VALIDATING THE STAGE OF MATURITY AT HARVEST FOR BARLEY, OAT AND TRITICALE FOR SWATH GRAZING

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ABSTRACT

Two experiments were conducted to evaluate stage of maturity at harvest recommendation for barley, oat and triticale in a swath grazing system. Experiment 1 evaluated the *in situ* disappearance of dry matter (DM) and neutral detergent fibre (NDFD) of whole plant triticale. Neutral detergent fibre disappearance ($P < 0.05$) of triticale increased (P < 0.05) with advancing maturity from early milk (EM) to hard dough (HD). There was an interaction ($P < 0.05$) between incubation period and stage of maturity observed for DM degradability of triticale. Experiment 2 was a field study assessing the impacts of stage of maturity at harvest on barley, oat, and triticale evaluating forage yield, nutrient composition, dry matter intake (DMI), feed utilization, animal unit months per ha (AUM/ha), cow performance, and whole-system economics when used as a feed for beef cattle. The field study was carried out during the winters of 2015-16 (yr 1) and 2016-17 (yr 2) and evaluated three cereal crops (barley [cv. CDC Maverick], oat [cv. CDC S01] and triticale [cv. Taza]) when swathed at the soft dough stage or hard dough stages of maturity (3 × 2 factorial design with 2 replications/treatment in each year). One hundred and twenty cows (620.3 ± 18 kg) were allocated to 1 of 6 treatments that lasted 90 and 107 d in yr 1 and yr 2, respectively. Forage yield (kg/ha) measured prior to swathing was greater for crops swathed at the HD stage in comparison to SD ($P < 0.05$). However, there were no differences between barley, oat, or triticale ($P = 0.07$) in yield. Crude protein (CP) decreased from 12 to 11 % as crops matured and total digestible nutrients (TDN) increased from 55.7 to 61.0% ($P < 0.05$). Dry matter intake was not different among treatments ($P = 0.78$). Animal unit month per ha increased for crops harvested at the HD maturity in comparison to SD (11.5 vs. 9.15 AUM/ha; $P < 0.05$). There were no differences observed for final body weight ($P = 0.10$) or final body condition score ($P = 0.60$) of cows among treatments and cows were able to maintain a body condition score of 2.6 throughout the grazing period. Total production costs were greater for crops harvested at soft dough ($1.80/cow/d) than hard dough ($1.52/cow/d; $P < 0.05$). Total production costs were least for triticale ($1.36/hd/d) and the most for barley ($1.92/cow/d; $P < 0.05$). Results from the current studies suggest delaying swathing until hard dough increased forage yield, decreased CP concentrations but increased TDN, increased AUM/ha, and reduced system cost without affecting the performance of cows. Based on these results, the current recommendation for maturity at time of harvest may need to move from soft

dough to hard dough to maximize whole-plant potential of barley, oat and triticale in swath grazing systems.

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LIST OF ABBREVIATIONS

ADF Acid detergent fibre

ADG Average daily gain

BCS Body condition score

BW Body weight

CP Crude protein

DE Digestible energy

DM Dry matter

DMI Dry matter intake

EDDM Effective degradable dry matter

EM Early milk

FE Fecal energy

GE Gross energy

HD Hard dough

IE Intake energy

LCT Lower critical temperature

LM Late milk

ME Metabolizable energy

MP Metabolizable protein

N Nitrogen

NDF Neutral detergent fibre

NE Net energy

NE_g Net energy growth

NE_l Net energy lactation

NE_m Net energy maintenance

NE_y Net energy reproduction

NIRS Near infrared reflectance spectroscopy

RDP Rumen degradable protein

RUP Rumen undegradable protein

RE Retained energy

SD Soft dough

TDN Total digestible nutrients

UE Urinary energy

1.0 GENERAL INTRODUCTION

Historically, beef cows on cow-calf operations in western Canada have been overwintered in confined feeding areas such as drylots/paddocks (McGeough et al. 2017). Overwinter feed costs can account for two-thirds of the costs associated with cow-calf production in western Canada (Larson 2011; Damiran et al. 2016). Kelln et al. (2011) suggested that drylot pen feeding is a demanding task, where the feed is brought to the cow and the manure is hauled away and spread on the land. There has been increased interest in maintaining beef cattle in extensive grazing systems utilizing perennial and annual forages to reduce labour, mechanical inputs, fuel costs and application of manure and urine (McGeough et al. 2017).

Swath grazing is a strategy to extend the grazing season by utilizing predominantly annual cereal forages that are mechanically harvested (swathed), typically in late summer/early fall for grazing in the fall and winter months (McGeough et al. 2017). According to the Western Canadian Cow-Calf Survey (2017), a total of 62 % of survey participants who responded to questions on winter-feeding management, with 28 % of those producers utilizing swath grazing as their main extended grazing strategy. Swath grazing also offers the potential to optimize nutritive value and yield by altering harvest date (Baron et al. 1992). The length of the growing season and resulting maturity at harvest are important factors affecting the nutritive value of the swathed forage (McGeough et al. 2017). The current recommendation for harvest time for swath grazing is cutting at the soft dough stage for barley and triticale and the late milk stage for oat (Baron et al. 1992; Aasen et al. 2004; Rosser et al. 2013). However, these stages were adopted from silage-based systems. Due to harvest and preservation differences between silage production and swath grazing, continuing research is needed to evaluate strategies to maximize the yield of digestible dry matter for annual crops used in these systems (Baron et al. 2011; Rosser et al. 2013).

Rosser et al. (2013), initiated research evaluating the stage of maturity for swathing of oat and barley with an intended use in greenfeed or swath grazing systems. In that study, in vitro-based results coupled with small-plot crop production suggested that harvesting at the hard dough stage optimizes digestible nutrient yield for barley and oats. Rosser et al. (2016) and Rosser et al. (2017) followed up that research using metabolic studies showing that delaying the maturity at harvest from the recommended late milk (oat) or soft dough (barley) to the hard dough stage did not negatively affect gross energy digestibility and only had minor impacts on feed intake. Those studies provided strong support that swath grazing recommendations can be delayed to the hard dough stage, but no studies have evaluated these recommendations under field feeding conditions.

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) review multiple extensive grazing practices; and (3) review current swath grazing recommendations for beef cattle.

2.0 LITERATURE REVIEW

2.1 Beef cow nutrient requirements

The winter months in western Canada can be the costliest time for producers to provide feed to their cow herd. Beef producers are constantly looking for viable options to decrease their production costs with winter feeding systems that utilize annual crops, such as bale grazing, corn grazing, crop residues, and swath grazing (McCartney et al. 2008; Jungnitsch et al. 2011; Lardner et al. 2017). The pregnant beef cow must be provided with adequate amounts of nutrients to meet maintenance, reproduction, and weight gain requirements (NASEM 2016). Beef producers are challenged with understanding the nutrient requirements of the gestating beef cow and how to utilize different feeding programs to help reduce winter feed costs without negatively affecting overall cow performance (Krause et al. 2013).

2.1.1 Energy

Energy is one of the most important nutrients that needs to be considered in beef cattle diets in cold climate conditions (Lardner et al. 2017). Energy requirements need to be met first in a beef cow's diet. Energy can be broken down into a variety of terms; gross energy (GE), digestible energy (DE), metabolizable energy (ME), and net energy (NE). Gross energy is measured as the heat of combustion, which is the energy released as heat when an organic compound is completely oxidized to carbon dioxide and water (NASEM 2016). Digestible energy is the portion that reflects diet digestibility (NASEM 2016) and, is determined by subtracting fecal energy (FE) losses from gross energy intake. However, for ruminants, digestible energy does not consider energy losses associated with digestion and metabolism of feed (NASEM 2016). It is notable that the largest energy losses are as fecal energy and heat (Ferrell and Oltjen 2008). Metabolizable energy is the estimate of the energy available to the animal and is defined as GE minus FE, urinary energy (UE) and gaseous energy (Ferrell and Oltjen 2008; NASEM 2016). Net energy concepts are important for expressing the nutrient requirements during different stages of the life cycle of a beef cow (Ferrell and Oltjen 2008). Retained energy (RE) is the energy deposited into animal tissues (Ferrell and Oltjen 2008). Retained energy represents a small portion (< 20%) of total intake energy (Ferrell and Oltjen 2008). The determination of NE assumes a linear relationship between RE and intake energy (IE), but it is curvilinear according to Garrett and Johnson (1983) and Ferrell and Oltjen (2008). Feed intake and body tissue loss comprise one portion of the curve and body tissue gain comprises the other portion of the curve, it is described when the intersection of these two lines meet it is considered maintenance (RE=0) (NASEM 2016).

Beef cows require energy for maintenance (NE_m), growth (NE_g), pregnancy or reproduction (NE_y), and lactation (NE_l). The requirement for maintenance has been described by NASEM (2016), as the amount of feed energy intake that will result in no net loss or gain of energy from the animal. Processes attributed to the NE_m include: body temperature regulation; essential metabolic processes; and physical activity (NASEM 2016). Approximately 70% of total ME required is needed for maintenance for a mature gestating beef cow (Ferrell and Jenkins 1985). Net energy maintenance will change depending on a variety of factors such as: body weight (BW); breed or genotype; sex; age; season; temperature; physiological state; and previous nutrition (NASEM 2016). To maintain body condition, general rules of thumbs have been developed including that for energy where it is commonly stated that a pregnant beef cow requires a minimum of 55, 60 and 65% total digestible nutrients (TDN) energy in the ration during mid-gestation, late-gestation, and lactation, respectively (Yurchak and Okine 2004; NASEM 2016). These recommendations, while crude and imprecise, allow for meaningful variables understood by beef cattle producers.

Cattle grazing during the winter months are exposed to cold temperatures and wind chill factors that fall below the thermal neutral zone of the animal and can result in cold stress and affect overall performance (Webster et al. 1970). When the temperature falls below the thermal neutral zone this can also be referred to as lower critical temperature (LCT) (NASEM 2016). When cattle are subjected to extreme cold stress, there can be a substantial diversion of dietary energy from productive functions to the generation of body heat (Young 1983). Lower critical temperature 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 2016). While the animal is in this type of environment, it is important to determine if the forage alone will meet the energy demands. Adjustment to an environment also affects the animal's ability to handle cold stress therefore affecting the NE_m requirements outside of the thermal neutral zone (NASEM 2016).

2.1.2 Protein

Protein requirements depend on the physiological state of the animals and are often described as the crude protein (CP) requirement on a dry matter (DM) basis (NASEM 2016). Blanket recommendations for a dry cow in early to mid gestation requires 7 to 9 % CP in the diet DM for maintenance, which increases to 11 to 13 % in lactating or young growing cows (NASEM 2016). Ensminger et al. (1990), stated that protein is necessary to prevent tissue breakdown from the body, as well as hair, horn and hoof growth in a beef cow. It is also important for the growth and reproduction of ruminal flora and fauna (NASEM 2016).

Protein is supplied in the diet as rumen degradable protein (RDP) or rumen undegradable protein (RUP), the difference between the two is that RDP is degraded in the rumen and RUP is not (NASEM 2016). The amount of RDP required in the cow's diet is based off microbial protein synthesis. Microbial protein synthesis is determined based off rumen degradation of dietary protein and is separated based on the needs of the rumen microorganisms and the animal (NASEM 2016). Metabolizable protein is the true protein that is digested in the intestine and the corresponding amino acids. Finally, amino acids are needed for productive and maintenance functions of the animal (NASEM 2016).

2.1.3 Water

Water contributes to roughly 70% of the total body mass (Macfarlane and Howard 1972; NASEM 2016). Water is a crucial nutrient in beef cattle diets (Ahlberg et al. 2018). Water is vital in body temperature regulation, growth, lactation, digestion, metabolism, cellular metabolism and mineral homeostasis (NASEM 2016). The minimum water requirement for cattle is mainly influenced by what is needed for body maintenance and growth, reproduction, fetal growth, lactation and what is lost by excretion in the urine, feces, respiration or sweat (NASEM 2016). The majority of beef cattle water consumption is from free choice drinking water and water available in the feed, there is a small amount available through metabolic water which is produced through the oxidation of organic nutrients (NASEM 2016).

There are a variety of factors that can affect water intake such as: physical access to water; dry matter intake (DMI); environmental temperature; and the stage or type of production (Lardner et al. 2013; NASEM 2016). Bond et al. (1975), determined that when water was withheld for 48 h from cattle consuming a high-concentrate diet there was a 44% decrease in DMI, while cattle consuming a high-forage diet had a 55% decrease in dry matter intake. Low water intake can reduce dry matter intake of an animal (NASEM 2016). Water requirements nearly double for lactating cows compared to dry pregnant beef cows (Lardner, 2003b; Lardner et al. 2013). Water quality can have a large impact on overall animal health and performance, and it is prudent for producers to monitor water sources to ensure proper intakes for cattle (Wright 2007).

2.1.4 Minerals and Vitamins

Beef cattle require a total of 17 minerals that can be further divided into two groups: macro minerals and micro minerals (NASEM 2016). Macro minerals are required on a per gram per day basis and include calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K), sodium (Na), chlorine (Cl) and sulfur (S). The macro minerals are important for structural components of bone, acid/base balance, membrane electric potential and nerve transmission (NASEM 2016). Microminerals are referred to as trace minerals and are required on a milligram to microgram daily dose basis. The trace minerals include copper (Cu), chromium (Cr), cobalt (Co), iodine (I), molybdenum (Mo), manganese (Mn), selenium (Se) and zinc (Zn) (NASEM 2016). Trace minerals are typically present in the body tissues at exceptionally low levels and are components of hormones, metalloenzymes, and enzyme cofactors (NASEM 2016). Trace minerals are essential for fetal development and the fetus depends on the dam for the adequate supply of these elements (Marques et al. 2016). Deficiencies in minerals can result from both limited amount withing the feedstuff and limited availability of the compound to the animal. The duration and concentration of mineral supplementation, physiological state of the animal, presence or absence of dietary antagonists, environment and stress all influence the cow's ability to properly metabolize the mineral (NASEM 2016). Feeds such as swathed barley and triticale have adequate levels of Mg, P and K but are deficient in Ca which can easily be corrected with a proper mineral supplement (Baron et al. 2014).

Vitamins are important for beef cattle to perform metabolic processes and sustain normal body function and life processes (NASEM 2016). Vitamins can be grouped into two major classes, fat-soluble and water-soluble. Fat-soluble vitamins include A, D, E and K. Vitamin A is critical for vision, growth, reproduction, maintenance of mucous membranes and immunity (Buskirk et al. 2002). The requirements for vitamin A increase from pregnancy (2,800 IU/kg DMI) to lactating (3,900 IU/kg DMI) (NASEM 2016). Vitamin D is required for Ca and P absorption and mobilization of Ca from bone (Buskirk et al. 2002). Vitamin E is a part of a multi-component antioxidant defence system in conjunction with Se, it is critical for overall immune function (Buskirk et al. 2002). The requirement for vitamin E also increases from pregnancy (300 IU/d) to lactation (500 IU/d) (NASEM 2016). The water-soluble vitamins include choline, B1 (thiamine), B2 (riboflavin), B3 (niacin), B5 (pantothenic acid), B6 (pyridoxine), B7 (biotin), B9 (folic acid), B12 (cobalamin) and vitamin C (NASEM 2016). The bacteria present in the rumen have the unique ability to synthesize water-soluble vitamins and supply them to the cow after passage to the small intestine (NASEM 2016). Meachem et al. (1966), reported that supplementing vitamin A to pregnant beef cows pre-calving (16,000 IU/d) and post-calving (40,000 IU/d) showed a decrease in calf morbidity by 50 % and an overall increase in cow conception rates by 10 %.

2.2 Beef cow performance indicators

Measuring cow performance is important to evaluate the effects of different winter-feeding systems. There are several metrics and a variety of techniques that can be utilized to measure cow performance such as: live body weight (BW) change; average daily gain (ADG); subcutaneous body fat reserves (rib and rump fat, body condition score (BCS)); and reproductive efficiency (Lowman et al. 1976; Corbett 1978; Schroder and Staufenbiel 2006).

2.2.1 Live body weight (BW)

Live body weight (BW) change is one of the easiest variables that can be measured to monitor cattle performance. Body weight reflects the change in protein and fat composition and non-carcass components (Schroder and Staufenbiel 2006). Corbett (1978) described BW measurement as an easy to measure variable that is subject to error and bias. Body weight includes the gastro-intestinal content which is influenced by DMI and time since last feeding (Schroder and Staufenbiel 2006), which can affect overall weight measurements. Corbett (1978) described that changes in diet can lead to fluctuations in overall passage rate and gut fill. Standardizing the weighing procedure can help decrease the error that can be associated with this procedure. Measuring BW in the morning over 2 consecutive days, withholding water and fasting animals are often used to reduce the variation in gut fill capacity (Corbett 1978; Cook and Stubbendieck 1986).

A pregnant animal can affect live weight gain due to changes in conceptus weight and the extra fluids associated with the growing fetus (Silvey and Haydock 1978; Schroder and Staufenbiel 2006). Due to these changes in body weight, it is important to adjust body weight for the changes associated with pregnancy (Silvey and Haydock 1978). Body weight can be adjusted to account the weight of the growing fetus using the following equation from NASEM (2016):

Equation 2.1 Conceptus weight (kg) = (CBW*0.01828)*e[<0.02*t)-(1.43e-005*t*t)]

Where, CBW is the calf weight at birth (kg) and t is the number of days the cow is pregnant.

2.2.2 Body condition score

Body condition scoring (BCS) is a low-cost, hands on method to determine the condition of cattle (Mulliniks et al. 2015). Body condition score is an effective management strategy that can be utilized to evaluate cow energy reserves and trajectory of the nutritional program (Kunkle et al. 1994; Kelln et al. 2011). Cow body condition will vary with mature size and influences nutritional requirements and reproductive efficiency (Emenheiser et al. 2014). In Canada, the Scottish scale ranging from 1 to 5 is typically used (Lowman et al. 1976). Low scores (BCS = 1) represent thin cows and high scores (BCS = 5) represent obese cows (Zulu et al. 2001). Body condition score uses a visual and physical examination of the lumbar, thurls (or rump) and tail head regions of the body (Zulu et al. 2001). However, one limitation of body condition scoring, is that any visual scoring system may vary depending on the technician, and ultimately its subjectivity, reliability and validity have been questioned (Kunkle et al. 1994; Zulu et al. 2001). There have been several studies to evaluate accuracy of BCS by measuring subcutaneous fat utilizing an ultrasound method (Garnsworthy and Jones 1987; Deomecq et al. 1995; Zulu et al. 2001), and these studies all reported high correlations between ultrasound measurements and BCS, which suggest that BCS accurately portrayed the amount of subcutaneous fat present.

