EFFECT OF THE MATURITY AT HARVEST OF WHOLE-CROP BARLEY AND OAT ON DRY MATTER INTAKE, FORAGE SELECTION, AND DIGESTIBILITY WHEN FED TO BEEF CATTLE

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By:

Christine Lynn Rosser

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ABSTRACT

The objective of this research was to determine the effect of stage of maturity at the time of harvest for barley and oat whole-crop forage on feed intake, ruminal fermentation and digestibility, and the impact forage allocation has on intake and ruminal fermentation. In the first 2 studies, whole-crop barley (Study 1; c.v. CDC Cowboy) and oat (Study 2; c.v. CDC Weaver) forage were harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages and offered ad libitum to ruminally cannulated heifers. Diets were supplemented in an attempt to balance crude protein (CP) among treatments. Heifer performance, dry matter intake (DMI), ruminal fermentation parameters, ruminal digestibility, and total tract digestibility were evaluated. In Study 3, whole-crop oat (c.v. CDC Weaver) forage harvested at HD and RP was offered ad libitum to ruminally cannulated heifers in either daily (1-D) or 3 d (3-D) allocations. Dry matter intake and ruminal fermentation parameters were measured. In Study 1, harvest maturity of barley did not affect DMI ($P = 0.70$; average 5.4 kg/d) or average daily gain (ADG; $P = 0.64$). Total tract digestibility was decreased for barley harvested at HD ($P = 0.003$), but harvest maturity did not affect daily digestible energy (DE) intake ($P = 0.52$). Minimum ruminal pH for heifers fed the barley forage was lowest for LM (6.09), intermediate for RP (6.13), and greatest for HD (6.25; $P = 0.016$). Total short chain fatty acid (SCFA) concentrations were not affected by harvest maturity ($P = 0.36$). In Study 2, harvest maturity of whole-crop oat did not affect DMI ($P = 0.26$; average 8.1 kg/d) or ADG ($P = 0.52$). There were no effects of harvest maturity of oat forage on total tract digestibility ($P = 0.78$) or daily DE intake ($P = 0.68$). The minimum ruminal pH from heifers fed oat forage was lowest for HD (5.84; $P = 0.012$), intermediate for RP (5.94) and greatest for LM (5.99). There was no effect of harvest maturity of oat forage on total SCFA concentrations ($P = 0.21$). The quantity of forage allocation (Study 3) had no effect on total or forage DMI over a 3-d duration ($P \geq 0.47$). Throughout the 3-d feeding period, 3-D allocated heifers had a reduction in the area pH was under 5.8 (214.4, 79.5 and 10.9 pH × min/d, for d 1, 2 and 3, respectively; $P = 0.003$). Total SCFA concentrations were not affected by forage allocation or harvest maturity ($P \geq 0.14$), however there was an interaction of forage allocation and day in the feeding cycle ($P = 0.046$). Heifers allocated 1-D had no change

in total SCFA concentration over the 3-d feeding period (averaged 122 m*M*), but 3-D allocation had elevated concentrations on d 1 (138 m*M*) intermediate on d 2 (135 m*M*) and decreased on d 3 (117 m*M*). These data suggest that harvesting barley and oat at the HD stage improves DM yield without negatively affecting cattle DMI and ADG. These data also suggest that providing 3-d allocations of forage does not affect DMI, but can increase daily fluctuations of ruminal pH and ruminal SCFA concentrations.

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LIST OF ABBREVIATIONS

1-D	daily allocation of forage
3-D	3-d allocation of forage
ADF	acid detergent fiber
ADG	average daily gain
BW	body weight
CP	crude protein
DE	digestible energy
DM	dry matter
DMI	dry matter intake
DOM	digestible organic matter
EDDM	effectively degradable dry matter
FP	fluid phase
GDD	growing degree days. The GDD was calculated by determining the average between the lowest and highest temperature within a day and subtracting 5°C.
GE	gross energy
HD	hard dough
iNDF	indigestible neutral detergent fiber
IVDMD	*in vitro* dry matter digestibility
IVOMD	*in vitro* organic matter digestibility

LM	late milk
LP	large particle
LU	liquefon unit
ME	metabolizable energy
NDF	neutral detergent fiber
NFC	non fiber carbohydrates
OM	organic matter
RP	ripe
SARA	sub-acute ruminal acidosis
SCFA	short chain fatty acids
SEM	standard error of mean
SP	small particle
TDN	total digestible nutrients
TMR	total mixed ration
WSC	water-soluble carbohydrates

1.0 INTRODUCTION

Winter-feeding can account for approximately 60% of the total cost of production for beef producers (Kaliel and Kotowich, 2002). These costs can potentially be reduced through the use of extensive winter-feeding systems such as swath grazing. Volesky et al. (2002) and McCartney et al. (2004) both found that through the use of swath grazing they reduced winter-feeding costs by approximately 50% compared to a conventional dry-lot feeding system. The majority of the cost reduction was due to reduced costs associated with feed (Volesky et al., 2002), labor, and manure removal (McCartney et al., 2004).

When harvesting forage for winter-feeding systems the goal should be to optimize forage yield and quality (Baron et al., 1992). It is currently recommended that whole-crop barley be harvested at the soft dough stage (Acosta et al., 1991; Khorasani et al., 1997) and whole-crop oat at the late milk stage (Kaulbars and King, 2004). These recommendations are based upon the recommendations for ensiling, which could result in a loss in potential nutrient yield when the forage is preserved by drying. For example, with advancing maturity there is an increase in DM and starch yield (Baron et al., 1992; Rosser et al., 2013). Additionally, concerns related to reductions in palatability and digestibility (Kilcher and Troelsen, 1973) of the whole-crop forage cut at advanced stages of maturity have limited investigation into the optimal maturity at harvest for dry-preserved forages. However, both Baron et al. (1992) and Rosser et al. (2013) found that allowing whole-crop cereal forage to advance in maturity did not result in a decrease in *in vitro* organic matter digestibility (IVOMD), or effectively degradable dry matter (EDDM), respectively. While those studies provided initial support that maturity at harvest could be delayed without negatively affecting digestibility, those studies utilized *in vitro* and *in situ* measurements, which have the potential to overestimate the digestibility of the forage with advancing maturity.

As plants mature there are many changes to the chemical composition of the plant that can have a negative impact on digestibility. It has been shown that with advancing maturity annual cereal will generally have an increase in lignin concentrations (Kilcher and Troelsen, 1973; Jung and Allen, 1995; Khorasani et al., 1997). This fiber component is considered to be indigestible by rumen microbes, and can actually impede the digestibility of other forage fractions (Jung and

Allen, 1995). The negative associative effects of starch and neutral detergent fiber (NDF) can also cause a reduction in forage digestibility. With advancing maturity of annual cereal forages there is an increase in starch content (Rosser et al., 2013) that may, if available, potentially lead to a decrease in ruminal pH. This decrease in ruminal pH can cause a shift in the microbial population in the rumen and a subsequent decrease in ruminal digestibility of NDF (Calsamiglia et al. 2002).

To reduce costs associated with labor and feed wastage it has been suggested that for swath grazing systems forage should be provided to be sufficient for 3-d allocations (Saskatchewan Ministry of Agricultrue, 2009c). Providing larger allocations of forage could enable the cows to sort through the forage for more palatable portions, such as grain and leaves the first day forage is provided. DeVries et al. (2005) found that providing a total mixed ration (TMR) once daily resulted in an increase in NDF content of refusals, compared to providing the TMR twice daily indicating that the amount of forage allocated may influence the sorting behaviour. Whole-crop annual forage that is harvested at more advanced maturities will have an increase in grain content in the total forage (Baron et al., 1992). Increasing grain content in the forage could potentially result in increased grain consumption the first day forage is provided, which could reduce ruminal pH and fiber digestion (Calsamiglia et al., 2002) on the first day of allocation.

Given the potential to increase forage yield by allowing plants to advance in maturity (Baron et al., 1992; Rosser et al., 2013) and a lack of studies evaluating whether stage of maturity will affect ruminal fermentation, the primary goal of the research conducted was to evaluate the effect of stage of maturity at harvest of dry-preserved barley and oat forage for beef cattle. In addition, a study was conducted to determine whether forage maturity and feeding frequency would increase the risk for altered DMI and ruminal fermentation.

2.0 LITERATURE REVIEW

Dry-preserved whole-crop barley and oat forage are often used in cow-calf production systems as a source of feed during fall and winter. Obtaining optimal nutrient yield and digestibility should result in reduced forage production costs and maximal forage utilization. However, there are many variables that affect nutrient yield and digestibility of dry preserved oat and barley whole-crop forage. For example, the environmental conditions during the growing season, as well as during harvest can affect forage yield and quality. While producers have limited ability to control the environmental conditions, several management factors can be altered to positively affect forage yield and digestibility. In particular, the growing potential of barley and oat forage is impacted by timing of seeding (Baron et al., 2012) and seeding rate (May et al., 2009). Conditions during harvest, including harvest maturity, method of harvest and the preservation method can all impact nutrient yield and digestibility. Finally, it should be acknowledged that altering the growing or harvest conditions can also result in differences in animal performance, forage intake, sorting behavior and utilization of the resulting forage. The objective of this literature review is to determine the effects of various management practices on the yield, quality and digestibility of whole-crop barley and oat forage.

2.1 Agronomic practices to enhance forage yield

2.1.1 Timing of seeding

A prominent recommended management practice for the production of forage used in a swath grazing system is to delay the timing of seeding. The recommendation for delayed seeding in swath grazing systems is largely designed to allow harvest to occur closer to the first frost. When harvest occurs close to the first frost it will reduce the amount of time forage sits in the swath prior to utilization and therefore should reduce potential nutrient loss due to leaching (Aasen et al., 2004). Aasen et al. (2004) determined that IVOMD loss (kg/ha) due to leaching from the end of September to the end of November was as high as 8.2 and 9.5% for barley and oat swaths, respectively. As such, the timing of seeding can have a large impact on nutrient yield and digestibility (Baron et al., 2012). To achieve a harvest in September (when considering growth conditions in western Canada) barley forage would have to be seeded as late as the last week of June (Baron et al., 2006). This practice would significantly alter the growing conditions

compared to seeding in mid-May. Assuming an average growing season, altering the time of seeding can shift the stage of maturity when plants are exposed to greater ambient temperature, moisture availability and photoperiod intensity. A secondary benefit of delaying the seeding date is the potential for improved weed control because most of the weeds emerge prior to seeding (Bullied et al., 2003) implying that seeding may help to control weed survival. However, this relies on significant soil disruption and may not occur as dramatically with zero-till practices.

Though currently recommended, delaying seeding can drastically reduce forage DM yield (Baron et al., 1994; Kibite et al., 2002; May et al., 2007; Baron et al., 2012) with the magnitude dependent on the forage species. The reduction in yield is likely explained by less precipitation and shorter photoperiod during the growing season and greater soil and ambient temperature. Growth of forage with low precipitation decreases plant biomass and increases the proportion of stem relative to the other portions of the plant (Capper, 1998). Baron et al. (2012) seeded oat and barley forage at weekly intervals from mid-May to the end of June, and found that seeding at the end of June instead of mid-May resulted in linear decreases in barley forage yield from approximately 9.5 t/ha to 6.0 t/ha. Contrarily, oat forage yield initially increased by delaying seeding from mid-May to early-June, (approximately 9.0 to 10.0 t/ha) and then decreased with subsequent seeding delay (approximately 8.5 t/ha; Baron et al., 2012). The difference between the effect of delayed seeding on barley and oat forage is likely due to the plants having different responses to temperature and photoperiod. Barley requires less growing degree days (GDD) for maturation to occur compared to oat, which could have been the cause for the linear decrease in forage yield for barley compared to the quadratic response observed for oat (Baron et al., 2012). The reduction in DM yield resulted in a decreased carrying capacity from approximately 1026 to 692 animal unit days (AUD)/ha for mid-May to late-June planting (Baron et al., 2012). This assumes that 1 AUD is equivalent to a 550 kg cow.

In addition to the general reduction in forage yield, delaying the timing of seeding may also alter the nutrient concentration of the forage. May et al. (2009) found that delaying seeding of oat from early June to mid-June could result in a decrease in grain yield from 3.9 to 2.6 t/ha. Baron et al. (2012) found that delaying seeding from early May to mid-June did not affect starch content of barley and oat forage, averaging 13 and 8.5%, respectively. Using the reported yield and starch concentration, starch yield decreased from 1.25 t/ha to 0.78 t/ha for barley, and 0.77

t/ha to 0.72 t/ha for oat when seeding was delayed from early May to mid June (Baron et al., 2012). It has been suggested that the reduction in grain yield with delayed seeding is due to the increased temperature when the plant is flowering (Frey, 1998). Delaying seeding can also result in an increase in DM, OM and CP concentration of forages that are harvested at the same maturity (Chow et al., 2008). Baron et al. (2012) found that the effect of delaying seeding on fiber content of the forage was impacted by crop species. Delaying seeding of barley did not affect NDF or ADF concentrations, however delayed seeding of oat resulted in increased NDF and ADF concentrations (4 and 6 percentage units, respectively; Baron et al., 2012). This suggests that delaying seeding of barley and oat not only decreases forage yield, but can also potentially reduce forage quality as well.

Changing the environment that barley and oat plants are growing in by delaying seeding could also have an impact on digestibility. Fahey and Hussein (1999) found that when the temperature forages are grown under increases, there is an increase in the amount of lignification that occurs, which could reduce digestibility. For each percentage unit that lignin increases in the fiber there is approximately a 4% decrease in DM digestibility (Linn and Martin, 1989). As shown by Capper et al. (1998) decreasing precipitation during the growing season can result in a decreased leaf:stem ratio, which could decrease the digestibility of the forage (Baron et al., 1994). Chow et al. (2008) found that when forages are heading and the temperature is lower, there will be an increase in *in vitro* NDF digestibility. Baron et al. (2012) found that delaying seeding did not affect cell wall digestibility of barley forage, but for oat forage there was an initial decrease in cell wall digestibility when seeding was delayed by 20 d. Delaying seeding has the potential to result in decreased digestibility, but the data appears to be variable, suggesting that it may depend on year and growing conditions, as well as forage type.

