more palatable feed is offered.

Grazing preference data showed that cobs were preferred over other plant structures, as cob proportion decreased from 34% prior to grazing to 23.5, 6.2, and 1.1%, at the start, middle and end of grazing periods, respectively. This data supports observations by producers that cows often select the barley heads of whole plant barley, or cobs of whole plant corn, leading to selection of the highly fermentable plant portion. During greater allocation lengths, producers will offer cattle access to more kg of dry matter and potentially more kg of cobs, which if selected for heavily, could increase the risk of rumen acidosis.

Ruminal pH and fermentation parameters were not affected by allocation length or fiber supplementation main effects (the only exception being propionate and isovalerate concentration). Time spent below a rumen pH of 5.8 was greatest at the start of grazing and decreased in the middle and end of allocation to 143.18, 26.32, and 0 min/d, respectively. The acidotic conditions observed were not sever enough to be considered acute ruminal acidosis and were borderline to be considered subacute ruminal acidosis. Since the pH dropped below 6.0 we know fiber digestion was likely starting to be affected. Total SCFA concentration was also greatest at the start and least at the end of a 9 d allocation period. The SCFA data reflects with the cob disappearance data showing that the high consumption of cobs at the start of a new forage allocation provides a supply of readily fermentable carbohydrates to the rumen. In the current study, starch content was observed to be 20%, but in western Canada corn may reach 25-30% starch depending on cob maturity at the time the plant stops growing. Producers must be aware of the increased risk of acidosis when cobs are more mature.

Risk of acidosis aside, producers must keep in mind that grazing animal selection may not result in balanced nutrients in the ration. If offered a large allocation area, grazing cows will continue to select cobs until they are gone, leaving the less palatable, less digestible, and low nutrient plant structures (leaves, husk, and stem). A diet consisting of leaves, husk and stem for an extended period will result in a nutrient deficiency and poor animal performance. By offering supplemental hay the animal will likely still select for the highly fermentable cob portion first but will have a more palatable and fibrous feed to supplement the diet with after consuming only cobs. Hay supplementation may provide available protein for rumen microbes, at the mid and end of grazing allocations to ensure efficient fiber digestion. Supplemental hay may also provide additional forage, before cows are offered a new forage allocation. The current study results suggest maintaining a shorter grazing allocation can result in fewer diet fluctuations occurring.

Producer's reasoning for extended grazing allocations of 7 to 30 d, is often to save time and labour to reduce overall costs. In the current study, 9d allocation with or without fiber supplementation costs were numerically higher as corn forage costs were numerically higher in

9DNF and 9DF systems as these groups consumed more forage yet had poorer utilization of the allocated forage. When cattle are in the latter third of a 9d grazing allocation most of the forage available has poor digestibility which may limit intake. When the cattle begin to look gaunt producers often move them to a new allocation of forage and the pressure on the cattle to back-graze to clean up may not be as efficient as when in a 3d allocation. As more forage is offered more forage may be wasted which can result in higher overall cost to the producer.

In summary, the industry standard of limiting forage allocation to 3 d and based on current stud results can help reduce the risk of acidosis, increase forage utilization and mitigate diet nutrient fluctuations. Hay supplementation may still be recommended near the end of a forage allocation to balance the diet when the cows are consuming predominantly leaf, husk and stem material providing rumen fill before they are offered a new allocation. However, offering supplemental fiber (hay) will not reduce animal preference to select for highly fermentable cobs at the start of an allocation. Economic analysis also resulted in a 3 d grazing allocation as the more cost-effective allocation length due to the reduced waste. Economic costs reported in the current study support the advantage of corn grazing compared to traditional drylot management. Although there was no impact of trt on rumen pH and fermentation, behavior results would suggest that a shorter allocation length will reduce diet fluctuation and promote better whole-plant corn utilization while keeping costs low. Fiber supplementation may not be as effective as we once thought at altering grazing selection away from cobs however may be used to balance the diet if the costs are considered.Though the system is not without risk, whole-plant corn grazing can be considered in western Canada as an alternative to drylot feeding management.

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7.0 APPENDICES

APPENDIX A

Table A.1 Summary of seeding date, corn yield and CHU for both years.