The industry recommendation for effectively managing the cow herd using BCS is to evaluate the herd at least 3 times per year: at weaning; 60 to 90 d before calving; and at calving (Eversole et al. 2009). When cows are either too fat or thin, they are at risk for metabolic challenges, disease, decreased milk production, low conception rates and dystocia (Meyer et al. 2010; Funston et al. 2010; Log et al. 2012; NASEM 2016). Utilizing BCS as a tool to monitor cow performance is important to ensure cows' energy requirements are being met (Funston et al. 2010).

2.2.3 Subcutaneous body fat composition (rib and rump fat)

Evaluating subcutaneous fat in cattle is quantitatively measured to the nearest 0.1 cm using an ultrasound machine (Schroder and Staufenbiel 2006). Utilizing ultrasound technology is not a new practice and has been used for over 60 years to evaluate body composition in live animals (Stouffer et al. 1959). Ultrasound is a quick, non-invasive, and easy to learn method, that will transfer electrical pulses into high frequency sound waves by piezoelectric crystals (Schroder and Staufenbiel 2006). The image that is generated by sound waves is reflected between adipose tissue, fascia and muscle. After freezing the image on the ultrasound screen the layer of subcutaneous fat can be measured. Ultrasound technology has the potential to determine fat thickness and longissimus muscle with a high degree of accuracy when done by an experienced technician (Greiner at al. 2003). Ultrasound technology has been utilized to describe carcass traits in live cattle and for selection and management decisions (Greiner et al. 2003). Emenheiser et al. (2014), indicated that experienced ultrasound technicians can accurately measure carcass traits in mature beef cows with repeatable results.

2.3 Extensive winter grazing systems

Canadian beef producers use a variety of management systems for wintering beef cows, with each system comes different impacts on the soil-plant-animal interface as well as different costs (Kelln et al. 2012; Figure 2.1). Figure 2.1 depicts regional differences of extensive grazing practices. Cow-calf production is a low margin business. The economic assessment carried out by CanFax Research Services found that long-term margins (2005 to 2014) for cow-calf producers are less than $50/cow, so it is critical to ensure low cost of production (Larson 2011). Majority of producers have already moved away from overwintering cows in drylot settings to extensive systems, where cattle are fed directly in the field (Jungnitsch et al. 2011). According to Jungnitsch et al. (2011), field feeding can reduce costs, improve pasture growth, and improve nutrient retention in soil.

Some extensive grazing systems include stockpiled forage, bale grazing, corn grazing, crop-residue grazing, and swath grazing. Past research at the Western Beef Development Centre

(Lanigan, SK, Canada) has examined strategies for extensive winter grazing in western Canada (Kelln et al. 2012; Kumar et al. 2012; Krause et al. 2013; Kulathunga et al. 2016; McMillan et al. 2018; Anderson 2020; Jose et al. 2020). One of the biggest challenges in winter-feeding systems is to maintain forage quality and availability to match the nutrient requirements of the cow in various environmental conditions. When considering implementing an extensive grazing strategy, it is important to have wind protection, clean water available, and controlled access to the forage.

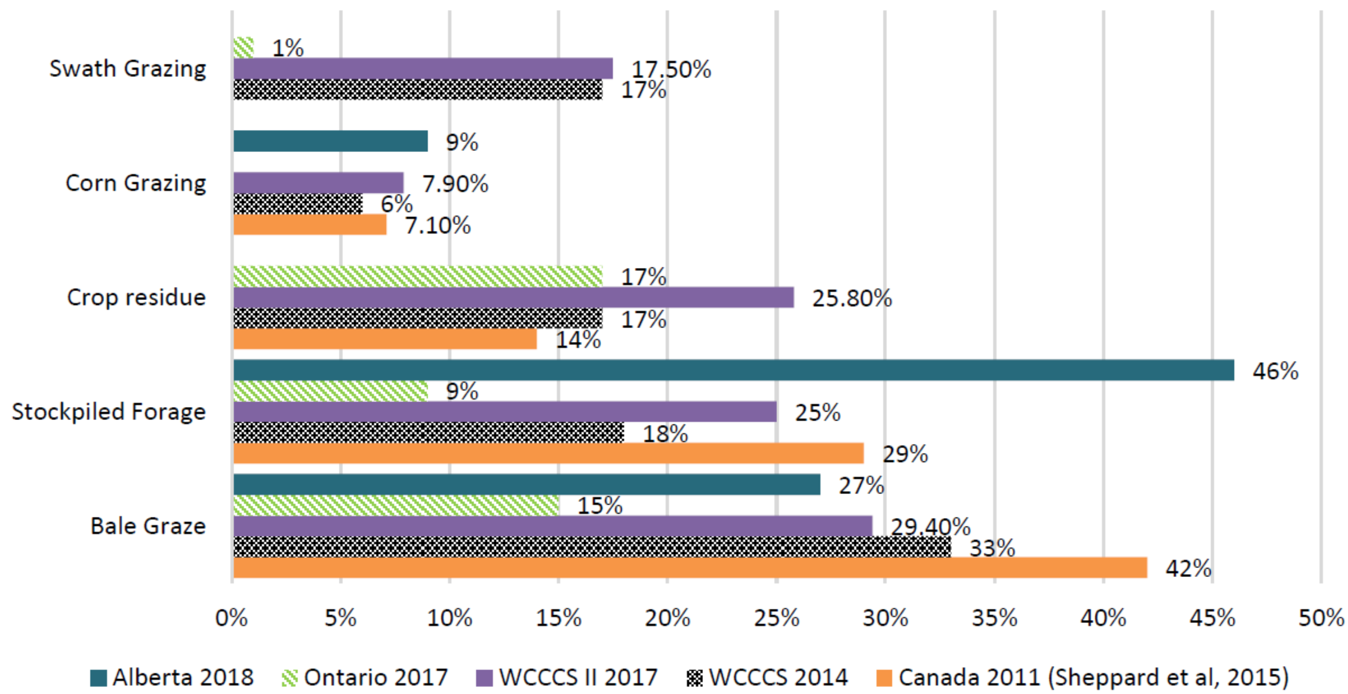

Figure 2.1 Adoption of extended wintering feeding methods by region. Adapted from BCRC National Adoption Rate Report 2019.

2.3.1 Annual forages

Grazing annual small grain cereal crops has been managed under a wide variety of soil and climatic conditions in Canada to extend the grazing season (McCartney et al. 2008). The economic costs that are associated with grazing annual cereals include: machinery, fuel, fertilizer, herbicide, and seed to grow the crop (McCartney et al. 2008). Grazing annual small grain cereal crops is an economical alternative to mechanical harvesting utilizing machines (e.g. combining), but machinery may also be needed to prepare the crop for animal consumption (e.g. swathing; McCartney et al. 2008). Annual crops are viable alternatives for cattle producers in western Canada, especially when perennial pastures are short in supply (McCartney et al. 2008).

Spring cereal crops that can be used to extend the grazing season include oat, barley, triticale, wheat, and rye (McCartney et al. 2008), with oat and barley being the most common (McCartney et al. 2008). Annual cereals such as triticale, barley, and oat are best used for early spring grazing or fall swath grazing as these crops are most productive around the same time as perennial forages (Aasen 2003). Depending on the year and soil zone, barley can yield similar or greater compared to oat (May et al. 2007). May et al. (2007), conducted a study evaluating seeding date and harvest date and reported small numerical differences in yield, with barley (6790 DM ha^{-1}) yielding slightly higher than oat (6280 kg DM ha^{-1}). Triticale, a cross between rye and wheat, was initially developed to have yield and grain quality like wheat, and the vigor and hardiness of rye (Oelke 1989). Seeding date is important because there must be a balance between total forage biomass production and potential weathering of the crop (May et al. 2007). In central Alberta, seeding date was evaluated (May vs. June) and it was concluded that, on average, early seeded cereals had 35 % greater forage yield compared to late seeded cereals (Kibite et al. 2002). May et al. (2007), also reported lower DM yield of oat and barley with later seeding dates (mid-May vs mid-June). At the time of harvest, planting date had no consistent effect on nutritive value, but a large implication was that delayed planting date reduced yield and increased the cost of digestible dry matter production (McCartney et al. 2008). Thus, strategies to avoid the need to delay seeding can have significant benefit to producers by increasing forage yield.

Winter cereals need a period of vernalization before the meristems initiate reproductive growth, which is unlike spring cereals (McCartney et al. 2008). Growth that occurs prior to the seed set is considered vegetative and following winter vernalization, growth is early and rapid (McCartney et al. 2008). Fall rye is a good winter cereal because the crop can be grazed later in the fall and if not grazed too low, the crop can survive the winter and the second year's growth can be utilized as green feed or pasture (McCartney et al. 2008). Fall rye and winter wheat yields are less in dry years but yield well in years with adequate available moisture (McCartney et al. 2008). Baron et al. (1999) determined that winter cereals are not used extensively in western Canada compared to the United States because of a much shorter growing season. Producers are generally limited by the cool climate in western Canada for the use of fall and spring growth of winter cereals for grazing (McCartney et al., 2008). Statistics Canada reported the spring cereal acreage of barley (8,256,600; 10,382,600) and oat (3,425,000; 4,157,300) has increased from 2015 to 2019 in

Canada; however, this was reported in total acreage and not split for grain vs. feed. (Statistics Canada, 2020, Table 32-10-0359-01).

2.3.2 Perennial forages

Native plant species (eg. Plains Rough Fescue) and legumes (i.e. alfalfa) are perennial forages that can be utilized as stockpiled forages (Baron et al. 2004). Perennial forage regrowth can be left standing and utilized as additional grazing after the initial hay harvest has taken place (Riesterer et al. 2000). Alfalfa can provide late season regrowth with adequate yield and quality, although this is completely dependent on plant management (Durunna et al. 2015). However, alfalfa that is stockpiled for fall grazing can have a rapid decline in nutritive value due to leaf loss from early frost (Kulathunga et al. 2016). Other legumes such as cicer milkvetch, sainfoin and birdsfoot trefoil are good perennial forages to utilize in beef cattle production. Perennial pastures are still the most cost-effective grazing system because of a low establishment cost when averaged over the lifetime of the stand (Baron et al. 2004; McCartney et al. 2008). Khorasani et al. (1997) described the Canadian climatic and soil conditions, suggesting that the short season in most areas can limit the extent of alfalfa utilization.

Tall fescue is a good perennial forage that can be utilized for late season/stockpile grazing because of adequate regrowth and its ability to withstand weathering events (Baron et al. 2015). Baron et al. (2004), describes that meadow bromegrass had moderate dry matter (DM) loss over winter, when managed in a stockpile system. Biligetu et al. (2014), describes combinations of alfalfa and western wheatgrass had the highest yield and nutritive value in the late summer and fall when compared to various warm and cool season forages in the semi-arid prairies.

2.3.3 Stockpile grazing

Stockpiled forage grazing utilizes forage that has accumulated during the late summer and fall and is grazed later when there is a forage deficit or planned grazing (Baron et al. 2004; Baron et al. 2005). The stockpiled forage can be available for grazing from October to early December, or until environmental conditions such as snow accumulation prevent grazing (Reisterer et al. 2000). Producers need to consider species selection, accumulation or rest periods between grazing or cutting, and soil nutrient management: these aspects are important when developing a sustainable stockpiled grazing system (Matches and Burns 1995). There is opportunity to utilize any grass or legume in a stockpiled system, but it is important to consider that legumes may not be as suitable because the nutritive value of the plant decreases as the leaves may be lost with advancing maturity or a frost event (Matches and Burns 1995). Costs are reduced through the minimization of harvesting, hauling, feeding and manure removal (Baron et al. 2004). Labor can be reduced by 25 % in comparison to conventional wintering of beef cows (Riesterer et al. 2000).

Stockpile grazing is one of the few extensive winter-feeding options where cows will gain weight due to the higher digestibility of the grass (Baron et al. 2014). Stockpiled forage quality can meet dry cow nutrient requirements in early to mid gestation, but during late gestation and lactation additional supplementation may be needed (Matches and Burns 1995; Kulathunga et al. 2016). Baron et al. (2014), described carrying capacity on pasture as a function of DM yield, stocking rate, utilization, and daily allocation of forage dry matter. Stockpiled forage had a reduced carrying capacity compared to an oat swath grazing system, while the only way to take advantage of the low-cost stockpiling system would be to maximize forage regrowth yields that will in turn, increase carrying capacity and reduce overall feeding costs (Baron et al. 2014).

2.3.4 Bale grazing

Bale grazing can reduce costs relative to traditional drylot feeding methods and allows for the deposition of manure out in the field (Jungnitsch 2011). Landblom et al. (2007), describes the different methods of how hay bales can be fed during the winter months, which include: i) allowing direct grazing of whole bales out in the field; ii) using a processor to break up and disperse the bale; or iii) feeding the bale in a bale feeder in a drylot system. Bale grazing can be considered intensive or extensive. From an intensive perspective, bales are transported to the field and placed close together allowing for high stocking rates or strategic placement; while the extensive approach is to graze the bales directly in the field where they were ejected by the baler (Saskatchewan Ministry of Agriculture 2008). Intensive bale feeding typically allows the bales to be roughly placed 40 feet apart, which approximately equals 25 bales/acre, while the extensive bale grazing system equates to approximately 2 to 4 bales/acre (Saskatchewan Ministry of Agriculture 2008). While this system does have costs associated with baling, placing bales, and the labour costs associated with feeding (removing strings or net-wrap), it is still less expensive than a drylot system due to the reduced equipment, labour, and infrastructure requirements (McCartney et al. 2004a).

Bale grazing advantages include reduced overall economic costs, increased nutrient recycling efficiency, and increased forage yield (Kelln et al. 2011; Jungnitsch et al. 2011) compared to a traditional drylot system. Jungnitsch et al. (2011) also described that bale processing and bale grazing resulted in more uniformly spread manure and feed compared to spreading manure with a tractor and manure spreader, which could potentially lead to greater forage yields and grass regrowth in subsequent years.

2.3.5 Crop residue grazing

Grazing crop residue provides a low-cost alternative for cow-calf producers, but the excessive nutrient losses during grazing can limit this resource (Russell et al. 1993). Cow performance while grazing on this system should be related to the annual variations in the amount of residue available and weather conditions (Russell et al. 1993). Cereal straw, leaf, and stem residue remaining after the grain is combined along with the chaff can provide up to 50 to 60 percent of winter dry matter intake for beef cows (McCartney et al. 2006), implying that supplementation may be necessary. Cereals have been developed for grain production and lodging resistance, which has led to highly lignified straw limiting its digestibility (McCartney et al. 2006). As a result, it is important to provide additional energy supplements to cattle to meet nutrient requirements (NASEM 2016). When low quality forages are utilized by grazing cattle on the prairies, additional protein supplementation is necessary to meet requirements and help with fibre digestibility and increase forage intake (Hess et al. 1994). Krause et al. (2013), compared oat and pea residue to traditional dry lot systems and found that overall feeding costs were lower for oat and pea residue systems compared to drylot feeding using hay, but also reported that supplementation with rolled oat grain was needed to maintain cow condition. Crop residues can be utilized as a low-cost feeding system for cattle producers with proper management of the cereal grain residues (McCartney et al. 2008).

2.3.6 Corn grazing

Winter grazing whole-plant corn is commonly seen in the prairies of western Canada (Baron et al. 2003). Corn is a warm-season annual that has a variable seeding date with a variation in the date of maturity depending on corn heat units (CHU) and overall location (May et al. 2007). McCartney et al. (2009) described how whole-plant corn growth depends on the CHU's accumulated in each region. Corn hybrids that are grown in western Canada typically require

>2300 CHUs in order to reach silage harvest stage (Lardner et al. 2017). Whole-plant corn has the physical and nutritional characteristics that are suitable for grazing beef cows in the winter months with additional supplementation depending on the cattle's physiological state (Baron et al. 2003; NASEM 2016). In southern Alberta, Willms et al. (1993), showed that grazing whole plant corn allowed cows to maintain body weight from November to February, and minimized feed inputs prior to calving. Corn plants have the height to stand above the snow, which allows cattle to graze without a problem in snow (Willms et al. 1993).

A study conducted by McCaughey et al. (2002) near Brandon, Manitoba (Canada) evaluated different varieties of corn as a swathed or standing crop. McCaughey et al. (2002), reported that swathed corn compared to standing corn allowed for an increase in carrying capacity and forage quality at the time of consumption. However, corn grazing trials in Lanigan, Saskatchewan (Canada) have shown that early maturing corn varieties provided exceptional late season grazing as a swathed or standing crop (Lardner 2002). Standing corn can also provide additional windbreak for cattle during the winter months (Baron et al. 2003). Anderson (2020) had compared 3-d of forage allocation of corn vs. 9-d of forage allocation when fed with or without a fibre supplement (low quality hay). Allocation of corn was best utilized with 3-d allocations, while decreasing the risk for ruminal acidosis, increased foraged utilization and mitigate diet nutrient fluctuations (Anderson 2020). Utilizing a low-quality fibre supplement in these corn grazing scenarios, did not prevent animals from selecting highly palatable portions of the corn plant (cob) at the start of an allocations (Anderson 2020).

2.3.7 Swath grazing

Swath grazing is a winter-feeding practice for dry gestating beef cows that is utilized on the western Canadian prairies, which involves consolidating forage into windrows, controlling access to the feed, thereby reducing overall winter-feeding costs relative to drylot feeding (Entz et al. 2002; McCartney et al. 2004; Baron et al. 2006). Swathing the forage into windrows allows the forage to be grazed in a variety of climatic conditions, including under snow in the winter (Baron et al. 2012). Swath grazing can reduce the winter feed costs by approximately 40 % by eliminating the costs associated with harvesting and hauling feed, and reducing manure spreading costs (McCartney et al. 2008). Swath utilization is a key factor that can determine if swath grazing will have an economic advantage over other feeding systems (Kaulbars and King 2004).

Forage quality is affected by seeding and swathing dates, with later seeding dates producing higher quality forages and earlier seeding dates producing higher yields (McCartney et al. 2008). Seeding for swath grazing typically takes place in June compared to April and early May seeding for cereals used for grain production (Lardner and Froehlich 2006). Utilizing warm season annuals such as millet and corn may be of benefit due to their heat and moisture tolerance (Lardner and Froehlich 2006). There is the potential for regrowth after harvest (swathing), which is an added benefit and can increase the overall forage quality in the field (Volesky et al. 2002).

One concern with swath grazing is feed wastage. Feed wastage may occur if feed is frozen to the ground or buried under snow, trampled, or otherwise contaminated (Nayigihugu et al. 2007). Hutton et al. (2004), explained that wastage is more likely to occur under light stocking densities and strip grazing should be implemented to encourage uniform consumption of all parts of the swath. Swath grazing usually meets the needs of beef cows in mid-gestation, however supplementation may need to occur if environmental conditions are unfavourable (Freeze et al. 1999).