This data suggests that seeding at later dates to minimize the amount of nutrient leaching that will occur may not be beneficial for producers. Delaying seeding will result in a decrease in forage yield, especially in the case of barley, and can reduce forage quality and digestibility. An alternative to delaying the seeding date is to harvest the forage at a later maturity stage. This would allow for increased yields, not only due to the date of seeding but also due to advancing maturity (Baron et al., 1992; Rosser et al., 2013).

2.1.2 Seeding rate

Altering seeding rate can impact both forage yield and quality, because it changes the number of plants present, and the competition between the plants. It is currently recommended to seed barley and oat at a rate of approximately 200 to 250 plants/m^2 (Saskatchewan Ministry of Agriculture, 2008; 2010). May et al. (2009) found that when they increased their seeding rate from 250 to 350 plants/m^2 they maximized grain yield. McCartney et al. (2005) found that barley and oat forage yield was maximized when seeding rate was 400 seeds/m^2. This is very similar to the results of May et al. (2009) when seeding rate in McCartney et al. (2005) was corrected for germination and seedling mortality. When seeding rate exceeded 350 plants/m^2 grain yield decreased, which may be partially due to a decrease in the weight of kernels (May et al., 2009). Walton (1975) found that for every kg/ha of seed utilized above 30 kg/ha there was an increase in DM yield of 4.8 kg/ha and 10.3 kg/ha for barley and oat, respectively. Doubling seeding rate from the 'normal' rate of 66 kg/ha to 132 kg/ha resulted in increased DM yield of approximately 490 and 1050 kg/ha for barley and oat, respectively, therefore it was determined that it would only be economical to increase the seeding rate for oat (Walton, 1975). Increasing the seeding rate results in a change in the plant's growth characteristics, which will alter the nutrient concentration of the forage. Walton (1975) found that increasing the seeding rate of barley and oat from 30 to 120 kg/ha resulted in a decrease in fiber concentrations without negatively impacting CP concentrations. Increasing seeding rate results in an increase in the number of plants present, however there is a decrease in the number of heads and kernels per plant (Guitard et al., 1961). This increased leafiness could potentially increase the IVOMD of the forage due to the increased digestibility of leaf compared to stem (Baron et al., 1987). Increasing seeding rate from the recommended 250 to 350 plants/m^2 can result in improvements in forage and grain yield without negatively impacting the nutrient concentrations of the forage, and potentially improves forage digestibility.

2.2 Harvest practices to enhance forage yield

2.2.1 Harvest maturity

The maturity at harvest for barley and oat forage has implications on nutrient yield and digestibility of the forage. As annual cereal forages advance in maturity, there is an increase in

the relative weight of the grain, accounting for approximately 50-55% and 45-50% for barley and oat, respectively, of the total plant biomass (McCartney et al., 2006). Changes in the whole-crop forage composition with advancing maturity, such as an increase in starch and reduction in NDF, can have a significant impact on feeding value of the forage although few studies have investigated the impact of forage maturity for dry-preserved forages. That said, it is argued that advanced stages of maturity may negatively impact forage palatability and intake, and increased lignification of the fiber may decrease digestibility (Kilcher and Troelsen, 1973).

As barley and oat forage mature there is an increase in forage yield and DM concentration, (Meyer et al., 1957; Kilcher and Troelsen, 1973; Bergen et al., 1991; Baron et al., 1992; Rosser et al., 2013). Baron et al. (1992) found that DM yield was maximized at approximately 336 GDD after heading; 48 GDD before full maturity. Along with the increase in DM yield there is also an increase in the amount of grain in the forage (Kilcher and Troelsen, 1973; Baron et al., 1992). Edmisten et al. (1998a) found that grain makes up more than half of the total plant DM when barley and oat forage are harvested at the hard dough stage. Kilcher and Troelsen (1973) found that as oat forage advanced in maturity the energy content in the grain increased, but energy content of leaves and stems both decreased. Due to the increasing grain content Kilcher and Troelsen (1973) found that the energy content of whole oat forage was similar when it was harvested between the milk and ripe stage. Since the oat forage has similar energy content regardless of harvest maturity, delaying harvest could result in increased gross energy yield. However, to obtain the energy that is present within the grain, cattle need to be able to digest the grain in the forage. As the grain component of forages increases there is an increase in IVOMD present within the grain, as well as the whole-crop forage (Kilcher and Troelsen, 1973; Baron et al., 1992) but that is partially due to the fact that the analytical procedure requires the forage to be ground and does not provide insight into whether the grain will be available when not processed. Total tract digestibility of the grain depends on the availability of the grain and it has been shown that, for barley, the pericarp needs to be damaged to be available to the cattle (Beauchemin et al., 1994). Beauchemin et al. (1994) found that whole barley is only 37.8% digestible, compared to 64.8% for barley that was chewed. Mathison (1996) found that feeding whole barley resulted in a 37% reduction in starch total tract digestibility compared to rolled barley. As such, if forage maturity is too advanced there is a potential for a decrease in grain utilization due to limited digestibility, despite marked increases in the whole-plant starch content.

Moreover, risk for loss of kernels may increase with advancing maturity; however, kernel loss is dependent on year and environmental conditions (Baron et al., 1992; Stacey et al., 2006). Collectively these data suggest that the digestible energy content of the forage can vary depending on the availability of the grain within the forage to be digested, as well as the amount of kernel loss that occurred.

Allowing forages to advance in maturity from vegetative stages to fully ripe stages can result in a decrease in protein concentration (Cherney and Marten, 1982). Kilcher and Troelsen (1973) found that allowing oat forage to advance in maturity from early growth to fully ripe decreased the CP concentration from 30 to 8% on a DM basis. The decrease in CP occurred in a linear fashion from the early leaf stage until the milk stage; whereas, CP level was minimally affected thereafter (Kilcher and Troelsen, 1973). Beck et al. (2009) harvested whole-crop wheat forage at the boot and dough stage and also found that CP concentration decreased. In the study of Beck et al. (2009) wheat (*Triticum aestivum* L.) harvested at the boot stage contained 15.2% CP and decreased to 8.9% at the dough stage on a DM basis. Brundage et al. (1979) found that the most severe decrease in CP for whole-crop barley forage grown in Alaska was between the early milk and early dough stage (7.3 to 5.8%, respectively). Moreover, the concentration of CP decreased from 8.2 to 5.1% for whole-crop oat forage harvested at heading and milk stages, respectively, then remained stable as maturity advanced to late dough stage (Brundage et al., 1979). Rosser et al. (2013) also reported that CP concentration of whole-crop barley and oat forage decreased between the late milk and hard dough stage (14.1 to 9.3%, respectively for barley and 13.8 to 10.1% for oat). The CP concentration was then similar between hard dough and ripe stages averaging 9.4 and 9.9% for barley and oat, respectively (Rosser et al., 2013). Allowing whole-crop annual forages to advance in maturity results in decreased CP concentration, which could increase the need to supplement cattle fed this forage, depending on the type of cattle (cows vs. calves), and the physiological state (early gestation vs. late gestation or lactation).

Harvest maturity of whole-crop annual forages appear to have variable effects on the NDF, ADF and lignin concentrations of the forage. Bergen et al. (1991) found that allowing barley and oat forage to advance in maturity from the milk to the dough stage resulted in a reduction in NDF concentration (3 and 11 percentage unit decreases, respectively). A reduction in NDF was also reported by Rosser et al. (2013) where advancing maturity of barley and oat forage from head

elongation to fully ripe resulted in linear decreases in NDF concentration (13.8 and 9.6 percentage units, respectively). Contrarily Edmisten et al. (1998b) found that the NDF concentration of whole-crop barley remained similar between the milk and soft dough stages, then slightly increased between the soft and hard dough stages, whereas NDF concentration of whole-crop oat forage was not affected by maturity. Edmisten et al. (1998b) seeded their barley and oat forage in mid-October, whereas Bergen et al. (1991) and Rosser et al. (2013) seeded their barley and oat forage in the spring which could potentially have resulted in the difference in NDF concentration. Brundage et al. (1979) and Edmisten et al. (1998b) both found no effect of harvest maturity of barley or oat forage on ADF concentration. Bergen et al. (1991) found minimal differences in ADF concentration when barley forage advanced in maturity, however ADF concentration of oat forage decreased by 5.2% when harvested at dough stage instead of milk stage. Even though there were minimal differences in ADF concentration with advancing maturity, there can be increases in the lignin concentration of the forage (Brundage et al., 1979; Edmisten et al., 1998b), which could potentially reduce forage digestibility (Van Soest et al., 1965). The general decrease in NDF and increase in ADF could suggest that harvesting whole-crop barley and oat forage at advanced maturity could reduce DMI if DM digestibility is negatively affected, however more research is required in this area.

There is variability in the observed results of *in vitro* dry matter digestibility (IVDMD) and IVOMD, but some of the variability can be attributed to harvest maturities that were evaluated. As annual cereals advance in maturity there is an increase in the proportion of stem present in the whole plant (Cherney and Marten, 1982; McCartney et al., 2006), but the IVOMD of stems decreases rapidly (Baron et al., 1992). The decrease in IVOMD content of leaves and stems may be counteracted by the increasing grain content in the whole-plant (Baron et al., 1992). Cherney and Marten (1982) found that allowing crops to mature resulted in a decrease in IVOMD, whereas Baron et al. (1992) found that there was no effect on IVOMD with advancing maturity. The difference in IVOMD trends can likely be attributed to the maturities that were compared. For example, Cherney and Marten (1982) evaluated whole-crop barley from flag leaf emergence to 28 d after head emergence whereas; Baron et al. (1992) compared maturity over 7 consecutive weeks after head emergence. Kilcher and Troelsen (1973) found that between the early leaf and ripe stages there was a decrease in IVOMD of the whole oat plant, but when just comparing between the milk and ripe stages, whole plant IVOMD was similar. There is a decrease in

IVDMD as whole-crop barley (Brundage et al., 1979; Edmisten et al., 1998b) and whole-crop oat (Edmisten et al., 1998b) advances in maturity from milk to dough stages. These measures were measured *in vitro,* which may not represent total tract digestibility of the forage. Using *in vitro* measurements does not allow for measurements of DMI, palatability/sorting, passage rate, associative effects of NDF and starch, or the availability of the starch in the kernels.

While numerous studies have used *in vitro* (Kilcher and Troelsen, 1973; Brundage et al., 1979; Baron et al., 1992) or in situ (Rosser et al., 2013) approaches to evaluate the impact of forage maturity on digestibility, there has been minimal research completed evaluating total tract digestibility of whole-crop annual cereals with advancing maturity. Beck et al. (2009) evaluated whole-crop wheat forage at the boot and hard dough stage and found a reduction in DM and NDF digestibility with advancing maturity. However, the majority of the research that has been done looking at the effect of harvest maturity of annual cereals on total tract digestibility has been completed on ensiled forage. Bolsen and Berger (1976) found that the total tract DM digestibility of barley silage decreased at milk stage, compared to boot and dough. They suggested that the increase in DM digestibility between milk and dough stage was due to the increasing grain content. Rustas et al. (2011) found no difference in total tract digestibility of DM or NDF for wheat forage ensiled at milk and dough stage, however saw variable response in NDF total tract digestibility for barley forage ensiled at milk and dough stage depending on location. Both Polan et al. (1968) and Bolsen and Berger (1976) found that NDF digestibility of barley silage decreased with advancing maturity, and attributed the decrease to an increase in lignification. The effect of harvest maturity of annual cereals on total tract digestibility appears to be variable, and needs to be investigated more extensively.

Harvest maturity of whole-crop forage can have an impact on DMI but as indicated above, most research has focused on ensiled forage. One study comparing the impact of dry-preserved whole crop wheat harvested at the boot or hard dough stages reported no difference for DMI when forage was offered at 40% of the total diet (Beck et al., 2009). Data arising from studies that have preserved the forage by ensiling should be interpreted with caution as the ensiling process can result in many changes that can alter the palatability of the forage compared to non-ensiled forage at the same maturity. Bolsen and Berger (1976) found that DMI was decreased when barley silage was harvested at milk stage, compared to silage harvested at either the boot stage,

or dough stage. Rustas et al. (2011) found that DMI was increased when barley was ensiled at dough stage instead of at the milk stage. They suggested that the increased DMI was due to a decrease in NDF concentration in the dough stage silage compared to the milk stage silage. Oltgen and Bolsen (1980) determined that when whole-plant DM was increased from 30 to 40%, intakes of silages increased. However, the above research was conducted on ensiled and chopped forage, not whole-crop dry stored forage, therefore more research must be conducted to determine the effect of harvest maturity on DMI.