Item	2015-2016	2016-2017
Seeding Date	June 3, 2015	May 31, 2016
Corn yield, T DM/ha[1]	11.69	13.16
CHU[2]	2132	2185

[1] Corn yields collected at start of study each year.

[2] Data collected from seeding date until the first day with min temp less than -3°C (Lardner et al. 2017); Daily CHU= (Ymax+Ymin)/2 where Ymax=[3.33* (Tmax-100]-[0.084*(Tmax-10)^2] (if Ymax<0, set Ymax=0) and Ymin= [1.8 * (Tmin-4.40] (if Ymin<0, set Ymax=0).

APPENDIX B

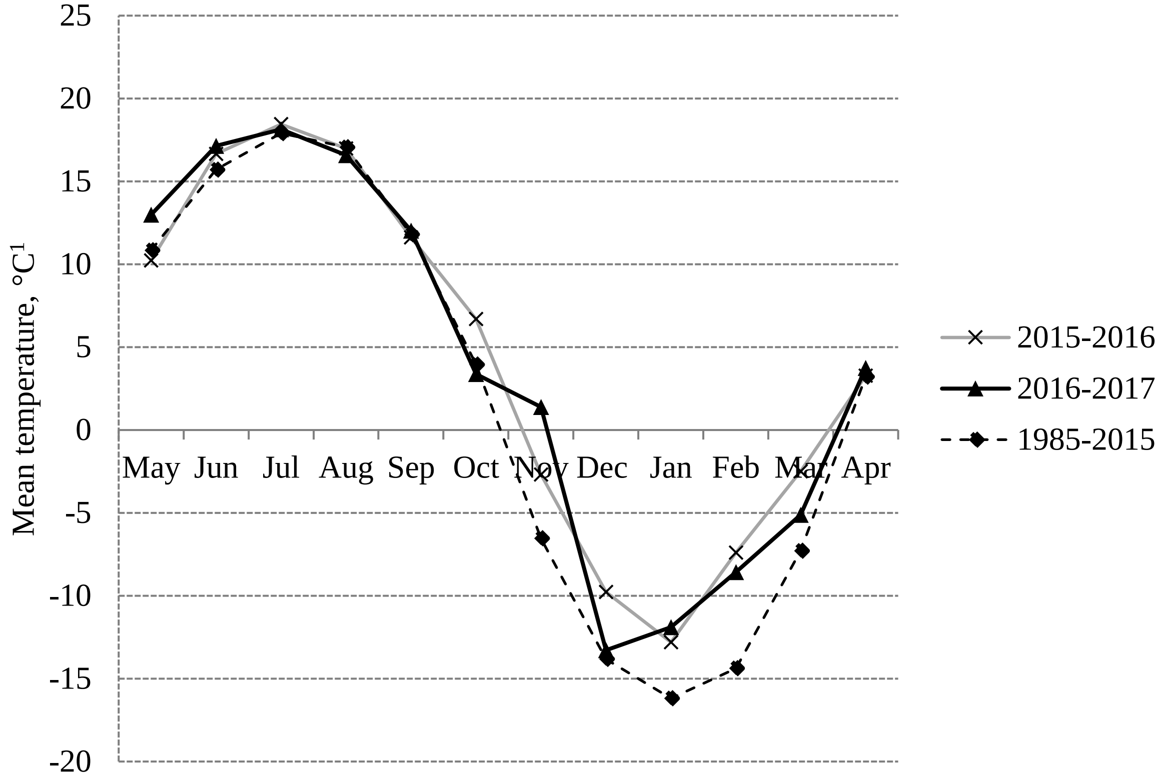


Figure B.1 Average monthly temperature for yr 1 (2015-2016), yr 2 (2016-2017), and the 30 yr average (1985-2015).

[1]Temperature data long term (1985-2015) temperature average from Environment Canada's climate data (www.climate.weatheroffice.ec.gc.ca) for Leroy, Saskatchewan.