2.4 Prediction of dry matter intake (DMI)

Determining DMI is important to verify because it is related to overall animal productivity and performance (Cook and Stubbendieck 1986). Measurement of DMI is critical to understanding grazing behaviour and nutrition, to improve pasture management, and to optimize grazing production systems (Undi et al. 2008). Dry matter intake is believed to be related to forage digestibility, but there is no research that suggests the amount of forage available and gut fill may influence intake (Jung and Allen 1995; Allen 1996). There are a variety of factors that can affect DMI; body composition, age, physiological state, environmental conditions, and overall forage management (NASEM 2016). There have been many methods used to determine DMI in cattle, the majority have been developed for housed animals and it is much more difficult to accurately determine intakes of cattle in grazing pasture systems (Dove and Mayes 1991).

2.4.1 Direct methods of estimation

Direct methods of measuring intake include visual observations for grazing time, bite size, and bite rate (Cook and Stubbendieck 1986). Visual methods can be ideal for small, controlled studies, but are less suitable for large extensive grazing studies, and visual estimations are prone to observer bias (Cook and Stubbendieck 1986). A more advanced visual option would be to utilize

GPS sensor tag systems, that are more suitable for large grazing trials (Greenwood et al. 2014). These sensor systems can record chewing, biting, drinking, head lowering, ruminating, walking, and lying down without altering the natural behaviour of the animal (Greenwood et al. 2014). A more direct method for determining DMI is the herbage disappearance technique which involves pre- and post- grazing yield clips (Kelln et al. 2011). Burns et al. (1994) described that DMI can be estimated directly by constant weight monitoring or weighing animals at the start and end of each grazing period or measuring the total herbage mass before and after grazing. The following equation represents the daily intake per animal (Cook and Stubbendieck 1983; Kelln et al. 2011).

Equation 2.2 Dry matter intake (kg) = (DM available kg – DM residual kg) / (n*p)

Where, n is the number of animals and p is the number of days.

The sampling area should be pre-determined, and a representative sample must be taken in order represent an accurate DMI. McCartney et al. (2004), suggested that for swathed forages, the weight of a 4 m length of pre- and post- grazed swath should be used and this information could be combined with the width of the harvester to calculate final weight per unit area. Volesky et al. (2002), utilized 20 randomly allocated 0.25 m^2 quadrats that were clipped to the ground level and used to calculate crop yield.

2.4.2 Indirect methods of estimation

Indirect methods for estimation of DMI involve determining fecal output and forage digestibility (Burns et al. 1994). Estimating DMI of grazing animals can be determined using internal and external markers (Undi et al. 2008). In grazing trials, forage intake is difficult to measure and conducting total tract digestibility measurements is impractical. As such, fecal markers can be used to determine digestibility and intake (Cochran and Galyean 1994). Fecal markers are designed to be measured in the feces and may include naturally occurring compounds present in the feed (internal markers) or those added to the feed or administered to an animal (external markers; Dove and Maye 2006). A widely used technique to estimate DMI considers changes in diet composition as a result of digestion driven by the change in marker concentration in feces relative to that in the diet (Undi et al. 2008). External markers such as ytterbium, chromium oxide, and n-alkanes can be used to estimate fecal output (Gordon 1995; Undi et al. 2008). Long-chain n-alkanes, which occur naturally in the waxes of the plant cuticle are used as markers to estimate DMI of grazing animals (Undi et al. 2008).

2.5 Forage quality and chemical composition

Forage quality is always important and is critical for the overall productivity and performance of cattle and is an extremely significant aspect under extensive winter-feeding systems (Funston et al. 2010). In a grazing scenario, 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). There are many factors that can affect overall forage quality and chemical composition of a crop. These factors include maturity, crop species, soil fertility, environmental conditions, and the final storage of the crop (May et al. 2007). Testing forages to obtain accurate analysis of nutrient content, identify potential toxins, and establish forage value is a recommended practice for beef producers to ensure animal requirements are being met (BCRC 2019). It is critical to take a representative feed or forage sample, and this is conducted by sampling multiple random samples taken from many parts of the feed or forage of interest and forming a composite (Adesogan et al. 2000). In a grazing scenario, forage clipping, bale cores, or swath samples can all be dried and sent for analysis (Mathis and Sawyer 2007).

2.6 Current recommendations for swath grazing

The main goal of a swath grazing system is to optimize forage yield and quality when harvesting forage for winter-feeding systems (Baron et al. 1992) and to ensure adequate utilization of that forage. The current recommendation for annual cereals with respect to stage of maturity at harvest is based on the maturity that optimizes DM content, yield, and available carbohydrate for ensiling applications (Rosser et al. 2013). However, this recommendation for harvest may not be the ideal stage for whole crop feed used for swath grazing or greenfeed (Rosser et al. 2013). The current recommendation for barley is to be harvested at the soft dough stage for silage (Acosta et al. 1991; Khorasani et al. 1997) and oat is the late milk stage (Kaulbars and King 2004). Typically, these annual cereals are swathed in August which coincides with the soft dough stage (Baron et al. 1992). However, in contrast to silage, the post-harvest preservation of forage in a swath grazing system exposes the harvested material to climatic conditions including precipitation which can decrease crude protein (CP) content and increase NDF and ADF concentrations (Aasen et al. 2004). The current body of literature lacks evidence that these earlier stages of maturity represent the optimal stage for swath grazing or green feed (Rosser et al. 2013). Rosser et al. (2013) suggests that the current recommendation for the maturity at harvest may not optimize yield of digestible nutrients for whole crop cereals. Silage-based recommendations are suggested to try and balance the proposed decline in NDF digestibility and apparent total tract OM digestibility with advancing maturity and increases in total yield (Acosta et al. 1991; Khorasani et al. 1997). Silage-based recommendations have started at a practical point but due to differences in post-harvest storage between whole-crop forage and silage, initiates whether the yield of effective digestible dry matter (EDDM) is maximized at these maturities for swath grazing systems (Rosser et al. 2013). In fact, the yield of EDDM/ha nearly doubled with advancing maturity for oat, barley, and wheat, suggesting that the current recommendation for the maturity at harvest may not maximize the yield of digestible nutrients for whole-crop cereals (Rosser et al. 2013).

2.7 Effect of maturity on yield and quality

Maturity at harvest is one factor that can be easily manipulated but it is very important because of the direct impact on crop yield and quality (Baron et al. 1992). As annual cereals advance in maturity, the weight of the grain increases, which accounts for approximately 50 to 55 % and 45 to 50 % of the total biomass for barley and oat, respectively (McCartney et al. 2006). As annual cereals advance in maturity there is a change in whole-crop composition. For example, there is an increase in starch and reduction in neutral detergent fibre (NDF) which can have a significant impact on the feeding value. Kilcher and Troelsen (1972), found that advanced stages of maturity may have a negative impact on intake and palatability of cereal forage, while also seeing an increase in lignin in the fibre which may decrease digestibility. Certain cell wall fractions such as fibre (cellulose and lignin) tend to increase and decrease nutritive value, while continued plant development results in increased starch production and can increase total energy (Wallstein and Hatfield 2016). Nadeau (2007) explained that the differences in intake were due to variations in chemical composition and in the ear to stalk ratio of whole-crop cereals. Oat and triticale contain less starch in comparison to barley because of the lower grain:stalk ratio (Khorasani et al. 1997). Most of the fibres are found in the stem of the plant (Cherney and Marten 1982), oat and triticale contain more fibre than barley when harvested at a similar maturity stage (Khorasani et al. 1997). As the kernels are developing, the water-soluble carbohydrates that are present are polymerised to starch beginning around the milk stage of development (Crovetto et al. 1998). Fibre concentration of whole-crop cereals continues to increase to the heading stage of maturity and decreases during kernel filling (Filya 2003). Advanced maturity results in harder kernels and structural changes in the cell walls of the stem, which leads to stiffer stems (Kennely and Weinberg 2003). Lignin increases in the cell wall to roughly 50% by maturity and lignin in the stems increases to near 70% by the dough stage (Kilcher and Troelsen 1973). Delaying harvest to mature stages of growth has been demonstrated to lead to greater lignification of the stem, leaf sheath, and lemma/palea which ultimately reduces the digestibility of the straw/chaff portion (Hargreaves et al. 2009). The permeability of the grain testa can be reduced which can lead to reduced availability of the starch (Hargreaves et al. 2009) unless processed. However, previous studies have reported that advancing maturity does not result in a reduction in digestibility and showed that whole-crop forages intended for swath grazing may be harvested at the mature stages to utilize yield potential (Baron et al. 1992; Rustas et al., 2011; Rosser et al. 2013; Rosser et al., 2016).

Rosser et al. (2013), showed that the yield of EDDM increased linearly with advancing maturity for barley, oat, and wheat. As oat and barley crops mature there is an increase in DM concentration and total forage yield (Baron et al. 1992, Rosser et al. 2013). Total DM yield was nearly twice the amount at the mature stage relative to head elongation (Rosser et al. 2013). Baron et al. (1992) also reported an increase in the amount of grain in the forage, with maximal yield of whole-crop barley occurring roughly 5 days before the grain is fully mature. Rosser et al. (2013) found that in comparison to less mature stages, when whole-crop barley and oat were harvested at full maturity, the result was greater yield of effectively degradable dry matter (EDDM) when determined in situ. Kilcher and Troelsen (1972) determined that leaves retained energy value as the plant matured, in comparison to the stem energy which dropped quickly throughout plant development. The high digestibility of the kernel fraction being developed compensated for the declining stem quality, which allowed whole plant digestibility to remain at 50% or higher in the later stages of maturity (Kilcher and Troelsen 1973). An implication for delaying maturity at harvest could be a strategy to allow producers to seed at a normal time (increases yield), harvest later (reduces time in the swath), and due to greater DM content at swathing likely reduces curing time (and curing losses) in the field.

2.8 Animal management in swath-grazing systems

Performance of cattle in swath-grazing systems can vary year to year, depending on environmental conditions and management (Kelln et al. 2011). Ensuring animals become adapted to winter-grazing systems is important otherwise there is potential for DMI in cattle to be negatively affected (Kelln et al. 2011). Kumar et al. (2012) studied swath grazing systems for backgrounding fall-weaned calves. It was observed that the DE of the whole crop barley swath grazing system was greater than grass-legume hay (Kumar et al. 2012). Dry matter intake was similar between calves consuming swath grazed barley (soft dough) and calves fed in drylot (Kumar et al. 2012). Thus, modifications to management can allow for cattle to perform well regardless of forage fed.

The energy and protein requirement of cattle on swath grazing systems will ultimately be determined by the physiological state of the animals. The type of forage and maturity at harvest will have an impact on whether energy or protein need to be supplemented. Typically, as annual cereals advance in maturity there is a general decline in CP concentrations which may require additional supplementation depending on the class of cattle that are grazing and forage quality. There is also a possibility that energy may need to be supplemented. The energy content of whole-crop oat forage decreased with advancing maturity from the early leaf to milk stage, however the energy content stabilized as the grain content increased (Kilcher and Troelsen 1973). There is also the possibility for higher kernel losses as crops advance in maturity (Stacey et al. 2006).

Forage utilization with swath grazing may be attributed to a variety of environmental conditions, such as low temperatures, snow cover, and temperature fluctuations that cause forage to freeze to the ground and stocking rate (Baron et al. 2006). Baron et al. (2014) conducted a 5-year study with utilization of barley swaths ranging from 58 to 80 %. Feed utilization is an important aspect of managing swath-grazing systems and it has been recommended to allocate 2 to 3 d of feed in a strip grazing scenario (Saskatchewan Ministry of Agriculture 2008; Baron et al. 2006). Consequently, the nutritive value of forage is likely to decrease from day to day, because beef cattle will sort through the swathed forage, consuming grain heads first, and by the end of the 3-d grazing period a small amount of residue with a low nutrient value remains (Baron et al. 2006).

Management has a large impact on utilization of extensive winter-feeding systems; this is an important role to maintain the health of the animals and that feed utilization is being maximized (Alberta Agriculture and Forestry 2004). Waste for swath grazed perennial grass ranged from 4 to 18 % compared to feeding losses of round bales at 12 to 13 % (Volesky et al. 2002). Volesky et al. (2002) discussed cattle allowed to return to swath residue in the spring to increase the utilization of the crops because they will be able to consume the crop residue. Swath grazing systems are usually managed in a strip grazing method (Saskatchewan Ministry of Agriculture 2008). High-tensile electric or poly wire are commonly used to limit the amount of feed that is presented to the cows (Saskatchewan Ministry of Agriculture 2008).

The freeze-thaw cycle can cause problems in a swath grazing scenario by increasing the amount of nutrients that are leached from the swath and decreasing the forage availability to the animal. There is potential for a hard crust to be formed which decreases cattle's ability to access the forage. Aasen et al. (2004) described how nutrient leaching is also a potential problem for swath grazing systems and is reduced at freezing temperatures, but in the spring with milder temperatures this can fluctuate. Finally, when cattle are swath grazing it is important to have wind protection against environmental elements. Wind breaks (natural or man-made) can decrease environmental stress associated with winter grazing on pasture (Olson et al. 2000).

2.9 Cattle health concerns with swath grazing

Several animal health concerns may arise while grazing annual cereals. Annual cereals typically contain nitrates as one form of nitrogen and in normal conditions, nitrates in feed are not a concern (Leng 2008; Lee and Beauchemin 2014). Nitrate accumulation in forages can occur after stressful events such as prolonged drought, heavy applications of fertilizer, hail, or frost events (McCartney et al. 2008). Nitrate poisoning in cattle is dependent on nitrate levels in the feed, nitrate consumption rate, incomplete nitrate and nitrite reduction to ammonia in the rumen, and slow rumen passage rate (Lee and Beauchemin 2014). Depending on the severity of those factors, cattle can be poisoned by nitrates. Some symptoms may manifest as decreased feed intake and productivity, reproductive failure, respiratory failure, and even death (Lee and Beauchemin 2014). Nitrates are typically considered an undesirable compound in ruminant feeds due to ability to induce methemoglobinemia (Bruning-Fann and Kaneene 1993).

Ergot can infect annual cereals such as rye, triticale, wheat, barley, and oat (Platford and Berniak 1976). Consumption of ergot alkaloids can result in a variety of symptoms with varying severities (Strickland et al. 2010). These symptoms can range from subtle decreases in production to more pronounced forms of ergotism (Klotz 2015). When weather and soil conditions are aligned, the flower of the forage will remain open for a longer period, which allows the fungus *Claviceps purpurea* to infect the plant and allow the disease cycle to begin (McLaren and Flett 1998). According to Menzies (2004), rye and triticale flowers remain open for a longer period and allow the pathogen to infect the host. Ergot can lead to a variety of negative responses in the body and cause various physiological responses such as vasoconstriction, abortion, central nervous system disruptions, and hyperthermia (Strickland et al. 2010). The rumen is the main site where ergot alkaloids can be broken down and possibly absorbed (Delorme et al. 2007; Foote et al. 2014). In cattle, vasoconstrictive effects predominate and cause gangrenous syndrome, these clinical signs are typically amplified with low environmental temperatures (Canty et al. 2014). Canty et al. (2014), described that gangrenous signs, such as lameness in the hind limbs of cattle can be seen 2 to 6 weeks after the ergot body was ingested. Ergot alkaloids can also decrease reproductive efficiency through a decrease in pregnancy rates and a higher rate of dystocia and abortion (Browning et al. 1998). Preventing ergot toxicity is mainly based on limit feeding ergot infected forage or avoiding feeding ergot infected feed altogether (Canty et al. 2014). Severity of the infection is determined by plant source of infection, ergot alkaloid concentration, duration of exposure, ambient temperature, and the mixture of ergot alkaloids (Thompson 2016). The ergot concentration should not exceed 200 ppb in a pregnant cow ration, to avoid potential health and performance impacts (Thompson 2016).

Winter tetany is a metabolic disease caused by lower than average blood magnesium levels and can occur when cattle graze on winter wheat or other cereal grains (Radostits et al. 2000). It is typically seen in pregnant cows in late gestation or in the early stages of lactation; high milk producing cows are particularly susceptible (McCartney et al. 2008). High potassium levels in forage can reduce the amount of magnesium absorbed from the ration (McCartney et al. 2008). Additional supplementation of magnesium oxide and limestone may be needed to balance the high potassium and low magnesium and calcium in the ration (McCartney et al. 2008).

Bloat and acidosis are also a potential risk and has been documented when cattle grazed succulent and rapid growing winter wheat pastures (Howarth and Horn 1984). Swath grazing feed allocation is typically 3d (Saskatchewan Ministry of Agriculture 2009), it is likely that the amount of fibre and starch that is consumed will be different each day due to sorting. Selective consumption of different plant parts could cause variability in the nutrient composition of the diet, fermentability of the consumed diet, and variation in DMI across days (Rosser et al. 2017). Selective consumptions allow the cereal grain head to be consumed first, which are more digestible and could result in a reduction in ruminal pH (Rosser et al. 2017).

2.10 Feeding system economics

The cost of traditional confined feeding systems in the Canadian prairies is the biggest expense for cow-calf producers accounting for almost 60 to 65 % of total cost of production (Kaliel and Kotowich 2002). Economic analysis of alternative winter-feeding methods needs to take into consideration the costs that differ between the methods. Often these differing costs include feed (cost to purchase or produce the feed), direct costs (bedding), and yardage costs (equipment used for feeding and bedding, infrastructure depreciation, manure removal and labour (Larson 2011; Kelln et al. 2011). There have been multiple studies that have shown economic benefit when switching from a traditional drylot system to an extensive grazing system (Van De Kerckhove et al. 2011; Krause et al. 2013; Baron et al. 2014). Utilizing annual cereals grown for extending the grazing season for use in winter swath grazing has been shown to lower winter feed costs $57 to $70/cow compared to drylot feeding and requires 21 to 38 % less labour (McCartney et al. 2008). The cost of grazing the forage was approximately one-half as much for the swath grazing system compared with a silage system, further savings in yardage costs of $0.29 to $0.52/cow/d were realized by swath grazing compared with baled feed and silage systems, respectively (McCartney et al. 2004). Grazing swathed triticale consistently reduced total daily feeding cost/cow/d over a traditional drylot system and swath grazed barley (Baron et al. 2014). It was also shown that there was an average total cost savings of 61 %, 47 % and 37 % for triticale, corn, and barley, respectively (Baron et al. 2014). The primary factor for the savings in these extensive systems is to do with reductions in equipment costs, not including fuel and labour, and a 73% savings in yardage costs, respectively (Baron et al. 2014).

Overall, wintering cattle in an extensive system such as swath grazing can largely reduce overall total feeding costs. Alongside, advancing maturity in annual cereals, there is also the possibility to decrease the overall feeding costs even more because of the increase in days feeding in an extensive system due to the increase in DM yield (Rosser et al. 2016).