2.2.2 Harvest method

The process of cutting and curing is designed to minimize the amount of time required for plant cell death, post-harvest respiration, and the necessary reduction in moisture content to prevent mold growth. It is clear that respiration induces loss of soluble carbohydrates during the post-cutting period (Moser, 1980), but respiratory processes are inhibited with increased DM content. Greenhill (1959) reported that reducing the moisture content of the forage to 35% will stop plant cell respiration (Greenhill, 1959). Therefore, the quicker forages can dry, the less respiration losses that will occur. Alternatively, allowing plants to mature and the corresponding increase in DM content may help to minimize respiratory losses. Hundtoft (1965) found that typical DM loss for field-cured hay was between 17 and 26% when mowed and raked; practices that are not commonly used with dry-preserved cereals in western Canada. The use of a rake has been suggested to reduce DM yield by approximately 10% (Anderson and Mader, 1984) but this would be markedly increased with whole-crop cereals due to kernel loss. Moreover, cutting, baling and transportation of bales have been suggested to reduce DM yield by 11% if there is no rainfall during curing (Anderson and Mader, 1984). If rainfall occurs on the swaths, forage yield can be reduced by 20% (Anderson and Mader, 1984) partially because the baler has a reduced ability to pick up all of the swaths. However, if the forage was being utilized in a swath grazing system the reduction in forage yield after rainfall occurs may not be as great. The use of swath grazing systems has the opportunity to reduce DM yield losses since the forage is not handled as much as baled forage. However, this reduction in forage loss is only beneficial if the amount of nutrients leaching from the swaths is minimized.

Harvest method can have a large impact on the yield and digestibility of nutrients in the forage. The more the forage is handled the more potential there is for loss of forage material, which

could have a large impact on forage quality, and utilization of the forage. Some potential harvesting methods for whole-crop cereals include utilizing the standing crop for grazing, cutting the forage with a swather or haybine, or the use of yellow feed. The impacts of stockpiling and grazing standing cereal crops will be discussed in the following Section 2.2.3.

Forage can be cut and formed into windrows using either a swather or a haybine. The major difference between a swather and haybine is that a haybine has the addition of a conditioner, which 'crimps' the forage. The use of a haybine when cutting forage causes damage to the plant cells allowing the forage to dry quicker than forage that was cut using a swather. Longhouse (1960) found that alfalfa hay harvested using a conditioner or conventionally cut had a DM content of approximately 70 and 60%, respectively, within 24 h of cutting. By increasing the DM content of the forage, a reduction in respiration losses is assumed, but the use of a haybine may potentially increase nutrient loss due to leaching and, with whole-crop cereals, may increase risk for kernel loss. McGechan (1993) found that using a haybine increased nutrient leaching due to both rainfall and runoff compared with forage cut using a swather. The increase in leaching loss was due to the damage of plant cells during harvest. The amount of leaching that will occur may vary depending on harvest maturity as maturity influences chemical composition of the forage.

In western Canada whole-crop forage may also be harvested as yellow feed. Yellow feed is a process that utilizes a glyphosate treatment to desiccate the forage, allowing it to cure standing. When the forage is cured it can then be swathed and immediately baled. This practice is assumed to be beneficial in wet years where windrows may retain moisture over long periods of time resulting in greater leaching loss and potential mold growth (Saskatchewan Ministry of Agriculture, 2009a). Armstrong et al. (1992) found that when the glyphosate was applied to annual ryegrass (*Lolium rigidum*) after flowering there was a decrease in soluble carbohydrates resulting in a decrease in forage digestibility compared to annual ryegrass that was allowed to cure in swaths. When this harvest method was applied to whole-crop annual forage harvested at different maturities there were changes in the nutrient composition compared to conventional harvested forage (Rosser, C.L., A. Beattie, H.C. Block, J.J. McKinnon, H.A. Lardner, and G.B. Penner, unpublished). In that same study, yellow feed had a reduced CP and NDF concentration compared to conventionally harvested forage, which resulted in an increase in the NFC concentration of the forage. The increase in non-fiber carbohydrates (NFC) was more apparent

when the glyphosate was applied at earlier harvest maturities. *In situ* digestibility of DM for oat and wheat forage was greater at 24 h for yellow feed compared to conventionally harvested forage. Digestibility of NDF at 24 h was increased for barley yellow feed compared to conventionally harvested barley forage. The use of glyphosate to aid in curing process can be beneficial in wet years to ensure that the forage dries, without negatively impacting *in situ* digestibility of the forage when harvested at later maturity than late milk stage.

2.2.3 Preservation method

Forage that will be utilized in a winter-feeding system must be preserved from the growing season to feeding, without drastically reducing nutrient yield, quality or digestibility. Current harvest maturity recommendations for barley and oat forage are the soft dough (Acosta et al., 1991; Khorasani et al., 1997) and late milk stage (Kaulbars and King, 2004), respectively, but this is based upon ensiling characteristics, and this could have a potential impact on forage preservation. At the current recommended maturities, both barley and oat have a relatively low DM content, which increases the time required for forage to cure. Johnson et al. (1984) suggested that when forage was harvested at a higher DM the nutrients in the forage were better preserved compared to forages that required more time to cure. Dry-preserved forage can be stored either in bales for green feed, in the swath for swath grazing systems, or left standing for stockpiled grazing systems.

Whole crop barley and oat forage can be baled after curing for storage and utilization during the winter-feeding period. During the baling process, Johnson et al. (1983) found losses were greater when alfalfa forage was baled in small round bales (295 kg; 33.6% loss) compared to large round bales (544 kg; 30.2% loss) and square bales (25 kg; 16.5% loss). Baling alfalfa forage resulted in CP concentrations decreasing by approximately 2% compared to forage left in swaths (Johnson et al., 1983). Johnson et al. (1983) found that when the same forage was stored from June to late January in large round bales forage quality was maintained (DM, CP and digestible DM was 98.0, 93.5 and 94.8% of original baled forage, respectively). Smith et al. (1974) found that when large round bales were rained on, the forage on the exterior of the bale had an average total digestible nutrients (TDN) of 33.3%, compared to 56.7% in the unweathered core of the bales. Burzlaff and Clanton (1971) determined that storing forage in large round bales reduced losses due to nutrient leaching compared to forage that was left standing because nutrients were only

leached from the outside of the bale. It is expected that similar results would occur for whole-crop cereals. Indeed, Beck et al. (2009) found that DM loss was lower for wheat green feed round bales when forage was harvested at the hard dough (6.8%) stage compared to the boot stage (24%). Beck et al. (2009) associated the DM loss to curing, baling and storage of the bales for 118 and 84 d for boot and hard dough, respectively. This could suggest that allowing forage to advance in maturity may potentially result in decreased DM loss, however this may not take into account the increased potential for kernel loss with advancing maturity. Baron et al. (1992) and Stacey et al. (2006) found that harvesting at a ripe stage may increase DM loss due to kernel loss from the forage. This grain can make up a large portion of the energy content of whole-crop forage (Kilcher and Troelsen, 1973) therefore reduction in kernel loss can be very valuable.

If forage is being preserved in swaths over winter, one potential issue is the amount of weathering that will take place. It has been shown that the amount of weathering that will occur after swathing depends on the amount of precipitation after swathing (Aasen et al., 2004). Aasen et al. (2004) showed that there is a decrease in IVOMD in the forage between swathing (late September) and samples taken in late November and April. Aasen et al. (2004) also showed that as forage sits in a swath there is an increase in NDF and ADF concentration, especially between the November and April samples. However, once frozen, there were minimal decreases in forage quality until the forage thawed in the spring. The lack of change during winter and marked reduction after thawing has marked implications for producers on the timing of harvest and timing of forage utilization.

In general, the fiber concentration increases while sitting in the swath due to the loss of soluble nutrients, such as soluble carbohydrates (Burns and Chamblee, 2000) being leached out of the forage. Volesky et al. (2002) found that NDF and ADF concentrations of over-wintered swathed forage increased similar to that of standing forage. Kjos et al. (1987) conducted an experiment in Norway to investigate the effects weathering had on nutrient leaching with barley, oat and wheat straw left in the field during the month of September compared to straw that was baled immediately. During this time period there was 168 mm of precipitation which resulted in crude fiber concentration (% of OM) increasing by 2.9 and 4.2 percentage units for barley and oat straw, respectively (Kjos et al., 1987). Under western Canadian conditions, the CP concentration of the whole-crop swaths cut in late September, had minimal variation between harvest and

April, decreasing by 0.4 and 1.3 percentage units for barley and oat, respectively (Aasen et al., 2004). In that study there was an average of 100.9 mm of precipitation and average temperature ranged from -13.8 to 4.5 from September to April. This was also shown by Volesky et al. (2002) where CP concentration in swaths and bales remained steady throughout storage from September to February. Kjos et al. (1987) found that the weathering of CP (% of OM) appeared to depend on the crop, where barley straw increased 3.1 percentage units, and oat straw decreased 0.7 percentage units. Weathering of swaths can result in reduced OM, crude fiber, ether extract and nitrogen free extract when compared with non-weathered crops (Kjos et al., 1987). With advancing maturity there is a decrease in the concentration of soluble nutrients, which could suggest that allowing forages to mature may decrease the amount of nutrient leaching which may occur. However, with advancing maturity there is an increase in senescence which could contribute to an increase in the amount of forage lost, and is not available for consumption.

Forages can be left standing to be grazed in stockpiled forage systems. Leaving the forage standing will reduce losses associated with handling the forage, but other losses can be associated with standing forage. Stockpiled forages appear to leach nutrients at a similar rate compared to forages that are stored in swaths. Hitz and Russell (1998) found that IVOMD and CP concentrations of stockpiled forage consisting of a perennial and legume mix decreased over the winter grazing season, whereas the NDF and ADF concentrations increased. Throughout the winter grazing season acid detergent insoluble nitrogen concentration of stockpiled forages increases (Hitz and Russell, 1998). Lawrence and Heinrichs (1974) found that stockpiled perennial forage left standing had a reduced accessibility to be grazed during the winter, depending on snow cover.

2.3 Cattle responses in a swath grazing system

2.3.1 Forage intake

Feed intake is influenced by many different variables, which includes, *inter alia*, ruminal digestibility, ruminal fill, palatability, fermentation, ruminal osmolarity, ruminal pH and short chain fatty acid (SCFA) concentration (Baile and Forbes, 1974). The hypothalamus can integrate the factors listed above with other signals, such as hormones, to determine satiety (Sartin et al., 2011) impacting the intake of forages. Feeding and sorting behavior can also have an impact on

forage intake in dairy cattle (DeVries et al., 2005; DeVries et al., 2007) and likely influence the response in beef cattle under winter feeding settings.

Ruminal digestibility has an impact on ruminal distention, and the activation of tension receptors in the rumen, which can cause cessation of feeding (Allen, 2000). Ruminal distention is caused both by mass and volume of digesta present within the reticulum and rumen (Schettini et al., 1999). An increase in ruminal digesta will result in a decrease in voluntary intake of forages (Campling and Balch, 1961). Increasing ruminal digestibility can potentially lead to an increase in passage rate out of the rumen, thereby reducing ruminal fill effects (Allen and Mertens, 1988). Dado and Allen (1995) found that when NDF content in the diet decreased there was a decrease in digesta volume, reducing ruminal fill, allowing for an increase in intake. When NDF content decreases, there is also a decrease in DM content of the ruminal digesta (Dado and Allen, 1995). Waldo (1986) suggested that NDF concentration of forages could be utilized as an accurate predictor of forage intake. Generally when NDF concentration of a feed increases there is a decrease in dry matter intake (Dado and Allen, 1995; Allen, 2000). With advancing maturity whole-crop barley and oat forages have decreasing concentrations of NDF (Brundage et al., 1979; Bergen et al., 1991; Rosser et al., 2013) suggesting that if palatability is not a limiting factor, forage intake will not be negatively affected by harvesting at more advanced stages of maturity.

In addition to ruminal fill, the palatability of forages can have a large impact on DMI. Forage palatability can be affected by both forage and animal characteristics (Marten, 1978). It has been suggested that the starch content of plants may have an impact on palatability (Aderibigbe et al., 1982), where an increase in starch content increases palatability of forages. It has been shown that ruminants can detect bitter, sour, salty and sweet tastes (Goatcher and Church, 1970), and when these senses are surgically impaired, forage preferences change (Arnold, 1966). Palatability of forages can be affected by a learned response due to senses, or effects that occurred after eating (Provenza, 1996). Fernandez-Rivera and Klopfenstein (1989) found that cattle need to be adapted to foraging in extensive winter-feeding systems, such as swath grazing otherwise DMI and performance will suffer. Due to the increasing concentration in starch with advancing maturity it may be suggested that delaying harvest may increase the palatability of the forage if the cattle do not experience acidosis.

Physiological factors such as ruminal osmolality, pH and SCFA concentrations can impact dry matter intake. Increasing ruminal osmolality results in a reduction in DMI, and it has been suggested that this decrease is potentially due to the blood becoming slightly hypertonic (Forbes et al., 1992). Crichlow and Leek (1980) found that low ruminal pH stimulates chemoreceptors and this stimulation may have a regulatory role for feed intake. Additionally, it has been suggested that increasing propionate concentrations in the rumen can result in reduced intakes due to satiety signaling (Anil and Forbes, 1980) through the hepatic oxidation theory (Oba and Allen, 2003). Shepard and Combs (1998) found that propionate had a greater impact on reducing intake compared with acetate infused at similar amounts. Putting feedback mechanisms regulating DMI into perspective of forage maturity, it could be speculated that delaying harvest of whole-crop barley and oat forage and the corresponding increased starch concentration could result in increased ruminal propionate concentration and lower pH. This could potentially result in a decrease in DMI, even though the forage may be more palatable due to the increasing starch content.

The hypothalamus integrates many signals such as neural signals, and hormone signals to determine satiety. As described by Allen (2000) ruminal distension can stimulate tension receptors in the rumen, which sends a neural signal to the hypothalamus (Sartin et al., 2011) reducing forage intake. Propionate concentration appears to be a major satiety signal in ruminants due to its extensive utilization in the liver (Allen, 2000). Anil and Forbes (1988) found that infusing propionate into the portal vein had a larger impact on feed intake compared to the infusion of acetate or butyrate. Increasing levels of circulating urea can result in a decrease in DMI, likely due to the subsequent metabolism of ammonia (Oba and Allen, 2003). There are many hormones secreted throughout the body that can influence DMI, such as leptin, ghrelin and cholecystokinin (Sartin et al., 2011). Delaying harvest of whole-crop barley and oat forage results in decreases in NDF concentration, which may suggest there will be decreased stimulation of tension receptors in the rumen allowing for more forage to be consumed.