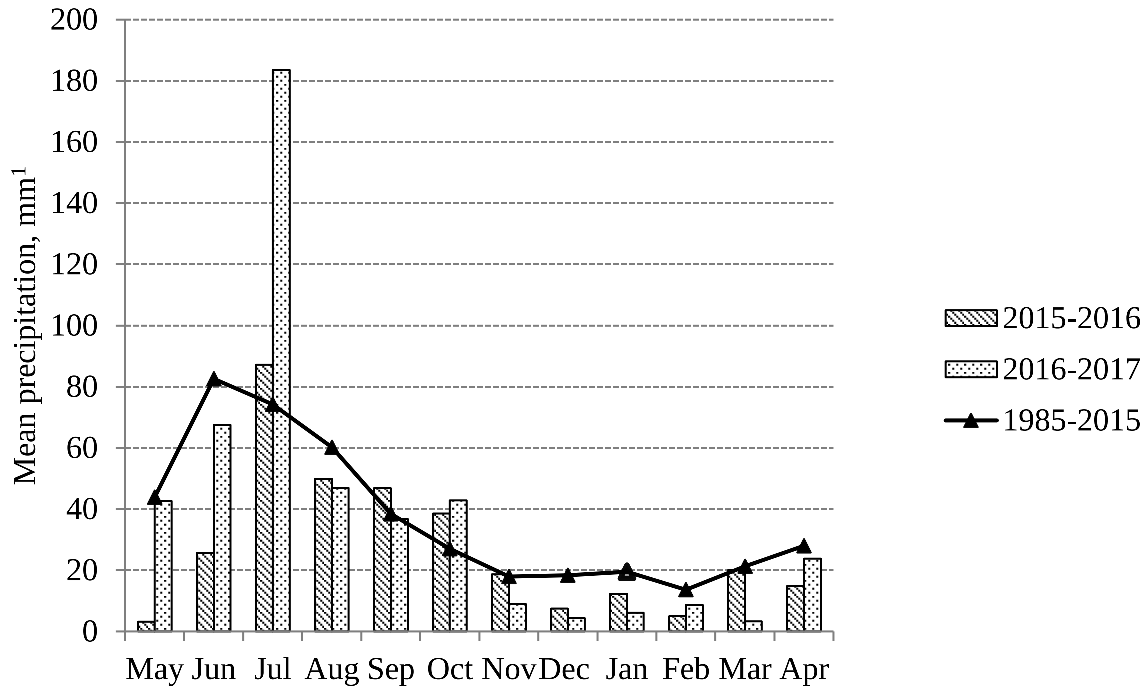


Figure B.2 Monthly precipitation for yr 1 (2015-2016), yr 2 (2016-2017), and the 30 yr average (1985-2015).

[1]Precipitation data and long term (1985-2015) precipitation average from Environment Canada's climate data (www.climate.weatheroffice.ec.gc.ca) for Leroy, Saskatchewan.

APPENDIX C

Table C.1 Effect of soil sample timing on soil nutrient levels over at 0-15 cm depth.

	Yr 1				Yr 2			
Item	Fall[1]	Spring	SEM	*P*-value	Fall	Spring	SEM	*P*-value
	……kg ha^{-1}……				……kg ha^{-1}……			
Nitrogen	31.2	106.4	12.06	0.02	51.2	52.4	6.21	0.89
Phosphorus	29.6	32.2	3.46	0.61	45.8	27.9	8.61	0.18
Potassium	937.6	924.9	115.05	0.94	1065.1	951.7	74.18	0.18
Sulfur	533.9	551.1	50.45	0.81	623.0	416.3	84.07	0.20

[1]Fall=samples collected after the first frost; spring=samples collected before field preparation

Table C.2 Effect of soil sample timing on soil nutrient levels over at 15-30 cm depth.

	Yr1				Yr 2			
Item	Fall[1,2]	Spring	SEM	*P*-value	Fall	Spring	SEM	*P*-value
	……kg ha^{-1}……				……kg ha^{-1}……			
Nitrogen	-	88.5	9.87	-	55.1	48.0	6.46	0.46
Phosphorus	-	26.0	3.37	-	33.5	17.3	4.29	0.02
Potassium	-	604.6	84.25	-	886.5	718.4	97.84	0.15
Sulfur	-	818.3	110.41	-	721.8	461.5	106.72	0.12

[1]Fall=samples collected after the first frost; spring=samples collected before field preparation
[2]Samples not collected in Fall Yr 1

APPENDIX D

Table D.1 Effect of allocation length and fiber supplementation on cow activity in yr 1.