2.11 Summary of Literature Review

Swath grazing annual cereals is an important winter grazing system for beef producers, which can provide adequate forage biomass and quality to meet pregnant beef cow nutrient requirements while reducing overall feed costs. Delaying harvesting of annual cereals from soft dough to hard dough, may result in increased yield and extend the winter grazing period. This thesis is analyzing how stage of maturity at harvest on oat, barley and triticale in a swath grazing system affects DM yield, EDDM yield, beef cow performance and system costs.

3.0 IN SITU STUDY EVALUATING THE EFFECT OF STAGE OF MATURITY AT HARVEST OF TRITICALE ON DRY MATTER AND NEUTRAL DETERGENT FIBRE DISAPPEARANCE

3.1 Introduction

Triticale, a cross between wheat and rye, was first produced in the late 1800s with the idea of combining the grain qualities of wheat with the low input requirements of rye (Oelke et al. 1989). Triticale is also recognized as a valuable forage crop and has the reputation of performing well on poor soils, under drought stress with reduced crop inputs (Roques et al. 2017). More research is required on the agronomy and feeding of triticale forage in different ruminant scenarios. However, there is limited data degradability of triticale with increasing maturity. Other cereals such as barley and oat have more research on NDF degradability and there are limited amounts on triticale NDF degradability. The NDF degradability of forage is not only closely related to feed intake but can also be used to evaluate physical rumen fill and energy prediction of forage (Patrick et al. 2001). Evaluation of forages for NDF digestibility is important in predicting total forage digestibility (Hoffman et al. 2001).

The NDF content of a forage varies widely, depending on species, maturity, and growing environment (Oba and Allen 1999). Hoffman et al. (2001), indicated that plants grown in cooler climates tend to have greater NDF digestibility than those grown in hotter climates. However, the primary factor that influences NDF digestibility is maturity at harvest (Hoffman et al. 2001). It has been long understood that forage fiber is not homogeneous, and it is incompletely digested by ruminants (Coblentz et al. 2018). As forages mature, there is an increase in fibre (ADF and NDF) content as well as increased lignification of plant structures, both of which result in decreased dry matter intake and digestibility (Allen 1996). Rosser et al. (2016), found that harvesting barley and oat at the hard dough stage and ripe stage did not negatively affect forage intake or the DE content for beef heifers and based on in situ degradation suggested that yield of effectively degradable DM was markedly increased with increasing maturity. However, there is limited data characterizing degradability of triticale with advancing maturity. The objective of this experiment was to determine the effects of increasing maturity on DM and NDF disappearance of whole plant triticale.

3.2 Materials and methods

3.2.1 Collection of forage samples

Approximately, 15 ha of triticale (cv. Taza) were seeded on June 5, 2015 and June 9, 2016 were collected at the Western Beef Development Centre's Termuende Research Ranch near Lanigan, Saskatchewan. In yr 1 (2015) and yr 2 (2016) the triticale crop was staged at early milk (EM), soft dough (SD) and hard dough (HD). A total of 9, 0.25 m^2 quadrats were collected at the stages EM, SD and HD, which were then composited into 3 experimental replicates within each stage of maturity for both yrs. Samples were ground through a 1-mm screen using a Thomas-Wiley mill (Model 4, Thomas Scientific, Swedesboro, NJ, USA).

3.2.2 Animals, housing and diet

This study used six Black Angus × Hereford heifers with a BW of 263 ± 19.0 kg. Heifers were surgically fit with a ruminal cannula (model 9C, Bar Diamond, Inc, Parma, Idaho, USA). During this study, heifers were housed individually in outdoor pens measuring 3.7 m wide × 6.1 m long at the University of Saskatchewan Livestock Research Building (Saskatoon, SK, Canada). Heifers were provided wood shavings as bedding with bedding removed and replaced as needed. Water was available ad libitum. Animals used in this experiment were cared for in accordance with the guidelines of the Canadian Council of Animal Care (2009). All heifers received a ration consisting of mature grass hay (82.4 % dietary DM), mineral and vitamin pellet (8 % dietary DM), and canola meal (9.6 % dietary DM). The hay was processed through a H-1000 Tub Grinder (DurTech Industries International, Inc. Jamestown, ND, USA) and was fed *ad libitum*. The mineral pellet contained 4.18% Ca, 0.39% P, 0.84% Na, 1.67% Mg, 1.64% K, 1.67% of S, 4.24 mg/kg Co, 134.6 mg/kg Cu, 7.4 mg/kg I, 414.9 mg/kg Fe, 308.8 mg.kg Mn, 2.08 mg/kg Se, 292.3 mg/kg Zn, 36,880 IU/kg vitamin A,13,820 IU vitamin D, and 276.6 IU vitamin E.

3.2.3 In situ procedures and laboratory analysis

All triticale samples were ground to pass through 1-mm screen in a Thomas-Wiley mill (Thomas-Wiley Laboratory Mill Model 4, Thomas Scientific, Swedesboro, NJ) prior to determination of in situ disappearance of DM and NDF. Ruminal degradation characteristics were determined using the in situ procedure described by Yu et al. (2004). The procedure involved weighing 7 g of each forage into number coded ANKOM nylon bags (5 x 10 cm, 6 µm pore size (Petex 07 - 6/5) with all bags heat sealed approximately 2 cm below the top. The rumen incubations were according to the "gradual additional/all out" schedule as recommended by NRC (2001) and described by Yu et al. (2004). Samples were incubated in the ventral rumen for 0, 30, 120, and 240 hr.

After incubation, all bags were removed from the rumen and rinsed in cold water six times, to remove any additional ruminal contents and to stop further microbial activity. A separate set of bags were prepared and rinsed under the same conditions except they were not placed in the rumen for ruminal incubation (0 h). After rinsing, the sample residues were dried to a constant weight at 55°C for 48 h in a forced air oven. Dry matter (DM) was analyzed by further drying samples in an oven at a temperature of 135°C for 2 h in a forced air oven. Weights were recorded for each bag and residue weights. Forage residue was weighed and composited by incubation time for a total of 3 samples per heifer per time point (240, 120, 30, 0 h). Neutral detergent fibre was analyzed using an ANKOM TM200 Fibre Analyzer (ANKOM, Technology, Fairport, NY) according to the procedure described by Damiran et al. 2008.

3.2.4 Calculations

Following the in-situ experiment, NDF was determined using the ANKOM fibre analyzer (ANKOM Technology Corporation, Fairport, NY). Neutral detergent fibre disappearance (NDFD) was calculated using the following equation (Damiran et al. 2008).

$$\textbf{Equation 3.1}\ \mathrm{NDFD} = \left(1 - \left(\frac{[\mathrm{W3} - \{\mathrm{W1} \times \mathrm{C1}\}] \times 1000}{\mathrm{W2} \times \mathrm{NDF}}\right)\right)$$

Where W1 is the filter bag weight, W2 is the sample weight (as is), W3 is the final weight (filter bag + residue NDF) after in situ incubation and sequential treatment with NDF solution, C1 is the blank bag correction (comparison of weight before and after incubation), and NDF is the NDF content (g/kg) of samples.

Dry matter was determined following the in-situ study. Dry matter disappearance (DMD) was calculated using the following equation (Damiran et al. 2008).

$$\textbf{Equation 3.2}\ \mathrm{DMD} = \left(1 - \left(\frac{[\mathrm{W3} - \{\mathrm{W1} \times \mathrm{C1}\}] \times 1000}{\mathrm{W2} \times \mathrm{DM}}\right)\right)$$

Where W1 is the filter bag weight, W2 is the forage sample weight (as is), W3 is the final bag weight after *in situ* incubation (filter bag + residue DM) and C1 is the blank bag correction (comparison of weight before and after incubation), and DM is the dry matter content (g/kg) of samples.

3.2.5 Statistical Analysis

In situ DMD and NDFD data were analyzed using the Proc Mixed model procedure of SAS Version 3 (SAS Institute Inc., Cary, NC). A randomized complete block design (RCBD) was used to analyze in situ disappearance of NDF and dry matter. Three-way interaction treated as fixed effects and year included as random blocking factor. Means were separated using Tukey's multi-treatment comparison method and differences were considered when $P < 0.05$ and trends were discussed when $P < 0.10$.

3.3 Results and Discussion

There was an effect ($P < 0.05$) of incubation time, for both DMD and NDFD seen in Table 3.1. Dry matter disappearance increased from 12.65 to 51.90 %, as the samples were incubated from 0 to 240 h seen in Table 3.1. NDF disappearance increased ($P < 0.05$) from 6.21 to 38.16 % from 0 to 240 h with increasing maturity from EM to HD. There was a significant ($P < 0.05$) interaction between incubation period and stage of maturity observed for DMD of triticale seen in Figure 3.1. The DMD was greatest for EM, SD and HD at the 240 h time point (29, 25 and 18% increase, respectively ($P < 0.05$), this would considered apart of the rumen slow pool. The digestion of the slow pool fibre is highly influenced by passage rate. Numerically, there was an increase in NDFD as incubation period increased. The potential digestibility is defined as the NDF fraction which disappears after a long incubation period and the remaining undigested component (uNDF) is considered unavailable for microbial digestion (Harper and McNeil 2015). The lack of digestibility in the uNDF fraction is due to the cross linking in the cell wall between lignin and hemicellulose (Harper and McNeil 2015). The uNDF fraction can only disappear by the passage rate. Neutral detergent fibre is the cell wall fraction of forages that includes a complex matrix of lignin, cellulose, hemicellulose, and pectin (NASEM 2016). The amount of NDF that is present in the plant will decrease as the plant matures, this is since the cell wall structure and composition will change within a plant as it matures (Harper and McNeil 2015).

Previous literature found that DM and NDF digestibility of whole-plant barley and whole-plant wheat decreased with advancing maturity due to increasing fibre concentration (Beck et al. 2009; Rosser et al. 2013). A study conducted by Rosser et al. (2013) using the in-situ technique reported values for DMD and NDFD of whole plant barley at various stages of maturity. Whole plant barley DMD decreased with advancing maturity from late milk to hard dough (44.7 and 40.3%, respectively) while NDFD increased with advancing maturity (58.3 and 71.6%, respectively) (Rosser et al. 2013). In this study similarities were noticed with whole plant triticale, DMD slightly decreased with advancing maturity from early milk to hard dough at the 240 h incubation time (33.22 and 32.46%, respectively) (P = 0.46), while NDFD increased with advancing maturity (14.08 and 28.25%, respectively) (P < 0.05).

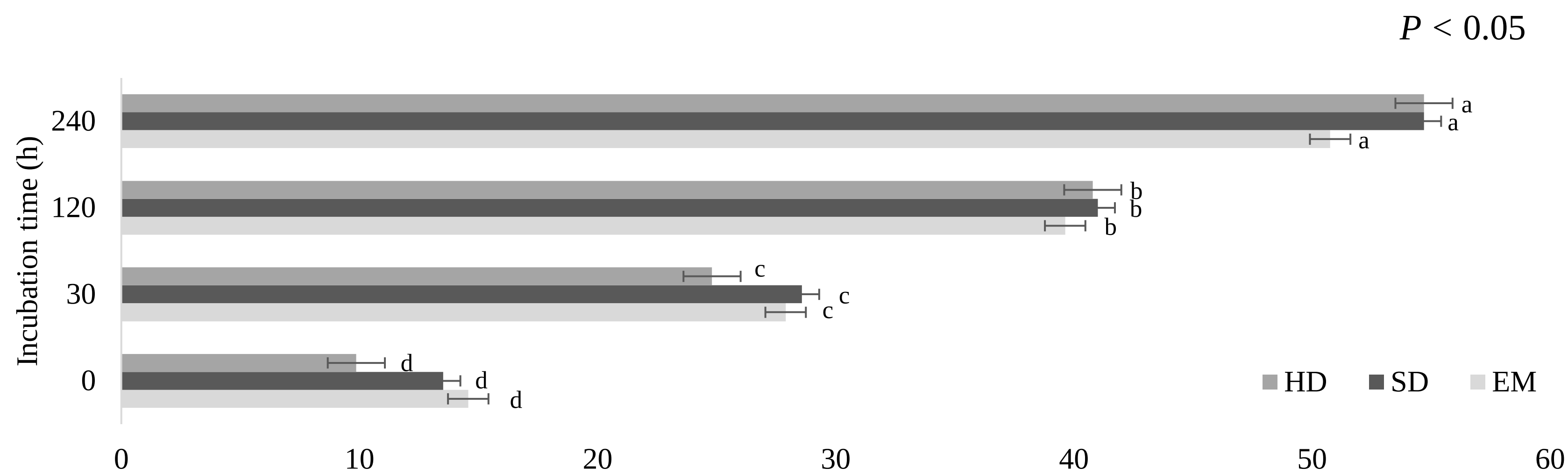

Figure 3.1 Effect of incubation time (h) by maturity interaction on DMD (%) over 2 yr. Vertical bars within treatment differ by letter (P < 0.05).

Table 3.1 Effect of in situ incubation time (h) and stage of maturity (SOM) on DMD and NDFD of triticale over 2 yr.

	Incubation time (h)					SOM[1]				P-Value[2]		
Item[3]	0	30	120	240	SEM	EM	SD	HD	SEM	I	M	I*M
DMD	12.65d	27.10c	40.38b	51.90a	0.60	33.22	33.34	32.46	0.45	<0.05	0.46	<0.05
NDFD	6.21c	11.12c	21.12b	38.16a	4.35	14.08b	15.13b	28.25a	4.30	<0.05	<0.05	0.67

[1]EM = early milk; SD = soft dough; HD = hard dough.

[2]I = incubation time; M = maturity; I*M = incubation maturity interaction.

[3]DM = dry matter degradability; NDFD = neutral detergent fibre degradability.

4.0 EFFECT OF STAGE OF MATURITY AT HARVEST OF CEREAL CROPS ON BIOMASS AND QUALITY, ESTIMATED FORAGE DRY MATTER INTAKE AND UTILIZATION, ANIMAL PERFORMANCE AND SYSTEM COST

4.1 Introduction

Approximately 60% of total cost of production for beef producers is due to winter feeding costs (Kaliel and Kotowich 2002). According to Volesky et al. (2002) and McCartney et al. (2004), changing from a conventional style drylot feeding system to a field swath grazing system can reduce overall costs by approximately 46 %. The overall reduction in cost is largely due to the decreased cost in feeding equipment use (Volesky et al. 2002), as well as decreased costs associated with manure removal and general labour (McCartney et al. 2004). As a result, swath grazing whole-plant small grain cereals, primarily barley and oat, during winter months has been used to extend the grazing season for beef cows in western Canada (Entz et al. 2002).

Triticale has been reported to have higher DM yield than barley (Baron et al. 2012). There is limited evaluation of triticale as a winter cereal for swath grazing in Saskatchewan and we are not aware of data that has evaluated the effect of stage of maturity at swathing on the nutritive value of triticale.

When harvesting crops for winter feeding, system the main goal is to maximize forage yield and quality to support performance of cattle (Baron et al. 1992). Forage quality is a very important aspect that is critical to maintaining the overall performance of cattle in an extensive winter-feeding system (Funston et al. 2010). There are a variety of factors that can affect forage quality including: maturity at harvest, crop species, soil fertility, and the final storage of the crop (May et al. 2007). Maturity at harvest is a critical and easily changed management factor that can affect total crop biomass and crop quality (Baron et al. 1992). Current recommendations for the stage of maturity at the time of harvest are based on silage recommendations to maximize dry matter content, yield, and total available water soluble carbohydrates (Rosser et al. 2013). The specific recommended stages of maturity for whole-plant barley and triticale is at the soft dough stage and late milk for oat (Acosta et al. 1991; Khorasani et al. 1997, Alberta Agriculture 2005). However, these recommendations are based on data derived from ensiling these crops, which may not represent the optimal stage of maturity for whole crops that are being utilized in a swath grazing system (Rosser et al. 2013). Rosser et al. (2013) showed that with a slight change in swathing date could, potentially double the yield of digestible DM. In an in situ study, Rosser et al. (2013) showed that a marked increase in effective digestible dry matter yield could potentially correspond to an increased carrying capacity in a swath grazing system. In addition, Rosser et al. (2016) reported that harvesting barley and oat at the hard dough relative to the late milk stage did not negatively affect DMI, ruminal fermentation, or apparent total tract digestibility further suggesting that such a recommendation may have merit for boarder application. However, all studies to date have been conducted using the in situ procedure or with cows individually housed in a barn. Given that exposure to winter environmental conditions affects feed intake and nutrient requirements, research is needed to evaluate whether maturity at harvest affects performance of cows under field-feeding conditions.

The hypothesis of this study was that harvesting whole-plant barley, oat, and triticale at late milk (oat), soft dough (barley and triticale) and hard dough will result in different forage biomass, crop nutritive value, DMI, cow performance, grazing days, and system costs when fed to dry pregnant beef cows. The objectives of this study were: (1) to determine the effect of maturity at harvest on crop biomass, nutritive value, dry matter intake and cow performance; (2) to determine the cost differences associated with swath grazing barley, triticale, and oat at two different stages of maturity; and (3) to provide new and updated recommendations for the appropriate stage of maturity to harvest barley, oat, and triticale for use in swath grazing programs in western Canada.

4.2 Material and methods

4.2.1 Study site and crop management

A 2-yr winter swath grazing study was conducted at the Western Beef Development Centre’s Termuende Research Ranch, located 8 km east of Lanigan, Saskatchewan, Canada (51º51'N, 105º02'W). The study site was located in the thin Black soil zone of Saskatchewan and the soil is classified as Chernozemic Black Oxbow soil (Saskatchewan Soil Survey, 1992). Each yr in June (June 5, 2015; June 9, 2016), a 48-ha field divided into 3, 16-ha paddocks were seeded to either barley (*Hordeum vulgare*, cv. CDC Maverick, 135 kg/ha), oat (*Avena sativa*, cv. CDC SO1, 135 kg/ha), or triticale (*Triticosecale*, cv. Taza, 135 kg/ha). Maverick barley is a two-row forage barley with smooth awns, intended for swath grazing or silage systems. Taza triticale is an awnletted (reduced awn expression) standard height triticale intended for a conserved forage, swath grazing crop. The variety CDC-S01 oat contains a high oil groat and low lignin hull that was developed as a forage and feed oat. All crops were supplied with 56.1 kg/ha of actual N fertilizer at the time of seeding. Pre-seed burn-off for weed control each yr was managed through an application of glyphosate [N-(phosphomethyl) glycine] with a dose of 3.45 L/ha (Roundup, Monsanto Inc., Winnipeg, Manitoba, Canada). Prior to the start of the study, each 16-ha field was further sub-divided into four, 4-ha paddocks using high tensile electric fence to enable harvest at two stages of maturity for each crop type (n = 2/crop type/maturity). Each yr, whole-plant oat was swathed at the late milk stage (LM; n = 2), and whole-plant barley and triticale at the soft dough (SD) stage (mid-August) representing the current recommendations for the stage of maturity at harvest. Additionally, crops were harvested at the hard dough (HD) stage (late August to early September) and left in windrows for winter grazing (Appendix A, Table A.2).