Shifting the site of starch digestion from the rumen to post-ruminal digestion can potentially improve animal performance. Digesting starch in the small intestine can increase the energy efficiency of the starch (Harmon and McLeod, 2001), but this advantage is only present if the starch is available to the animal. Reynolds et al. (2003) found that it was likely that altering the

site of starch digestion from the rumen to the small intestine could result in increased DMI. This increase in DMI is suggested because there may be less stimulation of hepatic oxidation occurring due to a reduced propionate production in the rumen (Reynolds et al., 2003) and subsequent utilization of propionate in the liver to synthesize glucose. Increasing the concentration of starch in the forage has the potential to increase the amount of starch that can escape ruminal fermentation, which could result in increased forage intakes and performance of cattle fed forage harvested at later maturities.

Feeding and feed sorting behavior of animals may also influence DMI. Feeding behavior includes the number and amount of time spent eating and ruminating each day. Dado and Allen (1995) found that when diets contained large amounts of NDF there is a corresponding increase in the number of ruminating bouts and time spent eating throughout the day. When a TMR with a 62:38 forage:concentrate ratio was provided to lactating dairy cows an increased feeding time (min/d) was observed compared to cows provided with a 51:49 ratio (DeVries et al., 2007). Fontenot and Blaser (1965) showed that cattle have a tendency to sort through forage, preferentially selecting components that are higher in protein and fat, lower in fiber. This could suggest that cattle in swath grazing systems will preferentially consume the grain component of whole-crop annual forages. This was observed by Lardner et al. (2008) where backgrounding calves that were swath grazing barley would preferentially consume barley heads instead of consuming the whole plant. DeVries et al. (2005) found that when a TMR was provided less frequently, there was an increase in the NDF content of the refusals compared with a TMR that is provided more frequently. This increase in sorting behavior could become increasingly important when forages are provided in larger quantities for a longer period of time.

2.3.2 Performance of cattle in a swath grazing system

The performance of cattle in swath grazing systems can vary greatly depending on the type of cattle and the environmental conditions. The performance of cattle in swath grazing systems will vary yearly (Kelln et al., 2011), which is why it is important to have an alternative winter feeding system available. It is also important that animals are adapted to extensive winter-feeding systems otherwise DMI of the cattle will suffer (Fernandez-Rivera and Klopfenstein, 1989; Kelln et al., 2011).

Over-wintering cows in swath grazing systems is an alternative to a dry-lot system that may reduce winter feeding costs. Kelln et al. (2011) found that mature cows swath grazing barley harvested at the soft dough stage had lower DMI through the winter grazing period compared to cows in bale grazing or dry-lot settings. Both swath grazing and bale grazing resulted in decreased body weight gain compared to cows fed in a dry-lot, however with the exception of the first year, cows did not lose body weight during the winter feeding period (Kelln et al., 2011). The utilization of swath grazing or bale grazing system did not reduce reproductive performance of cows compared to a dry-lot system (Kelln et al., 2011).

Swath grazing systems can be utilized as a backgrounding system for calves. Kumar et al. (2012) found the digestible energy (DE) content of whole-crop barley utilized in the swath grazing system was greater than a grass-legume hay (80% brome, 20% alfalfa). Calves swath grazing barley forage harvested at the soft dough stage had similar DMI (6.81 to 7.76 kg/d) and ADG (0.6 to 0.8 kg/d) as calves that were fed in a dry-lot setting (Kumar et al., 2012).

The combination of temperature and precipitation during the winter grazing season can have a significant impact on the performance of the cattle in swath grazing systems. Adams et al. (1986) observed that temperature and snowfall could significantly alter feeding behavior, which can have an impact on forage intake in winter-grazing systems. Lawrence and Heinrichs (1974) conducted a 3-yr study in Swift Current, SK and found that the combination of temperature and wind speed, as well as snow depth had the biggest negative impact on cattle in winter-feeding systems. It has been suggested that energy requirements of cattle grazing can increase by 10 to 20% compared to cattle that are being fed in a pen setting due to increased activity required for foraging (NRC, 2000). It has been shown that mature cows in swath grazing systems require 18 to 21% more DE to meet their maintenance requirements compared to cows fed in a dry-lot setting (McCartney et al., 2004). Kumar et al. (2012) suggested that maintenance energy requirements of calves in swath grazing systems also increased compared to calves fed in a dry-lot.

Throughout the winter-feeding period, the energy and protein requirements of cattle in swath grazing systems will be influenced by weather as well as their physiological state. The requirements to provide an energy supplement may depend on the weather conditions during the

winter-feeding period, as well as the energy content of the forage. Kilcher and Troelsen (1973) found that energy content of whole-crop oat forage decreased with advancing maturity from the early leaf to the milk stage, where energy content stabilized due to the increasing grain content. However if kernel loss occurs at more mature stages (Stacey et al., 2006) there may be a decrease in overall energy content of the forage.

The protein requirements of a backgrounding calf (250 kg) to gain 1 kg/d is 11% CP, whereas for gestating cows (550 kg) in second and third trimester their requirements are 7 and 9% CP, respectively (NRC, 2000). This means that the different types of cattle in a swath-grazing system will have different CP requirements, and these requirements may change over time. The type of forage and the maturity at harvest will have a significant affect on protein supplementation program. As annual cereals advance in maturity the CP concentration generally decreases, therefore if harvest is delayed there may be an increased need to supplement the cattle in the swath grazing system with protein.

2.3.3 Utilization

To reduce wastage of cereal forage in swath grazing systems, it has been recommended to control access to the swaths, providing approximately 3 d of forage (Saskatchewan Ministry of Agriculture, 2009c). Smith et al. (1974) compared forage provision with forage provided daily, every 2 d or every 4 d and observed that increasing the forage that was allocated to cows resulted in an increased refusal (% of offered) from 11% to 31% for daily and 4-d allocations, respectively. They associated the increased refusal to sorting through the forage, and trampling the forage. Baron et al. (2006) conducted a 4-year study and found that the utilization of whole-crop barley swaths ranged from 75 to 92%. A similar range was reported in a subsequent study with utilization of barley swaths ranging from 58 to 80% in a 5-yr study (Baron et al., 2014). Baron et al. (2006) suggested that variability in utilization in swath grazing systems may be due to a variety of conditions, such as snow condition, low temperatures, and fluctuations in temperatures causing forage to freeze to the ground. Allowing cattle to return to swath grazed paddocks in spring can increase the utilization of the forage because they may consume some residual forage (Volesky et al., 2002), however, the quality of the forage is likely low and may occur at a time with relatively high nutrient requirements (e.g. late gestation or early lactation depending on timing of calving).

Variation in utilization of swathed forage can be potentially impacted by difference in grazing intensity (due to management), nutritive quality of forage and environmental conditions, specifically temperature and snow cover (Baron et al., 2014). Curtis et al. (2008) increased the quantity of stockpiled perennial forage allocated to cows over a 3.5 d period from 2.25 to 4.50% of cow-calf pair body weight (BW). They found that with increasing forage allocation there was an increase in apparent DMI, but a reduction in utilization of the forage. Curtis et al. (2008) found that to optimize calf ADG and weight gain/ha forage should be allocated at approximately 3.25% of BW, which would result in 71% DM utilization. Attempting to maximize utilization of forage in swath grazing systems can result in reduced forage intake and greater variation in DMI among days, which may reduce the performance of cattle.

In a swath grazing system utilizing whole-crop annual forage, associative effects between NDF and starch could have an impact on animal performance. If the forage is provided in 3-d allocations (Saskatchewan Ministry of Agriculture, 2009c), it is likely that the amount of NDF and starch consumed each day will be different due to sorting. It has been suggested that cattle will preferentially consume the grain component of their diet before the forage component (Fontenot and Blaser, 1965). Given a 3-d allocation of forage it can be assumed that the cattle will consume the majority of the grain present within the first day of allocation. If the starch in the grain is available, it could result in decreased ruminal pH, which can reduce the amount of NDF that can be digested (Calsamiglia et al., 2002). The following days the forage would have a higher NDF concentration due to the reduction of starch in the total forage. Increasing NDF concentration of a diet can result in a decrease in DMI due to stimulation of distension sensors in the rumen (Allen, 2000) and may decrease palatability. However, there are no published studies describing sorting behavior, ruminal pH, and total tract digestibility in a swath grazing system.

2.3.4 Nutrient cycling

Cost of winter-feeding in extensive winter-feeding systems can be lower than dry-lot systems, partially because of the reduced costs associated with manure removal (McCartney et al., 2004). Costs that were only associated with labor and equipment requirements for manure removal and spreading in dry-lot and swath grazing systems was $0.282 and $0.054/cow/d, respectively (McCartney et al., 2004). Besides costs there can also be an improvement in nutrient cycling observed when extensive winter-feeding systems are utilized (Jungitsch et al., 2011; Kelln et al.,

2012). Jungnitsch et al. (2011) found that when extensive winter grazing systems were utilized there was an increase in soil nitrogen (average 167 kg/ha) compared to soil where manure from a dry-lot system was applied (average 51 kg/ha). The difference in soil nitrogen levels was attributed to urine being directly applied in extensive winter-feeding systems, and the nitrogen availability being reduced for spread dry-lot manure. This increase in N present in the soil means that more of the P that is in the manure can be utilized, resulting in 30-40, and 20-30% of the N and P, respectively, from the feed being recovered, compared to 1 and 3% of N and P, respectively, in a dry-lot system (Jungnitsch et al., 2011). This increase in N and P recovery from extensive winter-feeding systems can result in increases in subsequent forage yield (Jungnitsch et al., 2011). This suggests that the reductions in cost of production can also result in improved utilization of nutrients that are excreted resulting in increased forage yield.

2.3.5 Considerations for extensive winter-feeding systems

Among the issues that have been mentioned previously within this section, there are other considerations when utilizing extensive winter-feeding systems. Environment does not only impact the growing season of forages but can also impact on the preservation of the forage. Aasen et al. (2004) suggested that nutrient leaching would be reduced at freezing temperatures, however, during a mild winter and in spring temperatures can fluctuate. This fluctuation could potentially result in multiple freeze-thaw cycles, which can increase the amount of nutrients that are leached from the forage. The fluctuation could also result in a frozen crust on the snow, which can reduce the amount of forage that is available for consumption in the winter. Reduced availability of the forage in some years means that producers require an alternative winter feed source.

When utilizing an extensive winter-feeding system it is important that the cattle have shelter from wind, a source of water and that producers know the quality of their forage. Olson et al. (2000) found that providing windbreaks for cattle helped to reduce some of the stress associated with winter grazing on pasture. Water sources can range from hauling water, dugouts, pumping water, or consuming the snow as a water source. When using snow as a water source, it is important to ensure that the snow is appropriate to be used, meaning that there is enough present, and that it is not crusted over with ice (Saskatchewan Ministry of Agriculture, 2009b). Degen and Young (1990) found that utilizing snow as the only source of water during a winter feeding

period did not have an impact on body weight, water influx or urine osmolality compared to cows that had access to water. The utilization of snow as primary water source requires the snow to be melted after consumption, which has been calculated to require approximately 7 to 10 MJ/d (Degen and Young, 1990). This increase in energy requirements could result in increased forage intakes, or energy supplementation by producers. Nutrient concentration in forage can vary significantly between years, which can impact forage quality and the subsequent performance of cattle fed this forage. Adequate feed sampling in combination with monitoring the condition of the cattle is necessary for producers to determine whether a supplement needed to meet nutrient requirements, as well as the type and amount of supplementation required.

2.4 Conclusions

Whole-crop dry preserved barley and oat forage yield and quality are affected by conditions during the growing season, timing and method of harvest, and management of livestock during the winter-feeding period. Environmental conditions during these periods cannot be controlled, but proper management can minimize negative impacts associated with the climate. There are several gaps in our knowledge, such as the effect of harvest maturity on forage preservation and nutrient leaching, and nutrient cycling, which need to be addressed to optimize performance in swath-grazing systems. The gap investigated in this thesis is whether the current recommended stages of maturity optimize forage production, forage intake, ruminal fermentation and digestibility, total-tract digestibility, and feeding behavior.

2.5 Hypothesis

Allowing barley and oat to be harvested at the hard dough stage will result in an improvement in forage yield compared to the current recommendations (soft dough and late milk, respectively) without having a negative impact on forage intake, ruminal fermentation characteristics, or total tract digestibility. Increasing the amount of forage allocated will result in daily fluctuations in ruminal fermentation characteristics.

2.6 Objectives

The objectives of these studies were to evaluate the effect of harvest maturity of whole-crop barley and oat forage on forage intake, ruminal fermentation and total-tract digestibility, as well

as evaluate the effect of providing forage in daily, or 3-d allocations on forage intake and ruminal fermentation.