	Treatment			*P*-value		
Feature	3DF	9DF	SEM	Allocation	Fiber	Allocation*Fiber
Corn[1,2]						
% of time[3]	55.8	36.8	7.63	0.57	0.04	0.06
hr/d[4]	13.4	8.7	1.83	0.57	0.04	0.06
Fiber Supplement						
% of time	23.4	25.4	4.04	0.80	<0.01	0.81
hr/d	5.6	6.1	0.97	0.80	<0.01	0.80
Bedding Area						
% of time	19.7	37.9	7.71	0.57	0.34	0.09
hr/d	4.7	9.1	1.84	0.58	0.34	0.09
Water						
% time	1.1	0.4	0.40	0.02	0.41	0.45
hr/d	0.3	0.1	0.09	0.02	0.45	0.45

[1]Data collected using 5-min GPS fixes for 24hr/d. 3D trt for 3 consecutive days or 864 fixes. 9D trt for 9 consecutive days or 2592 fixes from 3 sampling periods.
[2]Feature locations determined by handheld GPS and compared to GPS fixes using ArcGIS 10.3
[3]% of time at feature = no. fixes within feature/total no. fixes
[4]Hr/day= [(no. fixes*5 min)/60min]/no. of days

Table D.2 Effect of allocation length and fiber supplementation on cow activity in yr 2.

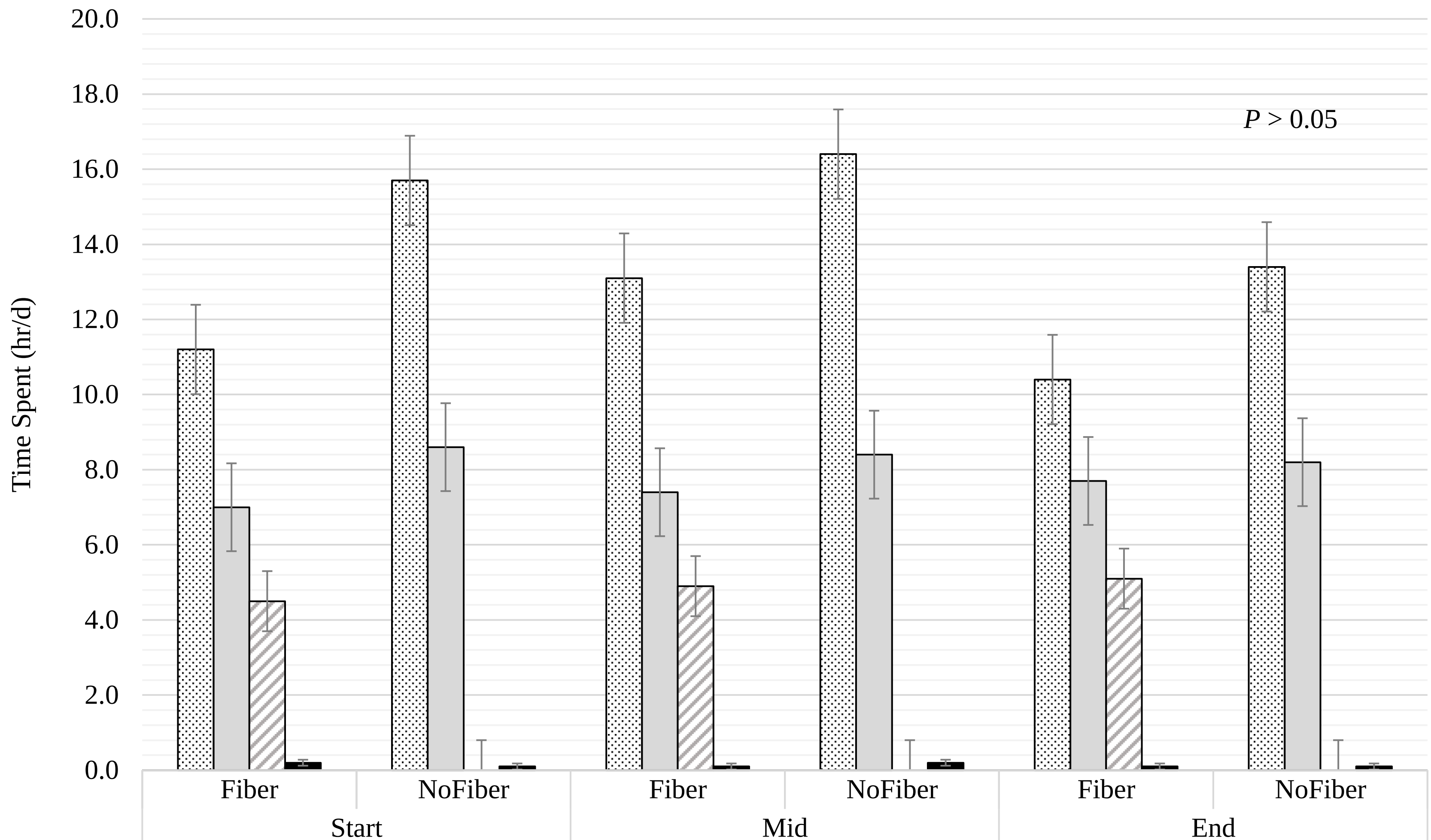
	Treatment			*P*-value		
Feature	3DF	9DF	SEM	Allocation	Fiber	Allocation*Fiber
Corn[1,2]						
% of time[3]	49.3	55.7	12.79	0.34	0.73	0.89
hr/d[4]	11.8	13.4	3.07	0.34	0.73	0.89
Fiber Supplement						
% of time	14.3	9.7	1.53	<0.01	0.15	0.15
hr/d	3.5	2.3	0.36	<0.01	0.14	0.14
Bedding Area						
% of time	35.4	34.2	11.89	0.99	0.87	0.95
hr/d	8.5	8.2	2.85	0.86	0.99	0.95
Water						
% time	0.9	0.5	0.19	0.06	0.20	0.24
hr/d	0.2	0.1	0.04	0.01	0.12	0.12