Daily precipitation amounts were recorded, and daily maximum and minimum temperatures were gathered from May 2015 to March 2017 using Environment Canada Climate data. This data was then averaged for mean monthly precipitation and temperature. Long term (1985-2015) total precipitation (mm) and monthly averages (ºC) were obtained from the Environment Canada Climate data website (www.climate.weatheroffice.gc.ca) for Leroy, Saskatchewan.

4.2.2 Estimation of forage yield and nutrient composition

Forage dry matter (DM) yield was determined for barley, oat, and triticale by approximate unit area, extrapolating from 0.25-m^2 quadrats. In both years, forage samples were collected to estimate the total amount of forage biomass by collecting twenty 0.25-m^2 quadrat clips in each field. Forage regrowth samples were collected in both years after crops had been swathed to estimate total forage biomass by collecting twenty 0.25-m^2 quadrat clips in each field. The biomass weight was recorded on an as is basis and samples were dried in a forced air oven at 55°C for 72 h to determine the DM content. The DM yield was then calculated and converted to estimate DM yield per hectare.

Forage samples were collected at the start and end of trial and every 21 d in each year. This was accomplished by collecting 4 random grab samples of swathed whole plant barley, oat, and triticale in each replicate paddock. Sample DM was determined by drying in a forced air oven at 55ºC for 72 h and then grinding through a 1-mm screen using a Thomas-Wiley mill (Model 4, Thomas Scientific, Swedesboro, NJ, USA). Samples were sent to Cumberland Valley Analytical Services (Waynesboro, PA, USA) for analysis. Duplicate samples were analyzed for total digestible nutrients (Weiss Equation), crude protein (CP; AOAC; method 2001.11), ether extract (AOAC; method 2003.05), acid detergent fibre (ADF; AOAC; method 989.03), neutral detergent fibre (NDF; AOAC; method 989.03), starch (AOAC; method 920.40), calcium (Ca) and phosphorus (P; AOAC; method 968.08).

4.2.3 Estimation of dry matter intake and forage utilization

Each yr after swathing, 25, 3 × 1-meter of swath were weighed in each paddock using a portable platform scale to determine available DM yield of barley, oat, and triticale crops. At this time, an additional five random sub-samples were collected to estimate swath DM content. Swath weights were used to determine forage allocation to cattle during swath grazing period. Post-grazed forage residue DM was determined using the same technique in spring after removing any foreign material or fecal matter not associated with residues. A post-graze weight of the swath for all three crop types was determined by measuring 40, 3 × 1-m lengths of swath using a portable scale. Forage residue DM was determined by collecting five sub-samples and placing these samples in a forced air oven for 72 h.

Average dry matter intake (DMI) of each cow was calculated using forage DM disappearance between the pre- and post-grazed forage weights in each paddock according to technique described by Jasmer and Holechek (1984), Volesky et al. (2002), and Kelln et al. (2011).

Estimated forage intake was calculated using the following equation (Jasmer and Holecheck 1984; Kelln et al. 2012)

Equation.4.1 $$\text{Forage DMI kg hd}^{-1}\text{d}^{-1} = \frac{\frac{\text{kg of DM}}{\text{P}}_{\text{allocated}} - \frac{\text{kg of DM}}{\text{P}}_{\text{residual}}}{(\text{n}*\text{p})}$$

Where, P = 3d feeding period, n = number of cows per experimental unit (n = 10).

Crop utilization was estimated as the difference between the weight of the allocated and residual forage samples after drying and was used to estimate forage utilization by the cows as per the herbage disappearance (weight estimate) method (Jasmer and Holechek 1984).

4.2.4 Animal management

In each year (8 December, 2015 to 7 March, 2016 and 24 November, 2016 to 10 March, 2017), 120 dry pregnant mature Angus cows (due to calve in April) were stratified by body weight (661 ± 18 kg) and randomly allocated to 1 of 6 replicated (n = 2) paddocks in a 2 × 3 factorial arrangement. Treatments included: (i) triticale swathed at soft dough (SDT); ii) triticale swathed at hard dough (HDT); (iii) barley swathed at soft dough (SDB); iv) barley swathed at hard dough (HDB); oat swathed at late milk (LMO); oat swathed at hard dough (HDO).

Swathed forage was allocated based on cow BW, stage of pregnancy, forage nutrient density, and environmental conditions in accordance with the NRC (2000) beef model for non-lactating, pregnant beef cows as predicted by CowBytes Ration Balancing Program (CowBytes Beef Ration Balancer Program, Version 5.3.1, AAFRD, Edmonton, Alberta). The amount of feed allocated was intended for maintenance of body condition, with no BW gain other than that of conceptus growth. Feed was allocated on a 3-d basis and access was limited using portable electric fence. Cows had the ability to back graze. Cows were supplemented with a 2:1 mineral (16.5% Ca, 5% P, 1% Mg, 6.7% Na, 200 ppm I, 1500 ppm Cu, 4000 ppm Mn, 4500 ppm Zn, 20 ppm Co, 100,000 IU/lb Vitamin A, 50000 IU/kg, 100 IU/lb Vitamin E (min; Right Now Emerald, Cargill Nutrition) and cobalt iodized salt block. Water was checked and provided daily using insulated portable troughs. Each paddock had 2 portable windbreaks (3 × 8 m) with a straw bedded pack for shelter.

Cow performance was determined by measuring BW, BCS, and subcutaneous body fat thickness. Body weight was measured on 2 consecutive d at the start and end of the study and on a single day every 21 d throughout the trial. Body weights were taken in the morning to avoid the effects of gut fill on BW and were adjusted for conceptus growth based on the following equation (NASEM 2016).

Equation 4.2 $\text{Conceptus weight (kg)} = \text{CBW} \times 0.01828 \times e^{[(0.02 \times t) - (1.43e - 0.005 \times t \times t^{0})]}$

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

Subcutaneous body fat thickness and BCS were measured at the start and end of the study (Schroder and Staufenbiel 2006) by an experienced technician blinded to treatment. Body condition score was based on the Lowman et al. (1976) scale of 1 to 5 (1 = emaciated to 5 = grossly fat). Subcutaneous body fat was determined using ultrasonography between the 12th and 13th rib (site for 'grade fat') and rump fat (hip of thurl) using an Echo Camera SSD – 500 diagnostic real-time ultrasound unit (Overseas Monitor Corporation Ltd., Richmond, BC, Canada) equipped with a UST 5044-17-cm, 3.5-MHz linear array transducer. All cows were pregnancy checked by a veterinarian prior to study start to ensure all animals on trial were pregnant.

Once available forage had been grazed, individual paddocks were moved to drylot pens located at Termuende Research Ranch, 3 km from field study site. Each pen contained an open-faced shed, heated water bowl, round bale feeder, and cows had *ad libitum* access to a 2:1 mineral (Right Now Emerald, Cargill Nutrition) and cobalt iodized salt block. All cows received barley hay forage (62.3% TDN; 12.4% CP) while in the drylot. Drylot feeding costs were calculated until all treatments groups had consumed swathed field crops to compare grazing systems on an economic basis.

All experimental procedures were approved by University of Saskatchewan Animal Research Ethics Board (Protocol No. 20090107) and cows were cared for in accordance with the Canadian Council of Animal Care guidelines (CCAC, 2009).

4.2.5 Economics

An economic analysis of each grazing system was evaluated and presented on a $/cow/d basis. Total forage production costs were first calculated as the sum of input costs to grow and swath the annual forage. Costs included seed, fertilizer, herbicide, and equipment. Total forage production costs were divided by the DM forage yield to determine a cost/kg of forage DM which was then multiplied by the length and weight of the swath offered to estimate the daily cost of forage. Feeding and bedding records, time estimates to feed, check, and water the cows, and infrastructure values were used to estimate the total feed costs, bedding costs, depreciation, labour, equipment, and manure removal (drylot only) costs for each treatment in the swath grazing (SG) system and drylot (DL). Costs per cow per day were determined separately for SG and DL given not all treatments required drylot feeding and that the duration of the drylot feeding differed by replicate within treatment. The $/cow/d costs for SG and DL were multiplied by the d in each system to calculate the total feeding costs per treatment and then divided by total days on trial to come up with an average cost per treatment replicate.

4.2.6 Statistical analysis

Statistical analysis of forage yield and composition, cow performance (DMI, BW, BCS, subcutaneous fat thickness), and economic data were determined using the Proc Mixed procedure of SAS (SAS version 9.4; SAS Cary, NC) as a randomized complete block design (RCBD) with forage type (barley, oat, triticale), stage of maturity (recommended vs. late), and the two way interaction treated as fixed effects and year included as a random blocking factor. Each group of cows was considered an experimental unit for a total of 24 experimental units (n = 4/treatment) over the 2-yr study. Means were separated using Tukey's multi-treatment comparison method and differences were considered when $P < 0.05$ and trends were discussed when $P < 0.10$.

4.3 Results and Discussion

4.3.1 Weather

Total precipitation from May to August was 166 and 341 mm in yr 1 and 2, respectively (Appendix, Figure B.1). The 30-yr average is 280 mm, indicating that yr 1 was below average and year 2 was above average for total rainfall during those months. Tremblay et al. (2012) showed that total rainfall quantity and timing can have a direct impact on crop quality and yield. Minimal rainfall occurred in May of yr 1 (3 mm) compared to yr 2 (42 mm). July rainfall in yr 2 was 183 mm, exceeding the 30-yr average of 75 mm and yr 1 with 72 mm (Appendix B, Figure B.1). May to July in both yr 1 and 2 were warmer compared to the 30 yr average, August temperatures were cooler in yr 1 and 2 compared to the 30 yr average (Appendix B, Figure B.2). In yr 1, the late August temperature dropped down to 1.6°C, although not falling below 0ºC, there was a risk of frost during late summer. If temperatures fall below 0ºC, frost damage of cereal crops can occur (Savin et al. 1997). The temperature did fall below 0ºC on September 10, 2015 and October 5, 2016; however, the duration of these low temperatures is unknown. The maturation process of cereal crops is related to specific temperature sums, when average temperatures increase by 1 to 2°C it can result in a shorter grain filling period and negatively affect yield components (Savin et al. 1997). Drought stress can result in shorter grain filling periods and therefore lower yields in barley (Savin et al. 1997). Year 1 had drier conditions compared to yr 2, which did result in lower yields.

4.3.2 Crop biomass and nutrient composition

The effect of maturity at harvest on forage biomass over 2 yr is shown in Table 4.1. Each crop biomass was measured (utilizing the 0.25 m^2 quadrat) prior to crops being swathed, and regrowth was also accounted for and included in yield estimate to determine the total crop yield. Maturity affected ($P < 0.05$) pre-swath yield of crops as hard dough stage yielded an additional 1,783 kg/ha of forage biomass compared to soft dough stage (Table 4.1). There was a tendency ($P = 0.07$) for triticale to yield 24% greater forage biomass in comparison to oat and barley crops Baron et al. (1995) reported there was a general decline in regrowth when the initial cutting was delayed past heading and further observed that triticale had greater regrowth yield in comparison to rye and wheat crops. With the addition of regrowth biomass to total yield, there was no effect of maturity at harvest ($P = 0.34$), or crop type ($P = 0.13$) on total yield (Table 4.1).

Table 4.1 Effect of maturity and crop type on crop biomass over 2 yr (kg DM/ha).

	Maturity			Crop				*P*-value		
Item	Soft dough	Hard dough	SEM	Barley	Oat	Triticale	SEM	m	c	c*m
Pre-swath	7,778b	9,561a	912.8	7,975	8,126	9,907	977.3	**<0.05**	**0.07**	0.35
Total yield	8,906	9,561	0.09	8,545	8,928	10,277	823.4	0.34	0.13	0.45

a-b means with different letters in the same row are significantly different ($P < 0.05$).

m = maturity effect; c = crop effect; m*c = maturity by crop interaction effect.

SEM = standard error of mean.

Royo et al. (1994) reported that forage yield increased when cutting was delayed, but overall forage quality was not compromised. Baron et al. (1995) reported that initial monocrop yields increased when harvest was delayed. Coleman (1992) suggested that a minimum yield of 2,000 kg/ha is required to support efficient grazing and forage accessibility through the snow depth during the winter months. Baron et al. (2012) noted that forage biomass is influenced by plant species, stage of harvest and environmental conditions. Previous literature has shown that oat generally out-yield other cereal crops such as barley, wheat, triticale and rye (Baron et al. 1992). However, depending on variety, stage of growth, year, and location, barley and triticale yields can be comparable to oat (Cherney and Marten 1982). In the current study, Taza triticale had a tendency to yield higher in comparison to CDC-SO1 oat (P = 0.07; Table 4.1). However, McCartney and Vaage (1994) who evaluated several cereal crops, reported no differences between yields. McElroy and Gervais (1983), also reported that oat and barley harvested at the earlier stages of maturity (late milk and soft dough), had similar yields, which was also observed in the present study. The crops in the current study were seeded in early June, which is a later seeding date in comparison to crops being grown for grain production. A later seeding date is supported by Entz et al. (2002), who showed that forages grown for grazing can be planted later compared to those crops for grain production. Baron et al. (2012), explained that the effect of planting date can have a major impact on total forage yield or nutrient composition of small grain cereals such as oat, barley, rye, and triticale at time of harvest. There was a linear decline in forage yield (35 to 39%) in a study conducted in Lacombe, Alberta where multiple barley varieties were compared, and the seeding date was delayed each week from mid-May to late June (Baron et al. 2012). However, a study in Saskatchewan (May et al. (2007) did not see a reduction in barley yield when the crop was seeded on June 10. Rosser et al. (2013), observed an increase in DM yield as barley and oat matured from soft dough to hard dough (10.93 vs 14.27 t/ha and 9.48 vs 12.12 t/ha, respectively). There was also a linear increase in effective degradable dry matter (EDDM) with advancing maturity in barley and oat (Rosser et al. (2013). With an increase in EDDM, harvesting crops at the soft dough stage may not maximize the whole-crop potential to optimize the yield of digestible nutrients of preserved forages, such as swath grazing (Rosser et al. 2013). This increase in EDDM can be explained by the increase in total DM yield with advancing maturity (Rosser et al. 2013).

The effect of maturity at harvest on oat, barley, and triticale nutrient composition are shown in Table 4.2 Total digestible nutrients concentration increased ($P < 0.05$) with advancing maturity from SD to HD stage. Both NDF and ADF concentrations decreased ($P < 0.05$) from SD to HD. There was a tendency ($P = 0.09$) for DM to increase from soft to hard dough, and a 12% difference ($P < 0.05$) observed in the DM concentration between oat and triticale (Table 4.2). There was an effect ($P < 0.05$) observed for CP (Figure 4.1), starch (Figure 4.2), EE (Figure 4.3), Ca and P (Figure 4.4). The interaction effect of crop type and maturity are presented in Figures 4.1 (CP); 4.2 (Starch); 4.3 (EE) and 4.4 (Ca and P), there were significant interactions observed ($P < 0.05$). Late milk oat, soft dough barley and hard dough barley had the highest amounts of CP and hard dough oat had the least (*P* < 0.05; Figure 4.1). Starch content was the highest for hard dough barley and hard dough triticale and the lowest from soft dough barley and late milk oat (P < 0.05; Figure 4.2). Hard dough oat had the greatest amount of EE, in comparison to barley or triticale at either stage of maturity (*P* < 0.05; Figure 4.3). The variety of oat (CDC S01) has a higher fat content to other varieties. Calcium content was greatest in the late milk oat, soft dough barley and hard dough barley and was the lowest in hard dough oat, soft dough triticale and hard dough triticale (P < 0.05; Figure 4.4). Phosphorus content was observed to be the greatest amount in late milk oat, and the lowest concentration in hard dough oat, hard dough barley, soft dough triticale and hard dough triticale (*P* < 0.05; Figure 4.4). The concentration of starch was also affected by advancing maturity, doubling from soft dough to hard dough (*P* < 0.05) and there was 15% greater (*P* < 0.05) starch concentration for triticale compared to oat (Table 6.2). The CP content decreased (*P* < 0.05), and the TDN content increased (*P* < 0.05) from late milk (oat) and soft dough (triticale, barley) until hard dough. Typically, oat varieties are lower in nutritional value than other cereals (McCartney and Vaage 1993). Forage chemical composition can vary year to year, due to changes in climatic conditions, stage of plant growth at harvest, over winter weathering and plant type (Aasen et al. 2004), with significant evidence supporting variations in nutrient composition of forages reported by Jung and Allen (1995) and Rosser et al. (2013).

Table 4.2 Effect of maturity and crop type on forage nutrient composition over 2 yr.

	Maturity			Crop				*P*-value		
Item[1]	Soft dough	Hard dough	SEM	Oat	Barley	Triticale	SEM	m	c	m*c
DM (%)	59.5	63.0	1.96	57.3b	62.5ab	64.0a	2.19	0.09	**<0.05**	0.43
CP, % DM	12.0a	11.2b	0.16	11.2b	12.5a	11.2b	0.19	**<0.05**	**<0.05**	**<0.05**
TDN, % DM	55.7b	61.0a	3.13	57.4	59.0	57.1	3.16	**<0.05**	0.20	0.07
ADF, % DM	41.1a	36.0b	3.35	38.4	38.1	39.0	3.38	**<0.05**	0.75	0.19
NDF, % DM	60.4a	53.4b	4.85	57.6	56.5	56.5	3.10	**<0.05**	0.53	0.11
Starch, % DM	10.0a	20.0b	4.85	13.1a	14.9a	15.5a	4.87	**<0.05**	0.20	**<0.05**
EE, % DM	2.03b	2.27a	0.11	3.00a	1.60b	1.88b	0.12	**<0.05**	**<0.05**	**<0.05**
Ca, % DM	0.36a	0.28b	0.05	0.31b	0.41a	0.24c	0.05	**<0.05**	**<0.05**	**<0.05**
P, % DM	0.35a	0.31b	0.01	0.35a	0.34a	0.30b	0.01	**<0.05**	**<0.05**	**<0.05**

[1]DM = dry matter; CP = crude protein; TDN = total digestible nutrients; ADF = acid detergent fibre; NDF = neutral detergent fibre; EE = ether extract; Ca = calcium; P = phosphorus.

m = maturity effect; c = crop effect; m*c = maturity by crop interaction effect.

a-c means with different letters in the same row are significantly different ($P < 0.05$).

SEM = standard error of the mean.