3.0 EFFECT OF FEEDING WHOLE-CROP BARLEY (*HORDEUM VULGARE* L.) GREENFEED TO BEEF HEIFERS WHEN HARVESTED AT DIFFERING STAGES OF MATURITY

3.1 Abstract

The objective of this study was to determine the effect of stage of maturity at harvest of whole-crop barley on forage intake, ruminal fermentation, total tract digestibility and feeding behavior for beef heifers. The whole-crop barley forage (c.v. CDC Cowboy) was harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages and was offered ad libitum to 6 ruminally cannulated heifers in a replicated 3 × 3 Latin square design with 24-d periods. The diets were supplemented in attempt to balance CP across treatments. Average daily gain (ADG), cumulative weight gain, DMI, ruminal fermentation, ruminal digestibility, total tract digestibility, sorting, feeding behavior and ruminal fill were evaluated. Average daily gain, cumulative weight gain, DMI and organic matter intake were not affected by harvest maturity ($P \geq 0.64$). Total tract digestibility of DM, OM and NDF was decreased for HD compared to LM and RP ($P \leq 0.004$). Ruminal digestibility of NDF and ADF were greatest for LM ($P \leq .002$), but harvest maturity did not affect the ruminal digestibility of the other variables ($P \geq 0.24$). Heifers that were fed LM selected against NDF and ADF, but selected for starch content ($P \leq 0.013$) compared with heifers fed HD or RP forage. Ruminal fill and the feeding behavior of heifers were not affected by advancing maturity ($P \geq 0.16$). Minimum and mean ruminal pH was least for heifers consuming LM (6.09 and 6.45), intermediate for RP (6.13 and 6.53) and greatest for HD (6.25 and 6.56; $P = 0.016$ and $P = 0.031$, respectively). Nitrogen intake and balance (g/d) were greatest for HD, intermediate for RP, and least for LM ($P \leq 0.025$). These data suggest that feeding whole-crop barley forage that was harvested at the HD or RP stages of maturity can be advantageous due to improved DM yield without negatively affecting cattle performance.

3.2 Introduction

Approximately 60% of the total cost of production for beef producers is due to winter-feeding costs (Kaliel and Kotowich, 2002). It has been shown that changing from conventional dry-lot winter-feeding to extensive winter-feeding systems like swath grazing can reduce this cost by

approximately 50% (Volesky et al., 2002; McCartney et al., 2004). The reduction in cost is largely due to a reduction in the cost of feeding, especially the costs of baling and moving those bales (Volesky et al., 2002), as well as reduced costs associated with labor and manure removal (McCartney et al., 2004).

When harvesting forage for winter-feeding systems it is important to have high DM yield and adequate forage quality for the cows to consume during the winter-feeding period. Both DM yield and forage quality can be affected by the maturity of the forage at harvest (Linn and Martin, 1989; Baron et al., 1992; Rosser et al., 2013). It is currently recommended that whole-crop barley forage should be harvested at the soft dough stage (Acosta et al., 1991; Khorasani et al., 1997), but this is based on data derived for ensiling and may not represent the optimal stage of maturity for whole-crop dry stored forage. Baron et al. (1992) suggested that to maximize dry matter yield of whole-crop barley forage it should be harvested approximately 48 GDD prior to full maturity. In central Alberta, where the previous study was conducted this would be harvesting approximately 5 d before the grain is ripe. Importantly, allowing the forage to advance in maturity did not result in reduced *in vitro* organic matter digstibility (IVOMD) of the whole-crop barley (Baron et al., 1992). Rosser et al. (2013) also found that harvesting whole-crop barley at full maturity, compared to earlier maturities resulted in the greatest effectively degradable dry matter (EDDM) yield. This increase in EDDM yield could correspond to an increase in the carrying capacity in a swath grazing system, which would be beneficial for producers.

The studies reporting that harvesting at later maturities than currently recommended improves yield without reducing IVOMD, or *in situ* DM digestibility may lead to incorrect conclusions. *In vitro* and *in situ* studies have the potential to overestimate digestibility due to the need for samples to be ground and *in vitro* and *in situ* techniques cannot assess dry matter intake, passage rate, and associative effects. The associative effects of NDF and starch have the potential to have a negative impact on the *in vivo* digestibility of whole-crop barley at various harvest maturity stages. With advancing maturity there is an increase in the starch content in the whole-crop forage due to increasing proportion of grain (Baron et al., 1992). The increase in starch content could potentially result in a decrease in ruminal pH, which could reduce NDF digestibility (Calsamiglia et al., 2002). As well as the potential decrease in NDF digestibility due to ruminal

pH, with advancing maturity there is an increase the amount of lignin present in the forage, resulting in decreased NDF digestibility.

As forages mature the grain component, and lignin concentration of annual cereals increase, which may impact the palatability of the forage, as well as alter feeding behavior. It has been assumed that harvesting annual forages at more mature stages will reduce palatability, and therefore DMI would decrease (Kilcher and Troelsen, 1973). Leonardi and Armentano (2003) found that dairy cows would sort for the grain component of a TMR. If this same sorting behavior is observed in swath grazing systems it could pose as a potential risk of sub-acute ruminal acidosis (SARA). This risk could be increased if whole-crop forages are harvested at more mature stages when there is more grain, and starch potentially available.

The hypothesis of this study was harvesting whole-crop barley forage with advancing maturity would not have a negative impact on forage intake, ruminal fermentation, total tract digestibility or feeding behavior of beef heifers. Therefore, the objective was to evaluate the effect of harvest maturity of whole-crop barley forage on forage intake, ruminal fermentation, total-tract digestibility and feeding behavior when fed to beef heifers.

3.3 Materials and methods

3.3.1 Agronomic practices

On May 28, 2013 at the University of Saskatchewan, 3.25 ha of barley (*Hordeum vulgare* L.; cv. CDC Cowboy) were seeded using a John Deere 9450 hoe drill (Deere and Co., Moline, IL) at a rate of 269 plants/m^2 with 25.4 cm row spacing. Weeds were controlled by spraying with Refine SG (29.7 g/ha; E.I. du Pont Canada Company, Mississauga, ON), MCPA 600 Ester (2-methyl-4-chlorophenoxyacetic acid; 1.0 L/ha), and Axial (1.2 L/ha) Syngenta Canada, Guelph, ON) on June 24, 2013. Environmental conditions during the growing and harvest periods were collected from Environment Canada Weather Monitoring Service weather station at the Diefenbaker International Airport in Saskatoon, SK.

3.3.2 Harvesting/sampling

After the forage matured to the head elongation stage, 0.25 m^2 samples were collected twice weekly and subsequently analyzed for DM content using a microwave (DairyOne, 2014). This was conducted to determine the harvest area required to provide adequate forage for the experiment described below. Whole-crop barley forage was harvested at 3 different stages of maturity: 1) late milk (**LM**), 2) hard dough (**HD**) and 3) ripe (**RP**) Harvest was initiated when approximately 50% of the field was at the appropriate maturity and the harvest dates and environmental conditions are shown in Table 3.1. The forage was cut using a Massey Ferguson 200 self-propelled swather (AGCO, 4205 River Green Parkway, Duluth, GA) leaving a 10-cm stubble height. After cutting, the forage was allowed to cure in the field until it reached a DM content >87% and was then baled using a Massey Ferguson 1835 square baler (AGCO, 4205 River Green Parkway, Duluth, GA). The bales were then stored inside a building until they were utilized. In addition, at the time of each harvest, two 0.25 m^2 samples were collected leaving a 10-cm stubble height. The forage samples were then dried at 20°C for 4 d to simulate the curing process in the absence of precipitation and then dried at 55°C for 48 h to determine DM yield of the forage.

3.3.3 Experimental design

All experimental procedures involving the ruminally cannulated heifers were pre-approved by the University of Saskatchewan Animal Research Ethics Board (Protocol No. 20100021) and followed the guidelines of the Canadian Council of Animal Care (2009).

Six ruminally cannulated heifers (273 ± 16 kg) were used in a replicated 3 × 3 Latin square design to evaluate the impact of stage of maturity at harvest on voluntary intake, fermentation characteristics and total tract digestibility. Experimental periods consisted of 24 d and included 18 d of adaptation and 6 d for data and sample collection. Throughout the study, heifers were provided feed twice daily (0800 and 1600 h) with the forage and concentrate offered in separate feeders. The forage was provided to allow *ad libitum* intake, and heifers were provided a supplement at 0.8% of BW. While this appears to be a high supplementation rate it was based on available forage, and ensuring that there was enough forage for the entire experiment. In an attempt to maintain a high forage content the supplement consisted of an alfalfa pellet (16.6%),

Table 3.1. Environmental conditions[1] and harvest dates of whole-crop barley (*Hordeum vulgare* L.; cv. CDC Cowboy) forage harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages.

		Temperature, °C				
Maturity	Date	Minimum	Average	Maximum	Precipitation, mm	Growing degree days[2]
Swathing[3]						
LM	02-Aug-13	2.0	15.8	30.3	151.1	736.4
HD	16-Aug-13	2.0	16.2	32.2	164.1	916.5
RP	04-Sep-13	2.0	16.5	33.6	165.8	1165.1
Harvest[4]						
LM	16-Aug-13	4.4	17.6	32.2	13.0	189.3
HD	27-Aug-13	6.4	20.9	33.6	1.7	158.3
RP	09-Sep-13	11.0	20.1	33.3	0.3	90.5

[1]Data derived from the Environment Canada Weather Monitoring Service (Diefenbaker International Airport, Saskatoon, SK; http://www.climate.weather.gc.ca/climateData/dailydata_e.html).
[2]Calculated as (maximum temperature + minimum temperature) ÷ 2 – base, where the base is 5°C.
[3]Data is calculated from seeding (May 28, 2013) until the swathing date.
[4]Data is calculated from swathing to harvest date, when forage was baled, and moved into storage

as well as vitamin and mineral pellet (26.7%), and a combination of steam rolled barley and canola meal (56.7%; Table 3.2). The combination of steam rolled barley and canola meal differed among treatments in attempt to equalize dietary CP concentration.

3.3.3.1 Heifer growth performance and DMI

Heifers were weighed on 2 consecutive d before 0800 h; the day prior to and first day of each period. Average daily gain was calculated based on weight gain over the 24 d period. Voluntary DMI was measured from d 19 to 24. To measure DMI, the weight of feed offered and refused was recorded daily. A sample equating to 10% of the feed refusals was collected daily for each heifer and composited by heifer within period. In addition, feed samples were collected daily and period composites were prepared. The DM content of the feed and refusal samples were determined in a forced air oven at 55°C for 48 h and the DM was used to correct the as fed intake to DMI. It is important to note that heifers consumed all of their supplement, with the exception of one heifer that consistently refused to consume all of the supplement that was offered.

3.3.3.2 Ruminal fermentation and apparent ruminal digestibility

Starting at 0800 h on d 19 and ending at 0800 h on d 22, ruminal pH was measured every 5 min using an indwelling pH system (LRCpH, Dascor Inc., Escondido, CA). Prior to insertion in the rumen, the pH systems were standardized in pH buffers 4 and 7 at 39°C and systems were standardized using the same protocol upon removal from the rumen (Penner et al., 2006). The mV and regression data from standardization were used to determine the minimum, mean and maximum ruminal pH over the 72-h measurement duration.

At 0900, 1500 and 2100 h on d 22, 0300, 1200, 1800 and 2400 h d 23, and 0600 h on d 24 rumen digesta was collected from the cranial central, central, and caudal central regions (250 mL each). The digesta was combined and then strained through 2 layers of cheesecloth. After straining, the rumen fluid was mixed and sampled. For short chain fatty acid (SCFA) and ruminal ammonia analysis, 10 mL of ruminal fluid was added to 2 mL of 25% metaphosphoric acid or 2 mL of 1% sulfuric acid, respectively, at each time point. For osmolality analysis 10 mL of rumen fluid was collected at each sampling point and immediately stored at -20°C until further analysis. The samples for SCFA analysis were analyzed at each time point and used to determine the average value for each cow within period. Samples collected for ruminal ammonia and osmolality were

Table 3.2. Supplement composition and nutrient content of the complete diet, composed of whole-crop barley (*Hordeum vulgare* L.; cv. CDC Cowboy) harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages.

	Stage of maturity		
	LM	HD	RP
Supplement composition, %			
Alfalfa pellet	16.6	16.6	16.6
Vitamin and mineral supplement[1]	26.7	26.7	26.7
Rolled barley grain	33.3	11.6	8.3
Canola meal	23.4	45.1	48.4
Nutrient Content, %[2]			
DM	86.9	87.8	89.2
OM	90.3	87.5	88.0
CP	14.7	16.3	16.8
NDF	53.8	41.3	43.3
ADF	34.6	24.0	24.7
Starch	12.3	25.3	23.1
Crude Fat	2.1	2.0	1.8
Ca	1.0	0.6	0.6
P	0.5	0.4	0.4

[1]Major components (>5% of supplement) include ground barley (44.6%), corn dry distillers grains with solubles (DDGS; 25.0%), limestone (11.8%), canola meal (7.6%), and Dynamate (6.8%). Supplied 4.5 % Ca, 0.4% P, 4.6 mg/kg Co, 146 mg/kg Cu, 337 mg/kg Mn, 2.3 mg/kg Se, 314 mg/kg Zn, 40,000 IU/kg vitamin A, 15,000 IU/kg vitamin D, 300 IU/kg vitamin E, 402 mg/kg of monensin, and 0.6 mg/kg MGA.

[2]Nutrient content of the complete diet was calculated based on the nutrient content and inclusion rate of each ingredient.

composited by cow within period before analysis.

For determination of apparent ruminal digestibility a 3-marker system was utilized. The markers utilized included indigestible NDF (**iNDF**), Yb and Cr as markers for the large particle (**LP**; Reynal and Broderick, 2005), small particle (**SP**; Siddons et al., 1985) and fluid (**FP**; Udén et al., 1980) phases, respectively. Solutions of $YbCl_3$ (15.3 m*M*) and Cr-ethylenediaminetetra-acetic acid (Cr-EDTA; 48.3 m*M*) were infused into the rumen on d 14 to 24 at a rate of 1 L of each solution/d. The solutions were prepared to provide 2.77 g of Cr (Binnerts et al., 1968) and 3.35 g of Yb (Brito et al., 2006) per day. An initial dose of 500 mL each of the Yb and Cr solutions were directly dosed into the rumen on d 14. Prior to the first omasal digesta sample being collected the markers were infused for 8 d in attempt to achieve steady state of marker concentration within the rumen.