[1]Data collected using 5-min GPS fixes for 24hr/d. 3D trt for 3 consecutive days or 864 fixes. 9D trt for 9 consecutive days or 2592 fixes from 2 sampling periods.
[2]Feature locations determined by handheld GPS and compared to GPS fixes using ArcGIS 10.3
[3]% of time at feature = no. fixes within feature/total no. fixes
[4]Hr/day= [(no. fixes*5 min)/60min]/no. of days

Table D.3 Effect of allocation length and fiber supplementation on cow activity over 2 yr.

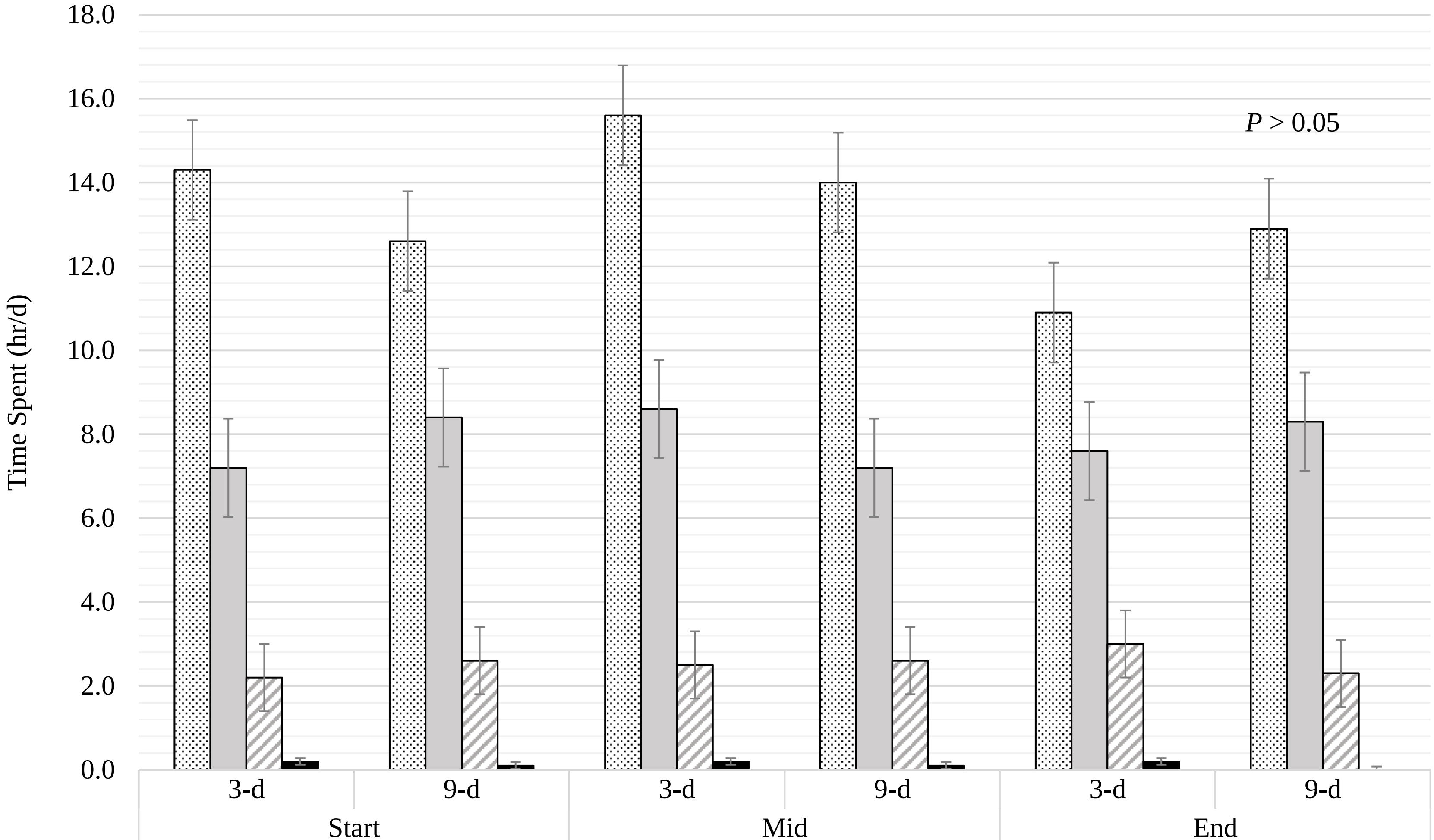
Feature	Treatment		SEM	*P*-value
	3DF	9DF		
Corn[1,2]				
% of time[3]	53.2	44.1	6.65	0.22
hr/d[4]	12.8	10.6	1.60	0.22
Fiber Supplement				
% of time	20.0	19.3	3.69	0.91
hr/d	4.8	4.6	0.88	0.90
Bedding Area				
% of time	26.0	36.4	6.37	0.19
hr/d	6.3	8.7	1.53	0.19
Water				
% time	0.8	0.2	0.40	0.73
hr/d	0.2	0.0	0.10	0.75