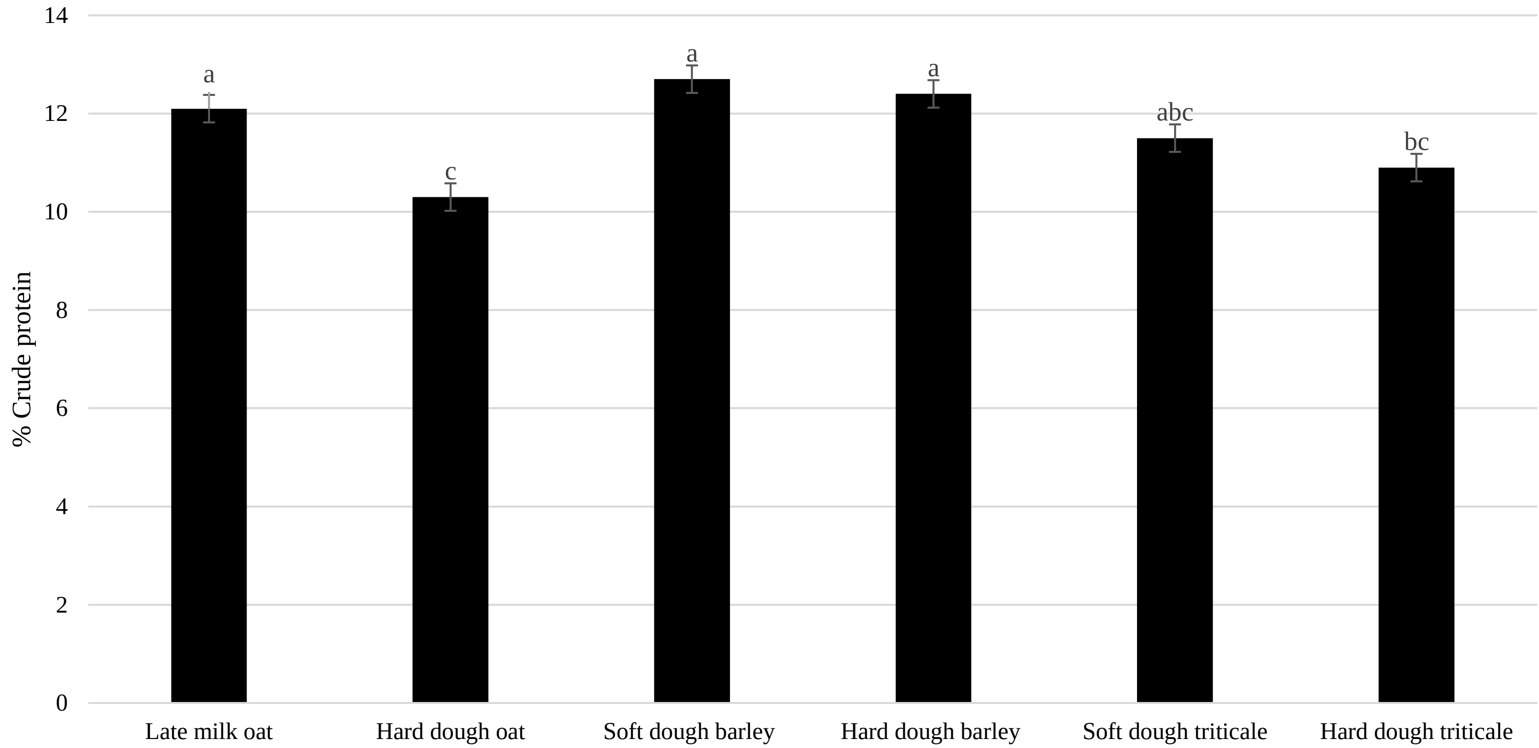

Figure 4.1 Effect of maturity by crop interaction on crude protein % over 2 yr. Vertical bars within treatment with different letters differ ($P < 0.05$).

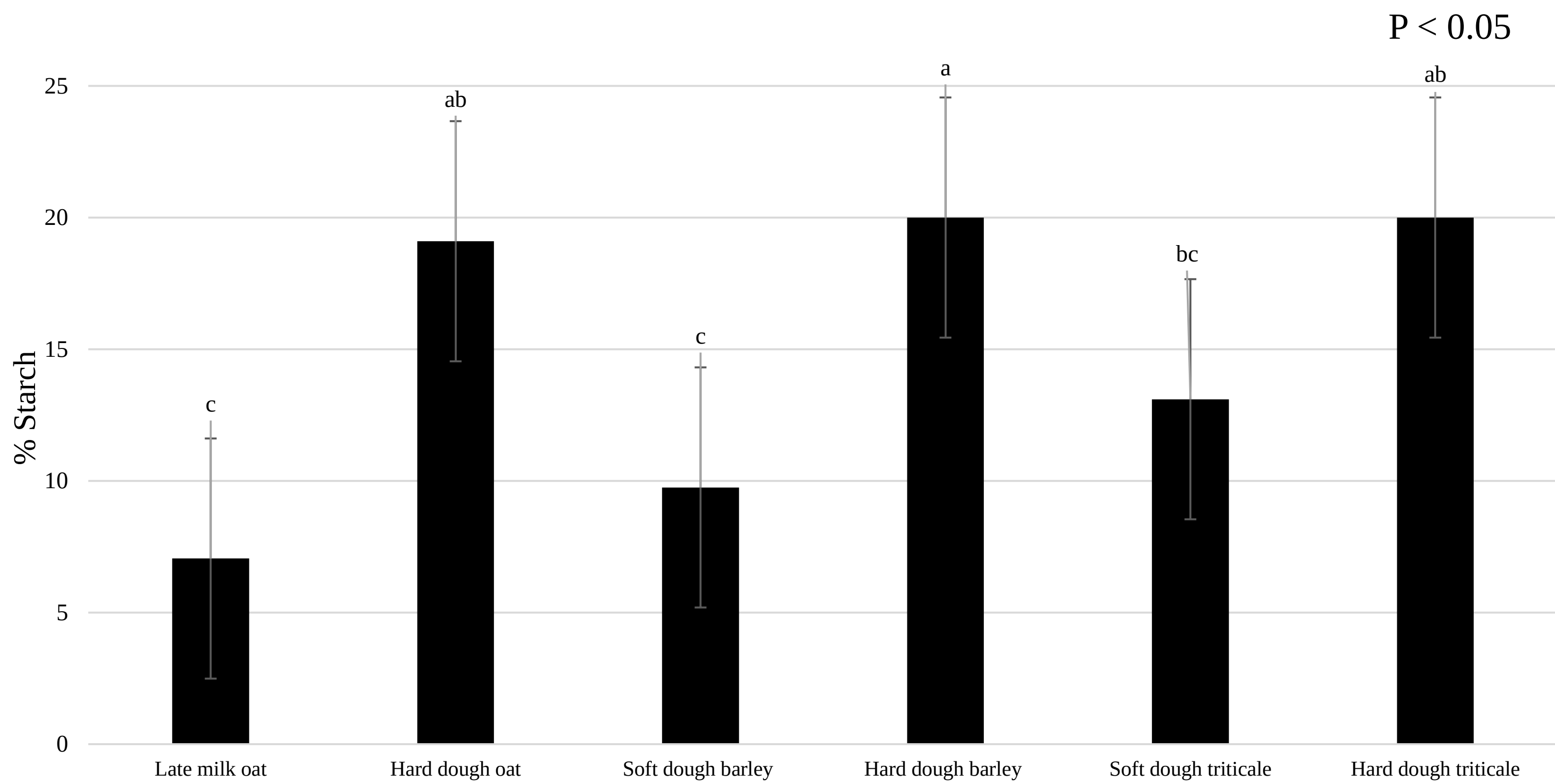

Figure 4.2 Effect of maturity by crop interaction on % starch over 2 yr.
Vertical bars within treatment with different letters differ (*P* < 0.05).

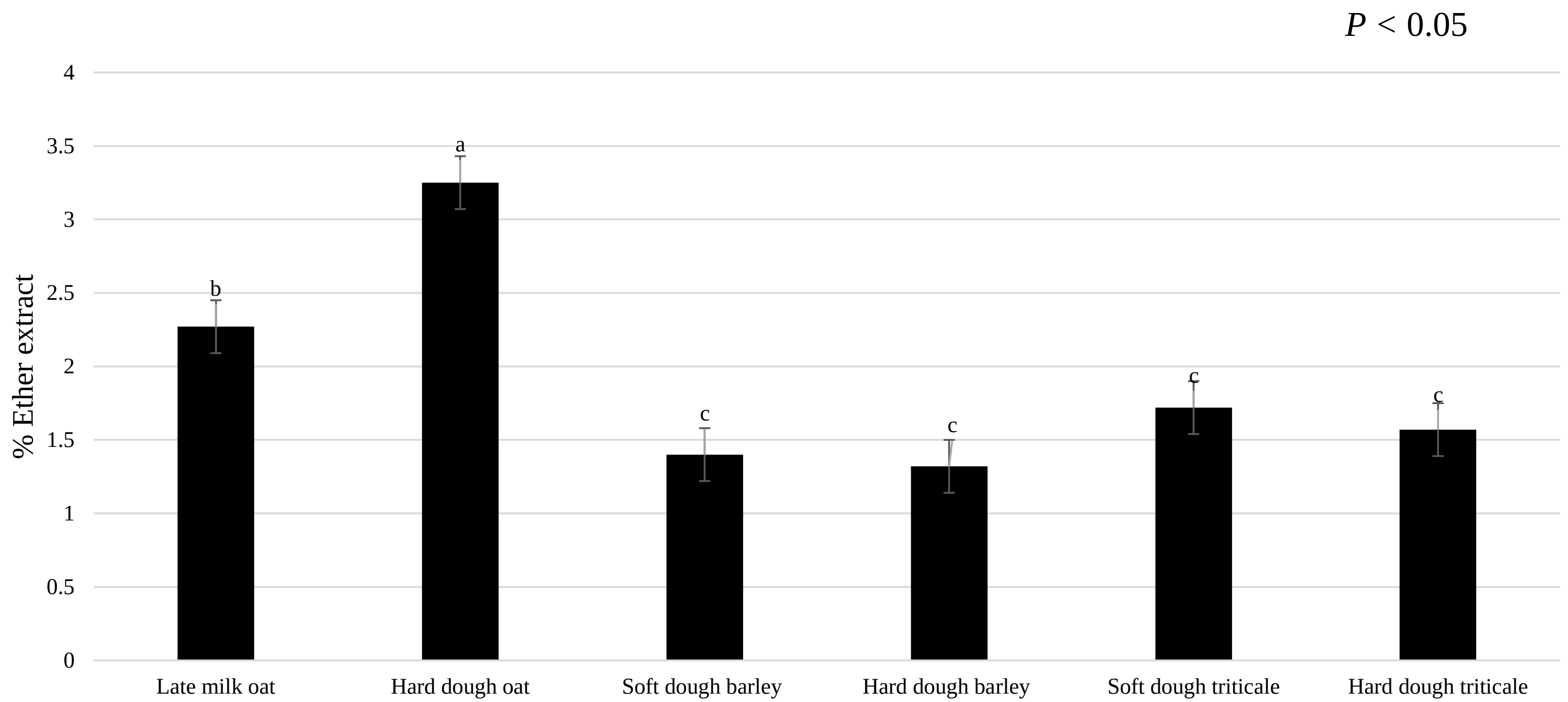

Figure 4.3 Effect of maturity by crop interaction on % ether extract over 2 yr.
Vertical bars within treatment with different letters differ ($P < 0.05$).

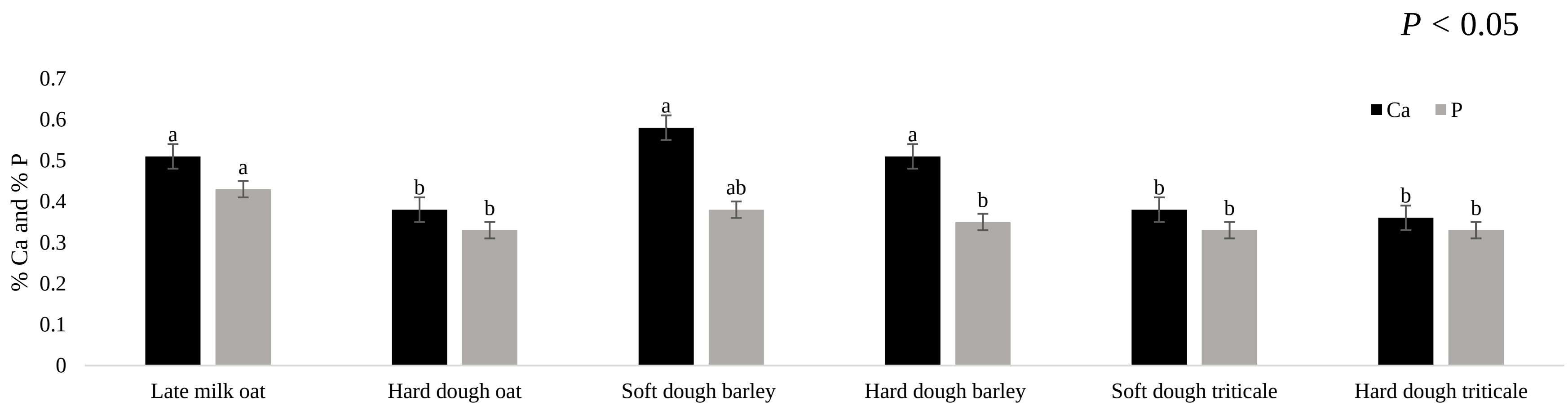

Figure 4.4 Effect of maturity by crop interaction on Ca and P (%) over 2 yr. Vertical bars within treatment with different letters differ ($P < 0.05$).

The possibility for nutrient losses due to weathering and leaf loss is higher in a swath grazing system, compared to a baling system (Baron et al. 2006; Kelln et al. 2011). Swathed field crops in a windrow are exposed to environmental conditions, including precipitation, which can decrease CP content and increase fiber concentration (Aasen et al. 2004). Rosser et al (2013), observed the CP content of oat was 13.8% in the late milk stage and 10.1% in the hard dough stage, which is similar for oat in the current study with 12% CP for late milk and 11.2% CP for hard dough. Crude protein concentration tends to be higher in triticale and barley than in oat silage (McCartney and Vaage 1993). Rosser et al. (2013) observed that NDF and crude fat (ether extract) levels decreased, while for the current study shows that NDF concentration decreased as maturity advanced, but the fat concentration increased from soft dough to hard dough stage. Rosser et al. (2013) also observed a decrease in calcium and phosphorus content of oat and barley forage as the crop matured ($P < 0.05$). Rosser et al. (2013) also reported that DM increased linearly for barley and oat, while for the current study there was a numerical increase in DM content. Data in the current study supports suggestions by Rosser et al. (2013) that the current recommendation for harvest maturity may not optimize total yield of the digestible nutrients for dry, stored whole-plant cereals, managed in a swath grazing system. As whole-crop barley matures, the relative weight of the grain accounts for more than 51% of total whole plant dry matter, this is a large reason for seeing an increase of DM as the plant matures (Hargreaves et al. 2009). McCartney and Vaage (1993) found that forage DM content was greatest for triticale, intermediate for oat and least for barley forage. In the current study, barley had similar forage DM content compared to oat, while triticale had higher DM, compared to oat forage. Khorasani et al. (1997) also observed decreases in NDF and CP as whole barley advanced in maturity. In the current study, total starch was observed to increase from 10 to 20% as forages matured from soft to hard dough stage.

Fibre content (ADF and NDF) increase until grain development in small grain cereals (Collar et al. 2004). According to Khorasani et al. (1997), as cereal crops mature the increase in grain starch can compensate for increased fibre levels in the stem and leaves. Khorasani et al. (1997) also observed that oat and triticale had the lowest NDF concentration at the boot stage, while barley and winter triticale had the highest. However, there was no difference ($P = 0.53$) in NDF content between crop types, which was also seen at the later stages in Khorasani et al. (1997) study, where no difference was observed between the oat, triticale, and barley. Brink and

Marten (1986) ranked cereal forages in order of increasing NDF, as barley, oat, and triticale, whereas this study observed no differences in NDF levels between the different crops. There was a difference observed in TDN ($P < 0.05$) content between soft dough and hard dough in the current study. Collar et al. (2004), observed in cool season annuals, such as triticale, that there was an initial decrease in energy followed by an increase as crops matured. Calcium and phosphorus content did differ ($P < 0.05$) as plants matured from soft to hard dough stage. Kilcher et al. (1981) described mineral concentrations tend to increase in the initial stage of plant growth and then decrease with advancing maturity.

Despite changes in nutrient composition with advancing maturity, the CP and TDN levels for barley (12.5 and 59.0%), oat (11.2 and 57.4%) and triticale (11.2 and 57.1%) were suitable to meet protein and energy requirements of a pregnant beef cow in mid-gestation (NASEM 2016).

4.3.3 Estimated dry matter intake and utilization

Table 4.3 shows the effect of maturity at harvest on estimated DMI (kg/d) and forage utilization. There was no effect ($P = 0.41$) of crop on estimated DM intake. There was also no difference ($P = 0.78$) in DMI between soft and hard dough stage. Utilization of the swathed available forage was lower for soft dough maturity compared to hard dough maturity ($P < 0.05$). Dry matter intake was higher in the current study compared to intakes reported by Rosser et al. (2016) who also observed no differences ($P > 0.05$) in DMI between harvest maturities of whole-plant barley and whole-plant oat (barley LM 5.1 kg/d vs. HD 5.6 kg/d; oat LM 8.7 kg/d vs. HD 8.3 kg/d). Beck et al. (2009) also found no increase in DMI reported as percent of body weight when harvest of wheat forage was delayed from boot to the dough stage. In the current study, cows were allocated 3 d of swathed forage in each field paddock which is important ensuring feed is utilized efficiently. There was a 17% increase in forage utilization between SD (59 %) and HD (76 %) maturities ($P < 0.05$). Determining DMI in a research field setting has challenges associated with the environment and the ability to accurately measure pre- and post-grazing residues (Kelln et al. 2012). McCartney and Vaage et al. (1993), reported a difference in silage intake of different crops, with triticale silage having the lowest DM intake, and attributed the reduced intake of triticale to palatability problems arising from the coarse texture of the forage. However, in the current study, there was no effect of crop or harvest maturity on DMI, with only a numerically greater DMI for triticale compared to oat and barley swathed forage.