Omasal digesta was collected at 0900, 1500 and 2100 h on d 22, 0300, 1200, 1800 and 2400 h on d 23 and 0600 h on d 24. To collect omasal digesta, the omasal orifice was located by hand at each time point and a sampling tube was inserted (Huhtanen et al., 1997). At each time point 450 mL of omasal digesta was collected and divided; 300 mL was used for omasal digesta phase analysis, and 150 mL as a spare sample. The omasal digesta was pooled by period, resulting in composite samples of 2.4 L for phase determination and 1.2 L as spare. The omasal digesta was stored at -20°C until further analysis could be completed.

To determine digesta phases, the 2.4-L composite omasal digesta was thawed and analyzed according to Brito et al. (2009). The digesta was filtered through 1 layer of cheesecloth using slight pressure and the particles that remained on the cheesecloth were considered the LP. The filtrate was centrifuged (1,000 × *g* for 5 min at 5°C) allowing a pellet to form. The pellet was considered the SP and the supernatant the FP. Digesta phases were then freeze-dried and ground to pass through a 1-mm screen for further analysis.

To determine iNDF content 1.5, 2.0 and 3.0 g of LP, SP and feed and refusals, respectively, were weighed into 5 × 10 cm nylon bags (6 µm pore size; Ankom Technology, Macedon, NY). The nylon bags were then randomly placed into 6 mesh bags (36 nylon bags/mesh bag) with a 1 kg weight placed in each bag to ensure bags were located below the rumen mat. Each mesh bag was incubated for 10 d in the rumen of ruminally cannulated heifers that were fed ad libitum grass

hay. Immediately upon removal from the rumen, the mesh bags were placed into cold water and the nylon bags were allowed to soak in cold water for 30 min before being placed into a forced air oven at 55°C for 48 h. Subsequently, bags were weighed and NDF analysis was conducted according to Ankom (2011) with alpha amylase (17,400 LU/ml; LU is a liquefon unit), and sodium sulfite (0.5 g/50 mL of neutral detergent solution).

The concentration of Cr and Yb in the omasal digesta was determined similar to that described by Vicente et al. (2004). Briefly, samples were ashed (1 g of sample) overnight at 550°C followed by digesting the ashed sample in a 1.5 *M* nitric acid containing 2 g of KCl/L for 3 min. Digested samples were then diluted (100 time dilution for LP and SP phases and 1000 time dilution for the FP phase) and Cr and Yb concentrations were analyzed using a Thermo Scientific iCE 3300 atomic absorption spectrophotometer (Thermo Fisher Scientific, 81 Wyman Street, Waltham, MA, 02454). Omasal flow from the rumen was calculated according to France and Siddons (1986). Ruminal digestibility was calculated as follows;

$$\text{Ruminal digestibility (\%)} = [\text{intake (kg)} - \text{ruminal outflow (kg)}]/\text{intake (kg)} \times 100$$

3.3.3.3 Apparent total tract digestibility

On d 22 to 24, total collections of feces and urine were conducted to determine total tract digestibility. Urinary catheters were inserted on d 20 and on d 22 to 24 the catheters were connected to 20-L containers that contained 200 mL of 37% hydrochloric acid. Total urine output was weighed and mixed at 0800 h daily and a 90-mL representative sample was collected and stored at -20°C until further analysis. Feces were scraped from the pens every 4 h throughout the collection period. At each time point, the wet weight of the feces was recorded and 5% of the weight was used to prepare a composite sample. The composite sample was stored at -20°C between collections and until further analysis was completed. Total tract digestibility was calculated using the following calculation,

$$\text{Total tract digestibility (\%)} = [\text{Intake (kg)} - \text{Fecal Output (kg]/Intake (kg)} \times 100$$

3.3.3.4 Feeding behavior and ruminal fill

To evaluate whether the stage of maturity at harvest affected selection for nutrients, a modified sorting index was utilized. The sorting index was calculated according to Leonardi and

Armentano (2003) with the modification that nutrient content of the diet and the actual nutrient intake was used rather than particle size distribution. The formula used was;

$$\text{Sorting Index} = [(\text{actual nutrient intake}) / (\text{theoretical nutrient intake})] \times 100$$

Using this equation, values less than 100% indicate selective refusals and values over 100% indicate selective consumption.

Feeding behavior was manually recorded every 5 min for 24 h starting at 0800 h on d 19. At each observation time, heifer activity (eating, chewing, drinking, or idle), as well as whether the heifers were standing or lying down was recorded. The activity at each time-point was assumed to persist until the subsequent observation. Feeding bouts were defined to occur when feeding time was greater than 10 min. The total amount of time spent each day for the behaviors recorded were calculated.

Total rumen evacuations were conducted after the final fecal collection on d 1 of the following period. The weight of all ruminal contents was recorded and sampled in duplicate to determine the DM content of the ruminal contents.

3.3.4 Chemical analysis

Feed and refusal samples were dried in a forced air oven at 55°C for 48 h and fecal samples were dried for 72 h. The samples were then ground using a hammer mill (Christy and Norris Ltd., Chelmsford, UK) to pass through a 1-mm screen. Feed, refusals, feces and omasal digesta were analyzed for dry matter (DM), ash, crude protein (CP), starch, crude fat, neutral detergent fiber (NDF), acid detergent fiber (ADF), Ca and P at Cumberland Valley Analytical Services (Hagerstown, MD). Dry matter was determined by drying at 135°C for 2 h in a forced air oven. Ash was determined according to the AOAC method 942.05 (AOAC, 2000) with the exception of using 1.5 g sample, 4-h ash time, and the residual weight was determined using hot-weighing. Crude protein was determined using a Leco FP-528 Nitrogen Combustion Analyzer (Leco, 3000 Lakeview Avenue, St. Joseph, MI 49085). Starch was analyzed according to Hall (2009) and fat was determined according to AOAC method 2003.05 using a Tecator Soxtec System HT 1043 Extraction unit (Tecator, Foss NA, 7682 Executive Drive, Eden Prairie, MN 55344). The concentration of NDF was analyzed according to Van Soest et al. (1991) with α-amylase and

sodium sulfite and the resulting material was filtered using Whatman 934-AH glass micro-fiber filters with 1.5 µm particle retention (GE Healthcare Life Sciences, Little Chalfont, UK). The ADF concentration was analyzed according to AOAC method 973.18, (2000) using Whatman 934-AH glass micro-fiber filters with a 1.5-µm particle retention (GE Healthcare Life Sciences, Little Chalfont, UK) instead of a fritted glass crucible. Lignin concentration was determined according to Goering and Van Soest (1970) with some modifications as follows. Following ADF analysis the filter and residue were added to a tube, and 45ml of 72% sulfuric acid was added. Tubes were agitated for 2 h, then residues were filtered, rinsed, dried and residue was weighed, then ashed 2h. Lignin concentration was then calculated by subtracting the original weight of filter and ADF residue from the weight of the ashed filter and fiber residue. The concentrations of Ca and P were analyzed according to AOAC method 985.01 (2000) but ashing was conducted using 0.35 g sample for 1 hr at 535 °C and samples were digested in open crucibles for 20 min in 15% nitric acid. Gross energy of the feed, refusals and feces was completed using a Parr 6400 bomb calorimeter (Parr Instrument Co., Moline, IL).

Ruminal SCFA were analyzed by gas chromatography (Agilent 6890, Mississauga, ON, Canada) according to Khorasani et al. (1996). Ruminal ammonia was measured using a phenol hypochlorite assay (Fawcett and Scott, 1960). Ruminal osmolality was determined using a Model 3250 osmometer (Advanced Instruments Inc., Norwood, MA) after centrifugation (12,000 × *g*, 4°C, 10 min) of the ruminal fluid. The total N content of urine was determined using the Kjeldahl procedure, AOAC method 976.05 (1990).

3.3.5 Statistical analysis

Data were analyzed using Mixed Model procedure of SAS (Version 9.3, Cary, NC). The model included the fixed effects of treatment and period, and the random effect of heifer. Initially the effect of square was utilized, but no effects were observed, therefore it was removed from the model. Forage yield data were analyzed using Mixed Model procedure with fixed effect of treatment. Mean separation was completed using the Bonferroni option when $P \leq 0.050$.

To test whether the sorting index was significantly different from 100 (no sorting) a t-test was conducted, and when $P \leq 0.050$ significance was declared.

3.4 Results

With advancing maturity, DM yield increased (Table 3.3) from 3.52 t/ha for LM to 5.43 t/ha for RP barley forage. There were lower concentrations of DM, OM and starch in forage harvested at LM compared to HD and RP. The concentration of CP and Ca initially decreased between LM and HD, but did not change between HD and RP. The concentration of NDF, ADF and lignin were greatest for LM, intermediate for RP, and least for HD.

Harvest maturity of the whole-crop barley forage did not affect ADG or cumulative weight gain of heifers over the 24-d period (Table 3.4; $P = 0.64$). The intake of DM, OM, and GE were not affected by harvest maturity ($P \geq 0.53$), but the intake of starch and CP increased between the LM and HD stages with no differences observed between the HD and RP stages ($P \leq 0.003$). The intake of NDF decreased between the LM and HD stages but was not different between HD and RP ($P = 0.008$), whereas ADF intake decreased with advancing maturity ($P = 0.026$). The omasal flow out of the rumen for all nutrients analyzed and ruminal digestibility of DM, OM, starch and CP were not affected by harvest maturity ($P \geq 0.11$). The ruminal digestibility of NDF and ADF initially decreased between LM and HD, were not different between HD and RP ($P \leq 0.002$). Total tract digestibility of DM, OM and NDF initially decreased from LM to HD, but the digestibility of DM, OM, and NDF for RP did not differ from LM ($P \leq 0.004$). The total tract digestibility of ADF decreased from 67.6 to 46.3 and 46.0% between LM, HD and RP, respectively ($P < 0.001$). Starch and CP total tract digestibility were not affected by harvest maturity ($P = 0.64$ and 0.06, respectively). The daily intake of GE and DE were not affected by harvest maturity ($P \geq 0.52$).

The amount of forage offered, refused, and refusals as percentage of offered were not affected by harvest maturity (Table 3.5; $P \geq 0.26$). The sorting index for DM and CP were not affected by maturity ($P \geq 0.43$), whereas heifers sorted against starch from LM, compared to heifers fed HD and RP (48.0, 110.5, 110.1, respectively; $P = 0.010$). The OM sorting index increased with advancing maturity ($P = 0.023$), however none of these values were different from 100. Heifers offered LM forage selectively consumed NDF and ADF ($P \leq 0.013$). Ruminal fill, reported on an as is and DM basis were not affected by maturity (Table 3.6; $P \geq 0.51$). The amount of time the heifers spent on the various feeding behaviors was not affected by maturity ($P \geq 0.18$). The

Table 3.3 Dry matter yield and chemical composition of whole-crop barley fed during the experiment (*Hordeum vulgare* L.; cv. CDC Cowboy) harvested at the late milk (LM), hard dough (HD), and ripe (RP) stages.

	Stage of maturity[1]		
	LM	HD	RP
DM yield, t/ha	3.52	4.99	5.43
Nutrient content, %			
DM	23.8	41.0	53.0
OM	90.0	93.1	94.0
CP	11.9	8.7	8.1
NDF	68.4	48.4	51.0
ADF	43.7	27.2	27.9
Lignin	6.0	3.6	4.0
Starch	3.0	25.0	24.6
Crude fat	1.7	1.8	1.5
Ca	0.52	0.33	0.29
P	0.34	0.29	0.32

[1]Arithmetic means of 2 - 0.25 m^2 samples taken at each harvest.

Table 3.4 Body weight gain, nutrient intake, ruminal digestibility and apparent total-tract digestibility of heifers fed whole-crop barley (*Hordeum vulgare* L.; cv. CDC Cowboy) harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages.

	Stage of maturity				
	LM	HD	RP	SEM	*P* value
Average daily gain, kg/d	0.7	0.6	0.7	0.09	0.64
Cumulative gain, kg/24 d	17.3	14.4	16.5	2.17	0.64
DM					
Intake, kg/d	5.1	5.6	5.4	0.40	0.70
Omasal flow, kg/d	2.5	2.8	2.7	0.17	0.54
Ruminal digestibility, %	50.4	48.3	50.2	2.24	0.77
Total tract digestibility, %	73.5[a]	68.4[b]	73.7[a]	1.16	0.003
OM					
Intake, kg/d	4.5	4.7	4.6	0.31	0.89
Omasal flow, kg/d	1.8	2.1	2.0	0.13	0.52
Ruminal digestibility, %	59.4	55.7	56.9	1.85	0.40
Total tract digestibility, %	74.4[a]	67.8[b]	73.2[a]	1.41	0.004
NDF					
Intake, kg/d	2.7[a]	2.2[b]	2.1[b]	0.16	0.008
Omasal flow, kg/d	0.8	0.9	0.9	0.07	0.37
Ruminal digestibility, %	69.7[a]	54.4[b]	54.9[b]	3.16	0.001
Total tract digestibility, %	71.7[a]	51.3[c]	62.3[b]	2.00	< 0.001
ADF					
Intake, kg/d	1.7[a]	1.2[ab]	1.1[b]	0.15	0.026
Omasal flow, kg/d	0.5	0.7	0.6	0.05	0.11
Ruminal digestibility, %	70.0[a]	44.4[b]	42.5[b]	4.82	0.002
Total tract digestibility, %	67.6[a]	46.3[b]	46.0[b]	3.21	< 0.001
Starch					
Intake, kg/d	0.6[b]	1.2[a]	1.1[a]	0.07	< 0.001
Omasal flow, kg/d	0.1	0.1	0.1	0.01	0.15
Ruminal digestibility, %	85.6	90.7	92.5	2.83	0.26
Total tract digestibility, %	90	91.8	91.5	2.12	0.64
CP					
Intake, kg/d	0.75[b]	0.91[a]	0.91[a]	0.05	0.003
Omasal flow, kg/d	0.5	0.5	0.5	0.03	0.54
Ruminal digestibility, %	35.1	38.4	43.2	3.20	0.24
Total tract digestibility, %	76.9	76.1	79.5	1.25	0.058
Gross energy					
Intake, Mcal/d	20.7	23.1	22.8	1.70	0.53
Apparent digestibility, %	72.9	68.8	74.0	1.48	0.070

Table 3.4 Body weight gain, nutrient intake, ruminal digestibility and apparent total-tract digestibility of heifers fed whole-crop barley (*Hordeum vulgare* L.; cv. CDC Cowboy) harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages. Continued.