[1]Data collected using 5-min GPS fixes for 24hr/d. 3D trt for 3 consecutive days or 864 fixes. 9D trt for 9 consecutive days or 2592 fixes.
[2]Feature locations determined by handheld GPS and compared to GPS fixes using ArcGIS 10.3
[3]% of time at feature = no. fixes within feature/total no. fixes
[4]Hr/day= [(no. fixes*5 min)/60min]/no. of days



	Start Fiber	Start NoFiber	Mid Fiber	Mid NoFiber	End Fiber	End NoFiber
Corn	11.2	15.7	13.1	16.4	10.4	13.4
Bedding	7.0	8.6	7.4	8.4	7.7	8.2
Bale	4.5	0.0	4.9	0.0	5.1	0.0
Water	0.2	0.1	0.1	0.2	0.1	0.1

Figure D.1 Effect of fiber supplementation and timing on grazing behavior.



	Start 3-d	Start 9-d	Mid 3-d	Mid 9-d	End 3-d	End 9-d
Corn	14.3	12.6	15.6	14.0	10.9	12.9
Bedding	7.2	8.4	8.6	7.2	7.6	8.3
Bale	2.2	2.6	2.5	2.6	3.0	2.3
Water	0.2	0.1	0.2	0.1	0.2	0.0

Figure D.2 Effect of allocation length and timing on grazing behavior.