Voluntary feed intake in grazing cattle can be limited by physical characteristics of plant species, preferential selection of plant species or plant parts by animals or by extremes in environmental temperature (Ingvartsen and Anderson 2000). Increases in feed intake can better the efficiency of the grazing ruminant (Allison 1985). Feed intake was found to decrease with increases in forage digestibility in high roughage rations fed to dairy cattle (Conrad et al. 1964). Baron et al. (2004) observed that consumption of 11 kg DM cow/d of swathed whole barley exceeded intake levels predicted by NRC (2000) required to provide the energy needs of the pregnant beef cow. Rosser et al. (2013) also looked at the associative effects between NDF and starch and how they impacted overall forage digestibility and hypothesized that harvesting whole-crop barley and oat forages at the hard dough stage would negatively affect forage intake. Between the maturity stages of late milk and ripe there was little effect on total dry matter intake (Rosser et al. 2016). The other concerns with increased maturity beyond the soft dough stage is the potential for reduced DMI, increased sorting, and therefore selecting certain parts of the plant ultimately resulting in a decrease in the digestibility of the fibrous fraction (Linn and Martin 1989). Rosser et al. (2016), observed heifers sorted against NDF and ADF when the forage was harvested at hard dough and ripe stages, but animals did not sort when forages were harvested at the late milk stages. Selectively consuming the more palatable plant parts early on during a multi-day feed allocation and leaving the high-fiber components may cause refused or reduced intakes (Rosser et al. 2016. This sorting can also be due to the amount of forage allocated, which can potentially allow cows to selectively consume specific plant parts on individual days (Kumar et al. 2012). During advancing crop maturity there is an increase in forage fragility which prevented the reduction in DMI (Rosser et al. 2014). However, in this current study, there was no difference in DMI between soft and hard dough treatments this could be due to forage fragility (Uylatt 1983).

An important management aspect of swath grazing is the necessity to limit access to swathed forages. If cows are allowed unlimited access to a field of swaths there is potential to waste much of the forage by lying on it, urinating and defecating on it (Karn et al. 2005). One of the biggest concerns with utilization in a swath grazing system is access to swaths if snow is deep or when swaths become iced over (Karn et al. 2005).

Table 4.3 Effect of maturity and crop type on DMI (kg/d) and forage utilization (%) over 2 yr.										
	Maturity			Crop				*P*-value		
Item[1]	Soft dough	Hard dough	SEM	Oat	Barley	Triticale	SEM	m	c	m*c
DMI, kg/d	12.8	13.2	0.99	11.8	13.1	14.0	1.19	0.78	0.41	0.78
DMI, % BW	2.0	2.0	0.14	1.8	2.0	2.1	0.17	0.76	0.30	0.81
Available forage, kg/ha	3,417b	4,583a	414.5	4,417a	3,333b	425.0a	438.8	**<0.05**	**<0.05**	0.39
Residual Forage, kg/ha	1,361a	1,111b	137.8	1,333ab	1,000b	1,375a	149.5	**<0.05**	**<0.05**	0.32
Forage utilization, %	59b	76a	2.96	65	69	67	3.63	**<0.05**	0.71	0.16

[1]DMI= dry matter intake.

m = maturity effect; c = crop effect; m*c = maturity by crop interaction effect.

a-b Means with different letters in the same row are significantly different (*P* < 0.05).

SEM = standard error mean.

4.3.4 Cow performance

Table 4.4 shows cow performance, adjusted for conceptus weight, when grazing either oat, barley, or triticale cut at differing maturity stages over 2 years. The overall objective for managing the dry, gestating beef cows was to maintain body weight throughout the grazing period. There was no difference (P = 0.60) in cow BCS change among the treatments, with cows able to maintain a satisfactory BCS score of 2.5 throughout the entire grazing trial period. There was a difference (P = 0.05) in rib fat change (mm), with a greater positive change (maturity × crop, P = 0.05) observed for cows managed in the HD oat system (0.78 mm), compared to cows managed in barley (no change) and triticale (0.05 mm) systems harvested at hard dough stage treatment (0.00 mm). There was an interaction observed in final BW (P < 0.05; Figure 4.6), where cattle in the hard dough oat system had the highest final BW and hard dough triticale cattle had the lowest. There was no effect of maturity or crop observed for initial BW, final BW, and rump fat change for cows across all treatments. There was a tendency observed for ADG (P = 0.06) and crop effect, where cattle in the barley systems had the highest ADG and cattle in the triticale systems had the lowest. Krause et al. (2013) reported that measurements of live BW changes, body fat thickness and BCS are adequate indicators for comparing the effect of wintering feeding systems.

In a study where swath grazing oat was compared to grazing stockpiled perennial grass in central Alberta, cows lost weight on the oat swath grazing system compared to stockpiled grass (Baron et al. 2016). However, a 5-yr study conducted at Brandon, Manitoba compared weight gains of cattle grazing either stockpiled alfalfa pasture or swath grazed cereals and reported positive weight gains (0.57 and 0.76 kg/d, respectively; Durunna et al. 2015). In a study in southern Alberta, cattle grazing winter wheat and corn gained 0.12 kg/d (Willms et al. 1993). These data highlight that a variety of swath grazing systems are sufficient to maintain cow BCS and further emphasize the need to evaluate animal performance during the grazing period.

There is an increased energy requirement to maintain body weight for cattle winter grazing in a swath grazing system relative to drylot feeding since walking, environmental stress, and foraging may increase requirements by 18 to 21% (McCartney et al. 2004). All cattle in the current study gained weight, however there was a tendency (P = 0.06) for greater final BCS change for cows grazing triticale swaths (Table 6.4). A study conducted by Jose et al. (2020), comparing cows grazing swathed barley in field paddocks to barley hay fed in drylot, reported that cows grazing barley swath had negative body weight change of -4.9 kg over a 78 d grazing period. The potential reason for BW loss for cows in the swath grazing system could be attributed to cold temperatures and feed accessibility from snow depth (Kelln et al. 2011). Heavy snowfall can reduce accessibility and make it difficult for cattle to find forage and beneath the snow (Kelln et al. 2011). Baron et al. (2014), also speculated that cows grazing on barley swaths had to expend more energy foraging and grazing compared to drylot systems, the extra energy needed from a combination of snow depth, smaller swath size and smaller herd size to share the work of accessing forage. There is also the possibility of cows sorting for seed heads of the plant in a swath grazing system (Rosser et al. 2017), which can potentially predispose them to a lower ruminal pH, which can have negative effects on forage digestibility and intake (Plaizier et al. 2012).

Lowman et al. (1976), described the Scottish BCS score ranging from 1 to 5, where 1 is emaciated and 5 is obese. The current industry recommendation for optimum BCS for mature beef cows in relation to acceptable reproductive performance in the fall is a BCS of 3.0, and 2.5 prior to calving (Beef Cattle Research Council 2018). Based on the recommended BCS for cows post-wean and pre-calving, there should be no negative effects on beef cow reproductive performance when managed in swath grazing systems and crops harvested either soft or hard dough as shown in this study. Baron et al. (2014), also reported cows had a reduced final backfat thickness of -3.0 mm when grazing swathed triticale, and cows grazing swathed barley had a -3.6 mm loss. In the current study, the backfat was not measured but the subcutaneous fat was measured at the mid-rib and the thurl or rump regions (Domecq et al. 1995). There was a crop effect ($P < 0.05$) on rib fat change for cows grazing barley and oat systems, where cows on oat swaths had greater rib fat change compared to cows on barley swaths, 0.49 vs 0.04 mm, respectively (Table 4.4).

Overall, cattle managed in all three annual cereal swath grazing systems harvested at differing maturities, maintained both BW and body condition. This would suggest that grazing graze these cereal crops harvested at a hard dough stage to maximize yield, will not negatively impact overall cattle performance.

Table 4.4 Effect of maturity and crop type on cow performance over 2 yr.

	Maturity			Crop				*P*-value		
Item	Soft dough	Hard dough	SEM	Oat	Barley	Triticale	SEM	m[1]	c	m*c
Body weight, kg										
Initial	620.9	619.8	20.6	621.8	621.4	617.9	20.6	0.52	0.19	0.11
Final	659.5	662.9	5.41	669.3	658.5	655.8	6.11	0.56	0.15	**<0.05**
Change	38.1	41.97	24.5	46.99	37.2	37.0	24.6	0.48	0.31	0.10
ADG, kg/d	0.57	0.48	0.28	0.56	0.65	0.38	0.28	0.32	**0.06**	0.77
BCS[2]										
Initial	2.62	2.62	0.07	2.58	2.64	2.64	0.07	1.00	0.27	0.84
Final	2.55	2.60	0.04	2.60	2.56	2.52	0.04	0.12	**0.07**	0.85
Change	-0.07	-0.02	0.04	0.03	-0.05	-0.10	0.04	0.23	**0.06**	0.60
Rib fat, mm										
Initial	3.83	3.80	0.44	3.80	3.78	3.86	0.44	0.79	0.90	0.45
Final	4.01	4.07	0.23	4.29	3.81	4.01	0.24	0.76	0.15	0.25
Change	0.18	0.28	0.23	0.49a	0.04b	0.15ab	0.24	0.45	**<0.05**	0.05
Rump fat, mm										
Initial	4.22	4.37	0.42	4.29	4.36	4.23	0.43	0.28	0.71	0.48
Final	4.26	4.40	0.37	4.14	4.49	4.36	0.40	0.65	0.65	0.43
Change	0.04	0.01	0.18	-0.15	0.10	0.14	0.23	0.92	0.63	0.41

[1]m = maturity effect; c = crop effect; m*c = maturity by crop interaction effect.

[2]BCS: 1 = emaciated and 5 = obese (Lowman et al. 1976).

a-b Means with different letters in the same row are significantly different ($P < 0.05$).

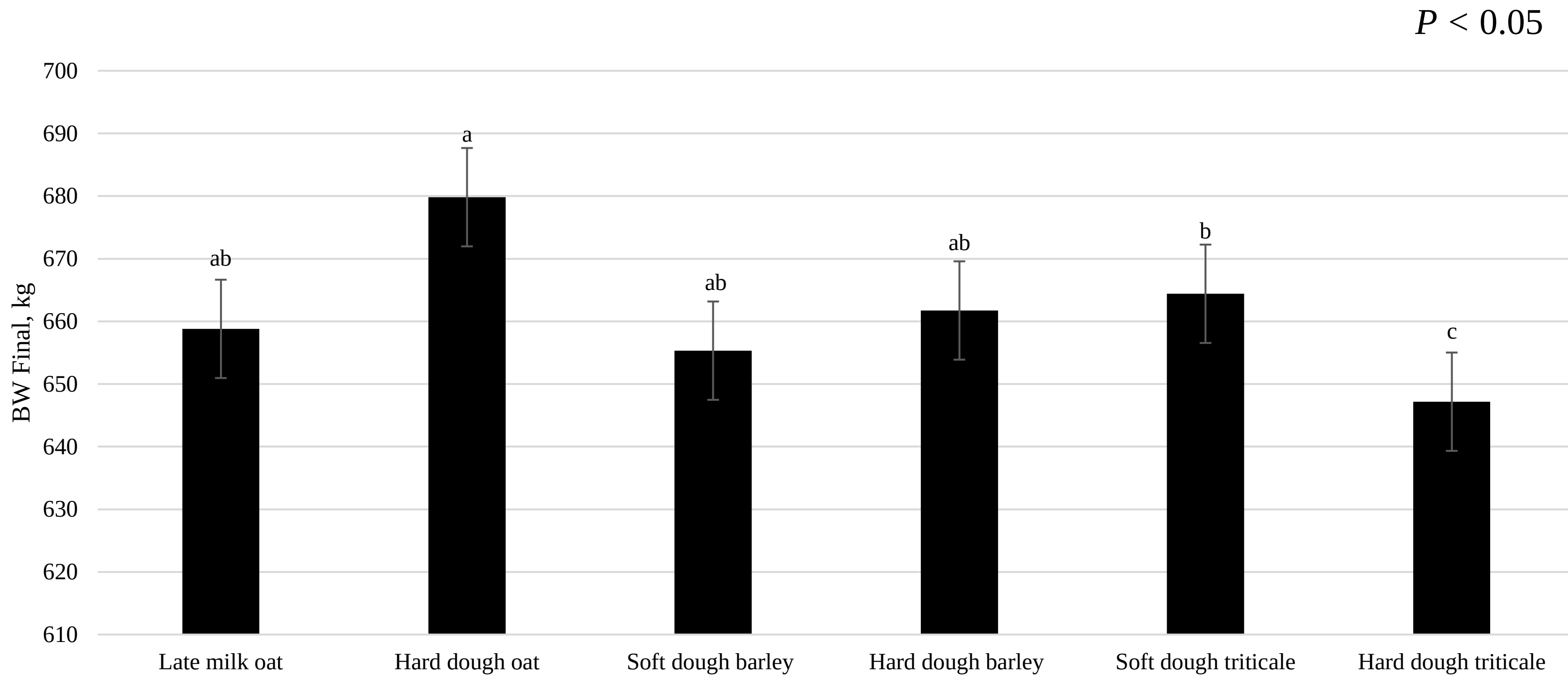

Figure 4.6 Effect of maturity by crop interaction on BW final, kg over 2 yr. Vertical bars within treatment with different letters differ ($P < 0.05$).

4.3.5 Animal unit month (AUM) per ha

Table 4.5 shows the effect of stage of maturity at harvest on calculated animal unit month (AUM) per ha over 2 yr. There was a difference of AUM per hectare observed as crops advanced in maturity from soft to hard dough (Table 4.5). Triticale and oat had the greatest and barley had the least AUM per hectare. When comparing number of grazing days an additional 17 d of grazing was achieved by the crop treatments swathed at hard dough compared to soft dough stage. Triticale had the greatest number of grazing days and barley the least, with 94 vs. 59 d, respectively. For ease of comparison, the grazing days were standardized into animal unit month (AUM) and accounted for paddock size in ha, with each swath graze system calculated on a per paddock basis. One animal unit was corrected to the equivalent of a 454 kg cow and the amount of dry matter forage required by one animal unit for one month (Society for Range Management Assessment and Monitoring Committee, 2017). Carrying capacity of a crop in an extended grazing system is important because it can influence daily feeding costs (Baron et al. 2006). In the study conducted by Baron et al. (2006), carrying capacity was a function of yield, feed intake (daily), and overall forage utilization. In the current study, HD oat and HD triticale yielded the greatest crop biomass and as a result these systems had the greatest total grazing days in the field. Of note, McCartney and Vaage (1993) suggested that there was no advantage to producing triticale silage as cattle feed in comparison to oat or barley silage. However, the extended number of grazing days achieved by the triticale crop in the current study (although grazed as whole plant) suggests there may be an economic benefit to growing triticale for livestock feed in western Canada.

Table 4.5 Effect of maturity and crop type on AUM/ha and grazing days over 2 yr.

Item[1]	Maturity		SEM	Crop			SEM	*P*-value		
	Soft dough	Hard dough		Oat	Barley	Triticale		m[2]	c	m*c
AUM/ha	9.15b	11.5a	0.84	12.0a	7.55b	11.4a	0.91	**<0.05**	**<0.05**	0.12
Grazing days	70b	87a	7.15	81b	59c	94a	7.37	**<0.05**	<0.07	0.07

[1]AUM/ha = animal unit month per hectare (adjusted for cow weight and paddock size).

[2]m = maturity effect; c = crop effect; m*c = maturity by crop interaction effect.

a-b Means with different letters in the same row are significantly different ($P < 0.05$).

SEM = standard error mean.

4.3.6 Economic analysis

The economic analysis associated with each swath grazing system included the cost of feed for the cows plus the cost and provide shelter to the cows (Tables 4.6 and 4.7). Feed costs included forage (swaths), mineral and salt, while costs for feeding and shelter included bedding, labour, machinery (including fuel use), and infrastructure depreciation. These costs were calculated on a cost per cow per day basis ($/cow/d) for each treatment.

The cost of forage (swaths) for each treatment was based on actual and published costs to seed and swath each crop, actual dry matter yields, swath weights and swath lengths allocated (as per feeding records). Mineral was priced at $31.95/25 kg bag ($1.28/kg and salt $5.50/block) and bedding straw was valued at $0.04/kg. Time estimated to allocate new swath, check cows and provide bedding were determined through research staff consultation. Labour was valued at $20.00/hr which is in line with the hourly wage rate for agriculture employees (StatsCan Table 14-10-0306-01). Equipment costs for tractor ($56.71/hr), bale processor ($15.00/hr) and truck ($30.00/hr) were based on suggested rental rates published in the *Farm Machinery Custom and Rental Rate Guide* published by the Saskatchewan Ministry of Agriculture (SK Agriculture, 2010, 2016-17).

The cost to grow and swath the crops averaged $439/ha ($424, $437, and $458/ha for oat, barley, and triticale, respectively; Tables 4.6 and 4.7). Different swathing dates (stages of maturity) had no impact on the cost to grow the crop, but the delayed cutting resulted in increased DM yield of the swath which impact the price per kilogram of dry matter.

Table 4.6 shows the effect stage of maturity at harvest and crop type on field feeding costs over 2 years. Field feeding costs included the cost of the feed associated with each of the treatments, labour, equipment and depreciation. Equipment and labour costs were derived from feeding records which tracked each occurrence (and amount) for swath allocation (number of feet of swath), straw bedding (portion of bale), windbreak moves and mineral provision (kg of mineral). A depreciation cost was also included to account for the infrastructure investment required in an extensive system, portable windbreaks, electric fence energizer, battery, solar panel, ground rods, posts, insulators, rebar, high tensile wire, gate handle and water troughs. The estimated value of the infrastructure for the entire study site was $3300 with an expected life of 15 years. Some of the infrastructure was shared across treatments and replicates resulting in annual depreciation of $87 which was divided by the number of cows per replicate and the number of days field feeding. To determine the total cost of swaths the total kg of feed consumed (DMI) was multiplied by the price per kg of dry matter forage. The total field feeding costs included the cost of the swaths, mineral/salt, bedding, machinery, labour and infrastructure depreciation. There were no differences observed between swath grazing systems for total field feeding costs due to crop type ($P = 0.24$) or maturity at harvest ($P = 0.67$). The earlier stages of maturity for oat (late milk) and triticale (soft dough) had numerically lower total field feeding cost compared to barley (Table 4.6). The higher cost for grazing soft dough barley crop could be associated with the fact that the cattle were grazing in the field for the least amount of time (51 d), in comparison to triticale or oat systems.

Table 4.6 Effect of maturity and crop type on total field feeding costs ($/cow/d) over 2 yr.

	Maturity			Crop				*P*-value		
Item	Soft	Hard	SEM	Oat	Barley	Triticale	SEM	m[1]	c	m*c
Swath	0.96	0.94	0.22	1.02	1.00	0.84	0.23	0.87	0.39	0.26
Mineral and salt	0.08	0.09	0.02	0.08	0.09	0.09	0.02	0.24	0.17	0.35
Bedding	0.09	0.09	0.03	0.10	0.08	0.10	0.03	0.51	**0.06**	0.21
Machinery (incl. fuel)	0.08	0.08	0.02	0.08	0.08	0.08	0.02	0.15	**0.08**	**0.08**
Labour	0.13	0.12	0.01	0.13ab	0.14a	0.11b	0.01	0.48	**<0.05**	0.21
Infrastructure	0.14a	0.11b	0.01	0.11b	0.15a	0.10b	0.01	**<0.05**	**<0.05**	0.13
Total field feeding costs	1.47	1.42	0.25	1.50	1.53	1.30	0.26	0.67	0.24	0.25

[1]m = maturity effect; c = crop effect; m*c = maturity by crop interaction effect.