	Stage of maturity				
	LM	HD	RP	SEM	*P* value
Digestible energy					
Intake, Mcal/d	15.1	16.0	16.8	1.14	0.52
Intake, Mcal/kg	3.0	2.8	3.1	0.07	0.083

[abc]Means within a row with the same superscript are not significantly different ($P > 0.05$).

Table 3.5. Sorting behavior of heifers fed whole-crop barley (*Hordeum vulgare* L.; cv. CDC Cowboy) harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages.

	Stage of maturity				
	LM	HD	RP	SEM	*P* value
Forage offered, kg	4.4	4.9	5.0	0.38	0.46
Forage refused, kg	1.5	1.5	1.8	0.15	0.26
Refusal, % of offered	33.6	32.1	35.8	3.82	0.63
Forage intake, kg	2.9	3.4	3.2	0.39	0.60
Supplement intake, kg	2.2	2.1	2.2	0.10	0.75
DM intake, kg	5.1	5.6	5.4	0.40	0.70
DM intake, % BW	1.8	1.9	1.9	0.11	0.78
Sorting Index[1], %					
DM	77.8^{z}	78.4^{z}	77.0^{z}	2.99	0.89
OM	99.9^{b}	100.4^{abz}	100.6^{az}	0.16	0.023
CP	99.0	97.0	99.3	1.70	0.43
NDF	117.3^{az}	108.7^{bz}	107.6^{bz}	2.87	0.013
ADF	102.2^{a}	89.3^{bz}	88.6^{bz}	2.86	0.009
Starch	48.0^{bz}	110.5^{az}	110.1^{az}	14.04	0.010

^{ab}Means within a row with the same superscript are not significantly different ($P > 0.05$).
^{z}Means with a superscript indicate values differ from 100.
[1]Sorting index calculated as [(actual nutrient intake)/(theoretical nutrient intake)] × 100 according to Leonardi and Armentano, (2003). Values below 100 indicate avoidance and values above 100 indicate selective consumption.

Table 3.6. Ruminal fill and feeding behavior of heifers fed whole-crop barley (*Hordeum vulgare* L.; cv. CDC Cowboy) harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages.

	Stage of maturity				
	LM	HD	RP	SEM	*P* value
Ruminal fill					
As is, kg	37.3	37.5	35.2	3.65	0.58
DM, %	7.5	7.6	8.1	0.42	0.51
DM, kg	2.8	2.8	2.8	0.26	0.97
Time, min/d					
Lying	848.3	911.7	869.2	36.7	0.18
Standing	591.7	528.3	570.8	36.7	0.18
Idle	812.5	723.3	764.2	53.09	0.50
Eating	268.3	282.5	308.3	23.83	0.46
Drinking	21.7	14.2	11.7	3.78	0.20
Chewing	337.5	420.0	355.8	35.62	0.21
Feeding bouts					
Number of bouts	13.8	11.3	11.8	1.56	0.43
Average duration, min	18.0	23.5	35.0	8.53	0.39
Average time between bouts, min	56.9	58.8	140.5	56.14	0.51
Chewing bouts					
Number of bouts	18.0	20.3	19.2	1.57	0.58
Average duration, min	18.0	21.0	20.0	1.93	0.50
Average time between bouts, min	43.5	36.9	48.8	4.03	0.16

average time heifers spent eating and chewing was 286 and 371 min/d, respectively. Maturity also did not affect the number, duration and time between chewing and feeding bouts ($P \geq 0.16$).

Minimum and mean ruminal pH was least for LM, intermediate for RP, and greatest for HD (Table 3.7; $P \leq 0.031$), whereas maximum pH was not affected by maturity ($P = 0.51$). The ruminal concentration of total SCFA was not affected by maturity ($P = 0.36$), averaging 100.78 m*M*. Harvest maturity did not affect the ruminal concentrations of acetate, propionate, butyrate or isovalerate ($P \geq 0.18$). The ruminal concentration of isobutyrate increased between LM and HD (0.77 and 0.92 m*M*, respectively; $P = 0.004$). There was an increase in ruminal valerate concentration between LM and HD, then a decrease at RP (0.92, 1.05 and 0.93 m*M*, respectively; $P = 0.016$). Harvest maturity had no effect on ruminal osmolality or ammonia concentration ($P \geq 0.68$) averaging 297.2 m*Osmol*/kg and 25.4 mg/dL, respectively.

Nitrogen intake was greatest for HD, intermediate for RP and least for LM (Table 3.8; $P = 0.006$). Fecal and urine N output were not affected by maturity, but total N output had a tendency to be higher for HD and RP compared to LM ($P = 0.42$, 0.25 and 0.073, respectively). Nitrogen balance was least for LM, greatest for HD, and intermediate for RP (26.5, 68.0 and 47.5 g/d, respectively; $P = 0.025$).

3.5 Discussion

The current harvest maturity recommendation for barley when used in dry-preserved feeding systems is at the soft dough stage (Acosta et al., 1991; Khorasani et al., 1997). This recommendation is based on characteristics required for ensiling instead of optimizing DM yield and nutrient digestibility, which Baron et al. (1992) suggested was more appropriate for dry-preserved forage. The current study supports past work by Baron et al. (1992) and Rosser et al. (2013) suggesting that DM yield can be improved by harvesting whole-crop barley at a more advanced stage of maturity relative to the current recommendation. However, a concern for harvesting whole-crop barley beyond the soft dough stage is the potential reduction in palatability and digestibility of the fibrous fractions (Linn and Martin, 1989). Moreover, while starch content increases with advancing maturity, it is not clear whether the starch contained within the kernels will be available. Thus, this study was conducted to determine the effect of

Table 3.7. Rumen characteristics of heifers fed whole-crop barley (*Hordeum vulgare* L.; cv. CDC Cowboy) harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages.

	Stage of maturity				
	LM	HD	RP	SEM	*P* value
Ruminal pH					
Minimum	6.09[b]	6.25[a]	6.13[ab]	0.047	0.016
Mean	6.45[b]	6.56[a]	6.53[ab]	0.035	0.031
Maximum	6.81	6.90	6.89	0.058	0.51
Ruminal SCFA, m*M*					
Total	105.01	99.07	98.18	3.807	0.36
Acetate	72.48	67.46	67.97	2.892	0.37
Propionate	19.91	18.68	17.24	1.025	0.23
Isobutyrate	0.77[b]	0.92[a]	0.95[a]	0.035	0.004
Butyrate	9.56	9.66	9.40	0.436	0.87
Isovalerate	1.12	1.23	1.30	0.064	0.18
Valerate	0.92[b]	1.05[a]	0.93[b]	0.036	0.016
Osmolality, m*Osm*	298.6	297.0	296.0	3.69	0.83
Rumen ammonia, mg/dL	24.0	26.3	25.9	2.62	0.68

[ab]Means within a row with the same superscript are not significantly different ($P > 0.05$).

Table 3.8. Nitrogen balance of heifers fed whole-crop barley (*Hordeum vulgare* L.; cv. CDC Cowboy) harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages.

	Stage of maturity				
	LM	HD	RP	SEM	*P* value
N intake, g/d	107.2[b]	163.7[a]	139.2[ab]	10.77	0.006
N output, g/d					
Feces	28.0	33.9	29.9	3.82	0.42
Urine	52.7	61.9	61.9	4.45	0.25
Total N	80.7	95.8	91.7	4.44	0.073
N balance, g/d	26.5[b]	68.0[a]	47.5[ab]	9.90	0.025

[ab]Means within a row with the same superscript are not significantly different ($P > 0.05$).

whole-crop barley harvest maturity on forage intake, ruminal fermentation and total tract digestibility.

The major finding in this study was that there were no differences in DMI, or refusals as a percent of forage offered between treatments suggesting that harvesting whole-crop barley at

advanced stages of maturity does not negatively impact palatability of the forage. The negligible effect of harvest maturity on DMI is supported by a lack of differences for ruminal fill among treatments. Even though there were no differences for DMI, ruminal and total tract digestibility of NDF was decreased at HD. Ruminal fill was 2.8 kg DM for all maturities, even though ruminal NDF digestibility was 69.7, 54.4 and 54.9% for LM, HD and RP, respectively. It would be assumed that a decrease in NDF digestibility would result in increased ruminal fill (Allen, 2000) however, this was not observed in this study. This is likely due to the varied NDF content in the forage (range from 48.4 to 68.4%) resulting in NDF intakes of 2.7, 2.2 and 2.1 kg/d for LM, HD and RP, respectively. Ruminal digestibility of NDF was greatest for LM (69.7% vs 54.4 and 54.9% for HD and RP), which had the lowest minimum ruminal pH (6.09), but pH was not low enough to negatively impact NDF digestibility (Calsamiglia et al., 2002).

Although there was a negative effect of NDF digestibility, total tract DM digestibility was not different when forage was harvested at LM and RP stages, although there was a decrease in DM digestibility when forage was harvested at HD stage. The reason for the reduction in DM digestibility at the HD stage but not RP stage is not clear. It should be noted that the magnitude of reduction in DM digestibility was small (5 percentage unit decrease) and despite the reduction, the total DM digested increased with advancing maturity (3.7, 3.8 and 4.0 kg DM/d, for LM, HD and RP, respectively). This finding supports previous *in vitro* (Baron et al., 1992) and *in situ* results (Rosser et al., 2013) indicating that advancing maturity does not negatively impact digestibility. This study also indicates that altering the maturity at harvest does not negatively affect the digestible energy content of the forage.

With advancing maturity, there was a marked reduction in NDF concentration and an increase in starch. Given past studies demonstrating that cattle, when fed a TMR, select for small particles, it could be expected that allowing the whole-crop forage to be more advanced in maturity may also influence selective consumption for parts of the whole-crop forage. Supporting this suggestion,

heifers fed LM forage (greater NDF and reduced starch compared to HD) preferentially consumed NDF and avoided starch. In contrast, heifers fed HD forage consumed more NDF and starch, but NDF preference was not as strong compared to LM. The increased preferential sorting for NDF when fed LM could potentially be due to the increased NDF ruminal and total tract digestibility compared to HD and the relatively low concentration of starch in the whole-crop forage. While selective consumption was affected, we did not observe differences in the amount of time spent eating or chewing.

Ruminal and total tract digestibility of starch was not affected by harvest maturity, suggesting that starch was available to the same extent regardless of harvest maturity. It was suggested that allowing barley forage to advance in maturity would result in a decrease in starch availability. Morgan and Campling (1978) determined that 52.4% of whole barley that was fed to adult dry dairy cows was excreted without being digested. Beauchemin et al. (1994) found that digestion of whole barley required damage to the grain pericarp to allow the rumen microbes access to the starch within the grain. Total tract digestibility of starch in this study averaged 91.1%, suggesting that the heifers were able to sufficiently damage the majority of the whole barley kernels.

In the current study, the diet was formulated with the assumption that the heifers would consume approximately 6 kg DM, and 70% of intake would be from the forage. Using these assumptions supplement ingredients were provided in a combination so final CP concentration of total diet would be 13.9%. Forage intake was lower than expected, therefore the supplement made up a larger proportion of total intake than predicted (37.5 to 43.1%), resulting in CP concentrations of 14.7, 16.3 and 16.8% for LM, HD and RP, respectively. This increased CP concentration in the total diet, and the difference in CP concentration between LM and the later maturities may have influenced some of the results that were obtained.

The CP concentration of the barley forage itself decreased with advancing maturity from 11.9% at LM to 8.1% at RP. The largest decrease in CP concentration was between the LM and HD stage, which corresponds to the greatest CP decrease reported by Rosser et al. (2013) for whole-crop barley forage. If forage were harvested at either the HD or RP stage a CP supplement would need to be provided during 3rd trimester to ensure CP requirements are met (NRC, 2000).

3.6 Conclusion

Harvesting whole-crop barley forage at HD results in improvements in DM yield without negatively affecting growth performance, forage intake, ruminal fermentation or total tract digestibility for beef heifers. Future work is needed to evaluate the effects of harvesting forage barley at various maturities in a field setting to evaluate the impact on feeding behavior, nutrient leaching from swaths, and voluntary intakes in a group setting.