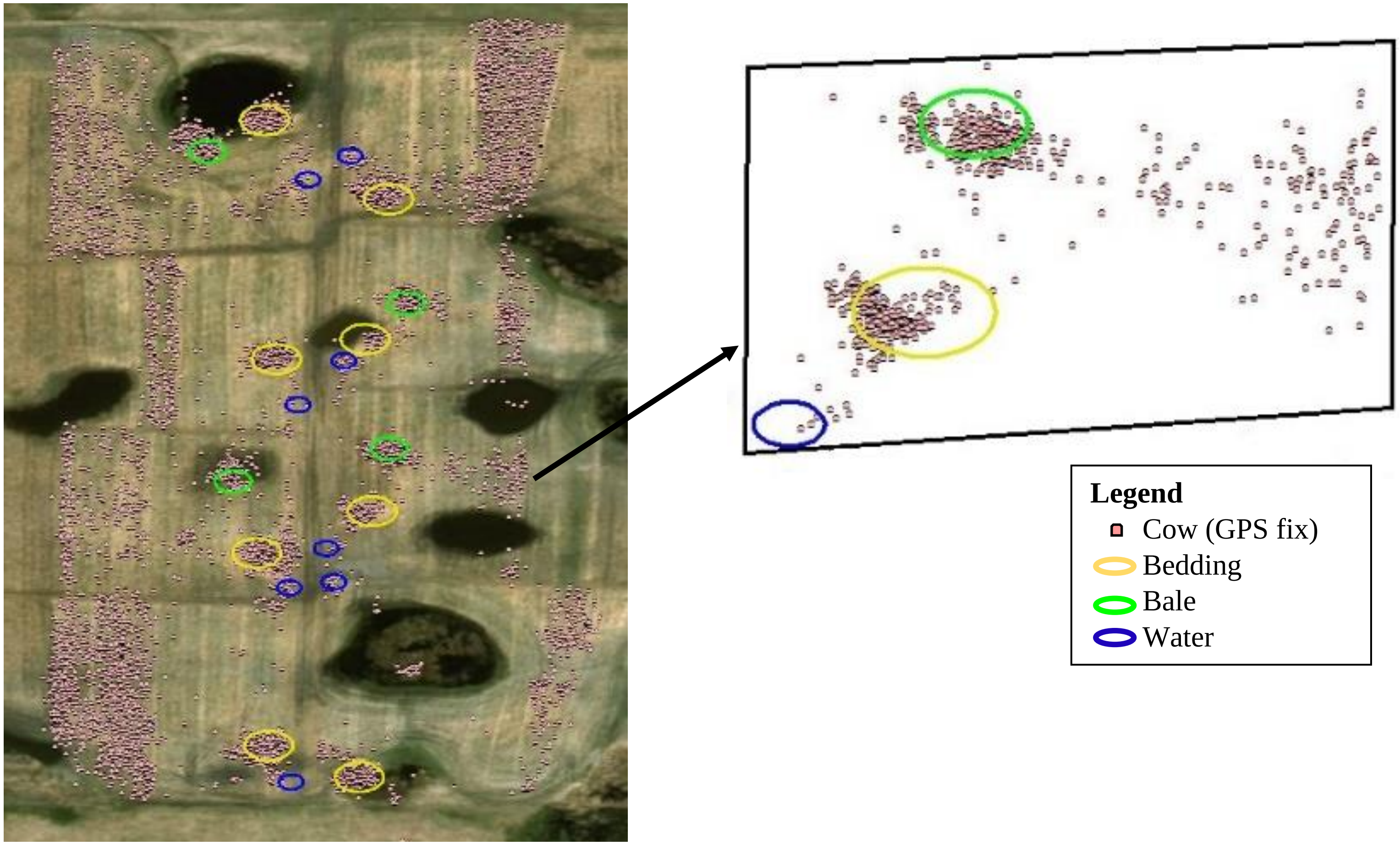


Figure D.3 Diagram of GPS collar data mapped in ArcGIS to show the buffer areas around the features that were used to calculate the time spent near features within the paddocks.