[a-b]Means with different letters in the same row are significantly different ($P < 0.05$).

SEM = Standard error mean.

Table 4.7 shows the effect of stage of maturity at harvest and crop type on drylot costs over 2 yr. As cattle finished swath grazing, they remained in their replicate groups and were placed on feed in a drylot setting until all treatments were finished swath grazing in field paddocks. The costs of manure removal and hay were included in drylot costs along with, mineral/salt, bedding, machinery, labour and infrastructure depreciation. Differences were observed between crop type ($P < 0.05$), where barley accumulated drylot costs of $2.46/cow/d, compared to triticale having the lowest drylot cost of $0.63/cow per day. This was due to the cows managed in the triticale swath grazing system remaining in the field longer compared to either barley soft dough or hard dough treatments. Soft dough barley had the highest cost per head per day ($2.52). There was a tendency for the earlier stages of maturity having higher drylot feeding costs in comparison to later stages of maturity, due also to the earlier swathed treatments provide fewer field grazing days.

Table 4.7 Effect of maturity and crop type on total drylot feeding costs ($/cow/d) over 2 yr.

	Maturity			Crop				*P*-value		
Item	Soft	Hard	SEM	Oat	Barley	Triticale	SEM	m[1]	c	m*c
Hay	1.41	0.85	0.24	1.49a	1.48a	0.42b	0.28	0.10	**<0.05**	0.78
Mineral & Salt	0.04	0.05	0.02	0.08a	0.05ab	0.01b	0.02	0.80	**<0.05**	0.46
Bedding	0.03	0.02	0.01	0.01a	0.06b	0.01b	0.02	0.48	**<0.05**	0.93
Machinery (incl. fuel)	0.29	0.19	0.04	0.29a	0.33a	0.09b	0.05	0.12	**<0.05**	0.58
Labour	0.10	0.07	0.02	0.10a	0.12a	0.03b	0.02	0.13	**<0.05**	0.60
Infrastructure	0.18a	0.11b	0.02	0.17a	0.22a	0.06b	0.03	**<0.05**	**<0.05**	0.24
Manure Removal	0.08a	0.05b	0.01	0.08a	0.10a	0.03b	0.01	**<0.05**	**<0.05**	0.24
Total drylot feeding	2.01	1.40	0.33	2.03ab	2.45a	0.63b	0.40	0.20	**<0.05**	0.60

[1]m = maturity effect; c = crop effect; m*c = maturity by crop interaction effect.
[a-b]Means with different letters in the same row are significantly different ($P < 0.05$).
SEM = Standard error mean.

Finally, Table 4.8 reports the overall effect of different stages of maturity at harvest and crop type on total production costs, by combining the costs from the extensive field feeding and drylot feeding (when incurred). Although there was no crop × stage of maturity interaction effect (P = 0.24; Table 4.8), our calculations show that hard dough triticale had the lowest total production cost ($1.24/cow/d) and late milk oat had the highest ($1.96/hd/d). However, there was an effect of crop ($P < 0.05$) and stage of maturity ($P < 0.05$) on total production costs when comparing the three cereal crops. There was also a difference for systems that were harvested at late stages of maturity had a decreased total production cost ($0.28/hd/d) in comparison to crops harvested at earlier stages of maturity. Overall feed costs were reduced substantially by managing beef cows in a swath grazing system in comparison to a drylot system, reduced costs for labor and equipment usage allowed for decreased cost of production combined with a total reduction of feed costs. A study conducted by McCartney et al. (2004) supports the current study results where total system costs for cows grazing swathed whole plant barley were 46% lower than cows fed *ad libitum* straw and barley silage ($0.84 and $1.54/cow/d, respectively). Previously it has been reported that cost for swath grazing oat was $1.06/hd/d (Baron et al. 2016) and swath grazing triticale and barley cost $0.78/hd/d and $1.24/hd/d, respectively (Baron et al. 2014).

Table 4.8 Effect of maturity and crop type on total production costs ($/cow/d) over 2 yr.

	Maturity			Crop				*P*-value		
Item	Soft dough	Hard	SEM	Oat	Barley	Triticale	SEM	m[1]	c	m*c
Total Production	1.80a	1.52b	0.19	1.68ab	1.92a	1.36b	0.20	**<0.05**	**<0.05**	0.24

[1]m = maturity effect; c = crop effect; m*c = maturity by crop interaction effect.

[a-b]Means with different letters in the same row are significantly different ($P < 0.05$).

SEM = Standard error mean.

Extensive field feeding systems such as swath grazing are a viable economic alternative in comparison to drylot systems. Growing annual cereals to use for extending the grazing season by winter swath grazing can have one of the biggest impacts in lowering winter feed costs (McCartney et al. 2004). McCartney et al. (2004) noted there was further savings in yardage costs of $0.29 to $0.52/hd/d when swath grazing was utilized compared to baled feed and silage systems (McCartney et al. 2004). Johnston (2000) reported that the cost per head per day for an oat-fall rye mixture and an oat-winter triticale mixture was ($1.48/hd/d and $1.51/hd/d, respectively). With winter feed input costs being the largest single expense for maintaining a cow, refining practices to increase the length of time cattle can graze in extensive systems is valuable to cow-calf producers.

4.4 Summary

Swath grazing is a viable winter-feeding strategy to extend the grazing season and reduce overall winter-feeding costs. Heavy snowfall and cold temperatures throughout the winter may impact cow performance in swath grazing systems and must be managed accordingly (Kelln et al. 2011). Managing annual cereals in swath grazing systems for maximum utilization and forage quality is of utmost importance to ensure that swath grazing remains a cost-effective strategy for producers. Managing crop stage of maturity at time of harvest is another aspect that may be easily changed to ensure adequate forage biomass and quality to maximize system potential when swath grazing. This study suggests that harvesting cereal crops intended for swath grazing can be delayed from the late milk/soft dough stage to the hard dough stage to maximize forage yield and nutrient composition without affecting overall cow performance. As well, swath grazing effectively extends the grazing season and substantially reduces the total production costs.

5.0 GENERAL DISCUSSION AND CONCLUSIONS

Cow-calf producers in western Canada continue to strive to utilize cost effective grazing strategies that will ultimately affect the overall profitability of their operation. Feeding cattle in the traditional dry-lot scenario has been shown to be a costly option to winter beef cows. Methods that extend the grazing season, utilizing annual cereals in a swath grazing system, have substantial economic and environmental benefits. Swath grazing systems that are managed well, can reduce labour, forage harvest, forage transportation, and manure handling costs. However, there are a number of variables including water availability, snow conditions, provision of shelter, and forage use by wildlife that can affect the overall success. Also, a swath grazing system must provide the necessary nutrients to meet nutrient requirements of pregnant cows.

According to the 2017 western Canadian Cow-Calf Survey, swath grazing is a grazing practice that is utilized by 17.5% of respondents. Annual cereals such as barley, oat, and triticale can provide acceptable biomass and nutritive value to meet beef cow nutrient requirements. The traditional recommendation for stage of maturity at harvest has been to swath the crop somewhere between late milk and soft dough stages, depending on the crop grown. These recommendations; however, have been derived for silage production and there has been limited research to evaluate if the recommendations are appropriate for a swath grazing system (Rosser et al. 2013; Rosser et al. 2016; Rosser et al. 2017). In the current study, the objectives were to evaluate the effect of stage of maturity at harvest on crop yield, nutritive value, estimated DMI and utilization, cow performance, AUM per hectare and estimated system costs. Delaying maturity to hard dough increases carry capacity, reduces costs, and does not negatively affect cow performance. In addition, triticale clearly proved to further reduce those costs by increasing carrying capacity without impacting cow performance.

Weather factors such as temperature and rainfall can affect overall crop yield. In the current study, across all crops, soft dough stage of maturity yield was 7778 kg/ha (DM) and hard dough stage of maturity yield was 9561 kg/ha (DM), with a 1783 kg/ha (DM) or 23% difference, supporting the observation of an increase in yield as the crop matures. Nutrient composition was different between soft dough and hard dough, with increased DM, TDN, and starch, and decreased CP, ADF, and NDF for cereals harvested at hard dough stage. Nutrient requirements for cows in mid to late gestation would be met, and cows would be able to maintain body condition and meet protein and energy requirements. However, this shift in nutrient composition will rely heavily on the starch being digestible as it is likely that NDF digestibility decreases with advancing maturity.

Dry matter intake data did not differ for stage of maturity at harvest and crop type, ranging from 11.8 to 14 kg / day. Similar intakes have been previously reported under field-grazing systems for barley and oat. The lack of difference for DMI is important and emphasizes that changes in yield will have a greater contributing effect to support carrying capacity than differences in feed intake and changes in chemical composition of the swath.

A difference in swath utilization was observed between crops harvested at soft dough and hard dough stages, with a 17% increase in utilization for hard dough stage crops compared to soft dough harvested crops. This seems to differ from anecdotal concerns expressed by producers and livestock specialists suggesting that more advanced stages of maturity may increase residual forage biomass. In fact, this research highlighted that residual biomass is lower with HD than when harvested at earlier maturities. Corresponding to the greater forage yield and lower residual biomass, the AUM/ha differed by maturity at harvest and crop type. The HD systems produced 11.5 AUM/ha while the currently recommended stages provided 9.15 AUM/ha. Ultimately, cattle in the HD systems were able to remain in the field for longer grazing periods due to the increase in yield between the two. It is important to recognize that delaying the maturity at harvest does not alter forage production cost and is an easily adoptable method to increase carrying capacity on a given parcel of land. In addition, triticale (11 AUM/ha) and oat (12 AUM/ha) systems outperformed the barley (7.5 AUM/ha) system for carrying capacity.

Environmental factors such as snow accumulation, wind chill, temperature, and pre-existing body condition score can impact the ability of cows to perform in a swath grazing system. During cold stress, it is important to ensure there is energy density, water, and wind protection in order for cows to maintain body condition score during winter grazing. In the current study, all cows maintained an adequate body condition of 2.5 from the start of grazing till the end. A body condition score of 2.5 is an adequate number for a mature dry-pregnant beef cow in mid to late gestation prior to calving.

In summary, the industry recommendation for maturity at time of harvest can be re-evaluated based on results from the current study. There was an increase in yield, which ultimately led to more grazing days in the field and reduced days in a drylot system. There were differences in nutrient composition observed, but the effects did not negatively impact the overall cow performance and continued to meet or exceed nutrient requirements for a dry gestating beef cow in mid to late gestation. Overall cost per head per day was reduced, moving cattle from a soft dough system to a hard dough system, which is encouraging for the producer's bottom line. Animal management remains an important aspect of any extensive grazing system to ensure adequate forage utilization and overall cattle performance. Swath grazing is an excellent winter-feeding strategy to extend the grazing season and reduce overall feed costs. Increasing the maturity at harvest from soft dough to hard dough for barley, oat and triticale was able to extend the grazing season for the dry gestating beef cows without effecting the overall forage quality of the crop.

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APPENDICES

APPENDIX A

Table A.1 Summary of seeding dates for both years.

	Barley		Triticale		Oat	
Item	SD	HD	SD	HD	LM	HD
Seeding Date						
2015-2016 (Yr 1)[1]	June 5, 2015	June 5, 2015	June 5, 2015	June 5, 2015	June 5, 2015	June 5, 2015
2016-2017 (Yr 2)[1]	June 9, 2016	June 9, 2016	June 9, 2016	June 9, 2016	June 9, 2016	June 9, 2016

[1]All crops were seeded at a rate of 2 bu/acre.

Table A.2 Summary of swathing dates for both years.

	Barley		Triticale		Oat	
Item	SD	HD	SD	HD	LM	HD
Swathing Date						
2015-2016 (Yr 1)[1]	August 13, 2015	September 29, 2015 (north) August 26, 2015 (south)	August 26, 2015	September 19, 2015 (north) September 11, 2015 (south)	August 14, 2015	September 29, 2015 (north) September 11, 2015 (south)
2016-2017 (Yr 2)	August 18, 2016	September 1, 2016	September 3, 2016	September 15, 2016	August 18, 2016	September 15, 2016

[1]Spring of 2015 – the northern portion of the field had grass/alfalfa prior to planting while the southern portion had barley stubble. It took the north portion of the field longer to get to the proper SOM in comparison to the south, this is the reason for two swathing dates on the HD replicates in yr 1.

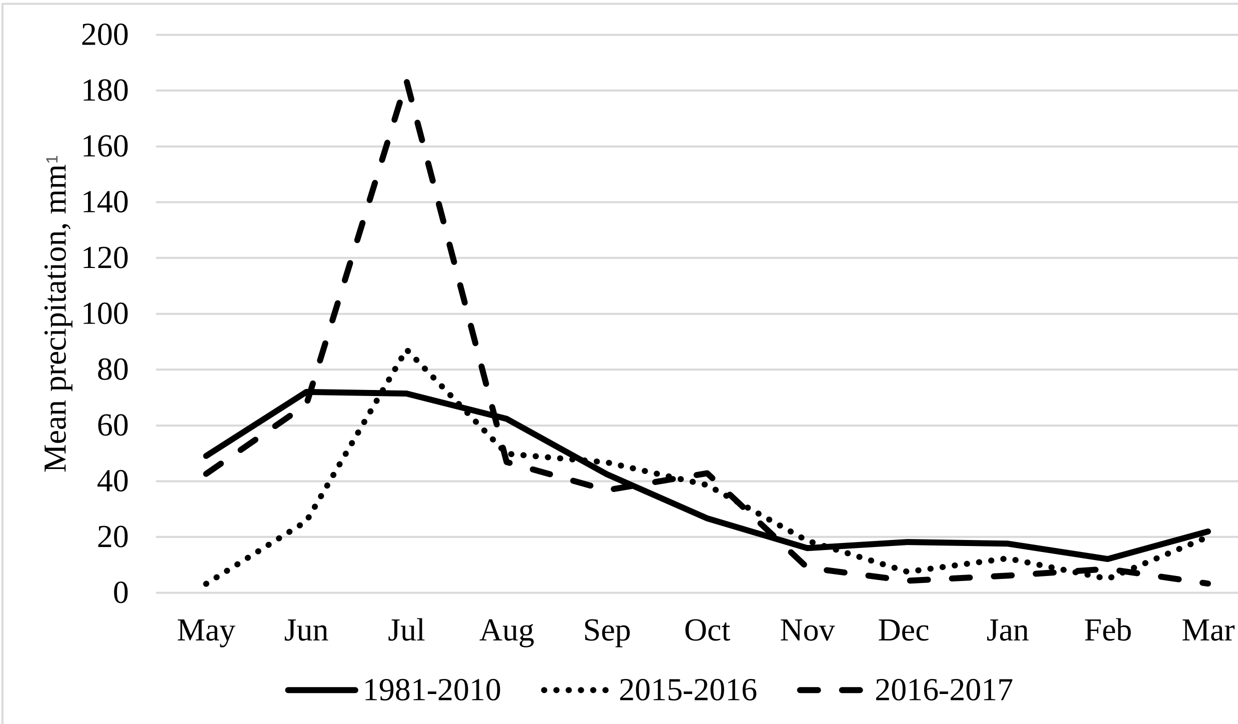

Figure B.1 Monthly precipitation for yr 1 (2015-2016), yr 2 (2016-2017) and the 30 yr average (1985-2015).

[1]Preciptation data from Environment Canada's climate data (www.climate.weatheroffice.gc.ca) for Leroy, Saskatchewan.

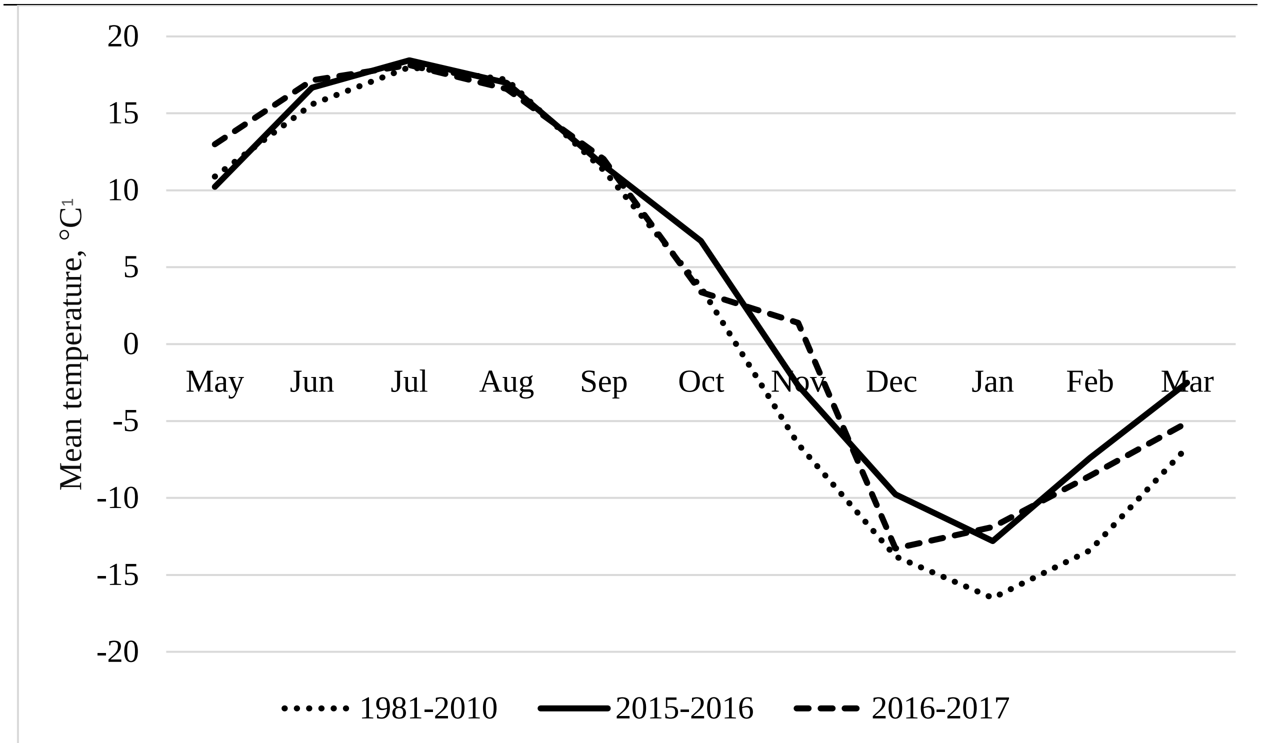

Figure B.2 Average monthly temperature for yr 1 (2015-2016), yr 2 (2016-2017) and the 30 yr average (1985-2015).

[1]Temperature data from Environment Canada's climate data (www.climate.weatheroffice.ec.gc.ca) for Leroy, Saskatchewan.