4.0 EFFECT OF HARVEST MATURITY OF WHOLE-CROP OAT (*AVENA SATIVA*) FORAGE ON FORAGE INTAKE, RUMINAL FERMENTATION AND TOTAL TRACT DIGESTIBILITY

4.1 Abstract

The objective of this study was to determine the effect of harvest maturity of whole-crop oat forage on forage intake, ruminal fermentation and total tract digestibility. Oat (c.v. CDC Weaver) was seeded May 17, 2012 and harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages. Forage yield and nutrient content were analyzed. The whole-crop oat forage was offered ad libitum daily to 3 ruminally cannulated heifers in a 3 × 3 Latin square design with 24-d periods. Each diet was supplemented at 1.6%BW, and was formulated to balance CP among treatments. DM intake, sorting indices, ruminal fermentation characteristics, ruminal digestibility, total tract digestibility and N balance were determined. Mean forage yield was 2.11, 4.70 and 4.15 t/ha, respectively for LM, HD and RP. Oat forage intake not affected by harvest maturity ($P = 0.74$), averaging 4.3 kg oat forage/d. Mean ruminal pH was greater for LM (6.35; $P = 0.003$) compared to HD (6.30) and RP (6.28). Total rumen short-chain fatty acid concentration was not affected by maturity ($P = 0.21$) and averaged 117 m*M*. Acetate concentration was greatest ($P < 0.001$) for LM (71.3%), intermediate for RP (70.2%) and least for HD (69.6%; $P < 0.001$). The molar proportion of propionate decreased with advancing maturity from 16.7 to 14.7% ($P < 0.001$) while the molar proportion of butyrate increased with advancing maturity ($P < 0.001$). Ruminal and total tract digestibility of DM, OM, NDF and ADF were not affected by advancing maturity ($P \geq 0.10$). This data suggests that harvesting whole-crop oat forage after the LM stage affects forage intake and increases propionate and butyrate concentration at the expense of acetate, but does not affect total tract digestibility.

4.2 Introduction

Beef producers in western Canada have readily adopted extensive winter-feeding strategies as an approach to reduce winter-feeding costs (Volesky et al., 2002; McCartney et al., 2004). Extensive winter-feeding systems, whether it is swath grazing or bale grazing, rely on readily available forage in the field and suitable forage quality to ensure cows have access to adequate

DM and nutrient content during the winter-feeding period. Forage yield and quality are affected by maturity at the time of harvest (Linn and Martin, 1989; Baron et al., 1992; Rosser et al., 2013). The current recommendation for the maturity at harvest of whole-crop oat forage is at the late milk stage (Kaulbars and King, 2004). However, this is based on ensiling characteristics, such as yield, DM content, available carbohydrate for fermentation, and palatability after ensiling (Acosta et al., 1991, McCartney and Vaage, 1994, Khorasani et al., 1997). When whole-crop oat forage is the final product, fermentation is not required to preserve the feed, therefore the amount of available carbohydrates present are not as important. When harvesting whole-crop dry-stored oat forage the goal should be optimal DM yield and forage quality.

It is generally accepted that allowing dry-stored forage to be more mature at the time of harvest results in increased forage yield, and a general decrease in digestibility (Linn and Martin, 1989; Kilcher and Troelsen, 1973). However, it is important to recognize differences in the growth patterns and arising nutrient profile between perennial forages (e.g. alfalfa) and annual cereal grains. For example, while both annuals and perennials will have greater DM when cut more mature, the reduction in digestibility with advancing maturity may offset the benefit arising from increased forage yield (Linn and Martin, 1989). With respect to annual cereals, Kilcher and Troelsen (1973) found that allowing oat forage to advance in maturity from the early leaf (4 weeks after seeding) to ripe stage resulted in an overall increase in DM yield, but a reduction in digestible organic matter (DOM). Notably the reduction in DOM was only present between the early leaf and late milk stage; a time before the starch content starts to increase.

Despite the suggestion of decreased digestibility with advancing maturity, Baron et al. (1992) found that allowing whole-crop barley forage to advance in maturity beyond 50% head emergence resulted in increased forage yield without negatively affecting in vitro digestible organic matter (IVOMD). Moreover, Rosser et al. (2013) found that harvesting whole-crop oat forage at full maturity resulted in the greatest effectively degradable dry matter (EDDM) yield compared to the same forage harvested at less mature stages. Thus, there is evidence suggesting that allowing annual cereals to be more mature at the time of harvesting may be advantageous. However, the previous studies (Baron et al., 1992; Rosser et al., 2013) used *in vitro* or *in situ* approaches and may have over-estimated digestibility due to the requirement of using finely ground whole-crop forage. Moreover, *in vitro* and *in situ* approaches do not take into account

palatability of the forage at more advanced maturities, or associative effects between the increasing starch content and NDF digestibility. As seen in Chapter 3, barley forage that was harvested at HD had decreased total tract DM and NDF digestibility, but starch digestibility was not affected by maturity. The depression in NDF digestibility observed in Chapter 3 was unlikely to be caused by associative effects of NDF and starch since ruminal pH was highest for HD forage, even though it had the lowest NDF digestibility. Therefore, the objective of this study was to evaluate the effect of harvest maturity of whole-crop oat forage on forage intake, ruminal fermentation, and total-tract digestibility. The hypothesis was harvesting whole-crop oat forage after the LM stage would result in improvements in yield, without negatively impacting DMI, ruminal fermentation or digestibility.

4.3 Materials and methods

4.3.1 Agronomic practices

On May 17, 2012 1.6 ha of CDC Weaver oat (*Avena sativa*) were seeded into barley stubble at the University of Saskatchewan using a John Deere 9450 hoe drill (Deere and Co., Moline, IL), at a rate of 269 plants/m^2 with 25.4 cm row spacing. Herbicide was applied June 22, 2012, which included Refine SG with MCPA Ester 600® (supplied 33.35% Thifensulfuron methyl + 16.65% Tribenuron methyl at 29.6 g/ha and MCPA (2-methyl-4-chlorophenoxyacetic acid) ester at 0.94 L/ha; E.I. du Pont Canada, Mississauga, ON, CA). The environmental conditions and harvest dates are shown in Table 4.1.

4.3.2 Harvesting/sampling

Twice a week after the forage reached the boot stage two 0.25-m^2 samples were cut leaving a 10-cm stubble height. The DM content was then determined using a microwave (Dairy One, 2014) in order to predict the area required for harvesting forages to achieve adequate DM yield at each harvest maturity. Forages were harvested at late milk (LM), hard dough (HD), and ripe (RP) stages using a Massey Ferguson 200 self-propelled swather (AGCO, 4205 River Green Parkway, Duluth, GA). After cutting, forages were allowed to cure in the field until achieving > 87% DM and then were baled using a Massey Ferguson 1835 square baler (AGCO, 4205 River Green Parkway, Duluth, GA). Bales were stored in a covered shed.

Table 4.1. Environmental conditions[1] and harvest dates of whole-crop oat (*Avena sativa*; cv. CDC Weaver) forage at the late milk (LM), hard dough (HD) and ripe (RP) stages.

		Temperature, °C				
Maturity	Date	Minimum	Mean	Maximum	Precipitation, mm	Growing degree days[2]
Swathing[3]						
LM	27-Jul-12	-2.0	15.9	32.2	229.8	782.9
HD	13-Aug-12	-2.0	16.4	32.2	273.3	1008.9
RP	28-Aug-12	-2.0	16.5	32.2	298.3	1190.3
Harvest[4]						
LM	08-Aug-12	5.4	18.7	27.9	29.3	177.7
HD	18-Aug-12	4.9	14.7	24.6	4.3	58.1
RP	03-Sep-12	6.4	16.6	31.0	0.8	80.75

[1]Data derived from the Environment Canada Weather Monitoring Service (Diefenbaker International Airport, Saskatoon, SK; http://www.climate.weather.gc.ca/climateData/dailydata_e.html).
[2]Calculated as (maximum temperature + minimum temperature) ÷ 2 – base, where the base is 5°C.
[3]Data is calculated from seeding (May 28, 2013) until the swathing date.
[4]Data is calculated from swathing to harvest date, when forage was baled, and moved into storage.

4.3.3 Experimental design

All experimental procedures involving the ruminally cannulated heifers were pre-approved by the University of Saskatchewan Animal Research Ethics Board (Protocol No. 20100021) and followed the guidelines of the Canadian Council of Animal Care (2009).

A 3 × 3 Latin square design was used with 3 ruminally cannulated heifers (390 ± 14 kg). Heifers were fed similar diets except for the stage of maturity at the timing of harvest for the whole-crop oat forage (LM, HD, and RP). The heifers were also supplemented with a concentrate provided at 1.6% of body weight. The concentrate consisted of 25% alfalfa pellet, 20% vitamin and mineral supplement, and 55% of a rolled barley and canola meal combination. Alfalfa pellets were utilized to maintain a high forage content, at least chemically, in the complete diet while still allowing for the measurement of whole-crop forage intake. The rolled barley and canola meal were fed at different ratios among treatments in an attempt to make the diets isonitrogenous (Table 4.2). Feed was provided twice daily (0800 and 1600 h) with the oat forage and concentrate offered in separate feeders to enable measurement of concentrate and forage intake. Experimental periods consisted of 24 d, including an 18-d adaptation period, and 6 d of data and sample collection. The first day of adaptation was a complete adaptation, where all of the forage offered was from the new forage maturity.

4.3.3.1 Heifer growth performance and DMI

Heifer growth performance and DMI were measured as described in Section 3.3.3.1. All of the concentrate that was offered to the heifers was consumed.

4.3.3.2 Ruminal fermentation and apparent ruminal digestibility

Ruminal fermentation and apparent ruminal digestibility were measured as described in section 3.3.3.2, with the following exceptions. Determination of omasal flow from the rumen based on marker concentrations was attempted according to France and Siddons (1986). However, prediction of digesta flow using Cr and iNDF resulted in estimates that were outside of physiological ranges. Therefore, passage rate had to be determined from Yb concentration in the spare whole digesta sample. Flow from the rumen was determined by the following calculation,

$$\text{Flow (kg/d)} = \text{YbCl}_3 \text{ intake (mg/d)} / \text{YbCl}_3 \text{ in whole digesta (mg/kg)}$$

Table 4.2. Ingredient composition of the supplement and nutrient content of the complete diet, composed of whole-crop oat (*Avena sativa*; cv. CDC Weaver) harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages.

	Stage of maturity		
	LM	HD	RP
Supplement composition, % DM			
Alfalfa pellet	25.0	25.0	25.0
Vitamin and mineral supplement[1]	20.0	20.0	20.0
Rolled barley	35.0	34.0	30.0
Canola meal	20.0	21.0	25.0
Nutrient content, % DM[2]			
DM	93.7	93.5	93.5
OM	90.0	90.9	89.9
CP	14.2	14.5	15.1
NDF	50.9	44.1	45.4
ADF	33.4	27.7	30.8
Starch	14.4	22.1	19.1
Crude fat	2.2	2.6	2.5
Ca	0.9	0.9	0.9
P	0.4	0.5	0.5

[1]Major components (>5% of supplement) include ground barley (50.3%), corn dry distillers grains with solubles (DDGS; 25.0%), limestone (8.7%), Dynamate (6.8%) and canola meal (6.0%). Supplied 3.4% Ca, 0.5% P, 4.6 mg/kg Co, 146 mg/kg Cu, 335 mg/kg Mn, 2.3 mg/kg Se, 314 mg/kg Zn, 40,000 IU/kg vitamin A, 15,000 IU/kg vitamin D, 300 IU/kg vitamin E and 308 mg/kg of monensin.

[2]Nutrient content of the complete diet was calculated based on the nutrient content and inclusion rate of each ingredient.

4.3.3.3 Apparent total tract digestibility

Apparent total tract digestibility was measured as described in Section 3.3.3.3.

4.3.4 Chemical analysis

Feed, refusals, feces, urine, and rumen fluid samples were analyzed as described in Section 3.3.4. with the exception that gross energy was determined using a Parr 1281 bomb calorimeter (Parr Instruments Co., Moline, IL).

4.3.5 Statistical analysis

Data were analyzed using Mixed Model procedure of SAS (Version 9.3, Cary, NC). Fixed effects were treatment and period, with the random effect of cow. Forage yield was analyzed using Mixed Model procedure, with fixed effects of treatment. Mean separation was completed using the Bonferroni post-hoc mean separation test. Significance was declared when $P \leq 0.050$.

To test whether the sorting index was significantly different from 100 (no sorting) a t-test was conducted, and when $P \leq 0.050$ significance was declared.

4.4 Results

The yield of DM was 2.11, 4.70 and 4.15 t/ha for LM, HD and RP, respectively (Table 4.3). The concentration of DM increased with advancing maturity while the concentration of OM, CP, crude fat, Ca and P did not change. The concentration of NDF decreased by 9.9 percentage units between LM and HD, then remained unchanged between HD and RP. The concentration of ADF was greatest for LM, least for HD, and intermediate for RP (46.6, 38.3 and 41.5%, respectively). Starch concentration increased from 2.7 to 14.5 and 12.8% between LM, HD and RP, respectively.

The intake of OM, NDF, ADF and CP decreased between LM and HD, then increased between HD and RP (Table 4.4; $P \leq 0.023$). Starch intake increased from 1.1 to 1.7 kg/d between LM and HD and then decreased to 1.6 kg/d for RP ($P < 0.001$). The intake of DM, GE and DE, as well as the apparent digestibility of GE were not affected by maturity ($P \geq 0.26$). The omasal flows of all nutrients analyzed were not affected by maturity ($P \geq 0.19$). Ruminal digestibility of DM, OM, NDF and ADF were not affected by maturity ($P \geq 0.43$). The ruminal digestibility of starch

Table 4.3 Dry matter yield and nutrient content of whole-crop oat fed during the experiment (*Avena sativa*; cv. CDC Weaver) that was harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages.

	Stage of maturity		
	LM	HD	RP
DM yield, t/ha	2.11	4.70	4.15
Nutrient content, %			
DM	23.1	35.4	54.2
OM	89.8	91.1	89.9
CP	8.1	8.2	8.8
NDF	70.9	61.0	60.9
ADF	46.6	38.3	41.5
Starch	2.7	14.5	12.8
Crude fat	2.1	2.7	2.7
Ca	0.22	0.20	0.26
P	0.28	0.32	0.30

[1]Arithmetic means of 2 - 0.25 m^2 samples taken at each harvest.

Table 4.4. Performance, nutrient intake, ruminal digestibility and apparent total-tract digestibility of heifers fed whole-crop oat (*Avena sativa*; cv. CDC Weaver) harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages.

	Stage of maturity				
	LM	HD	RP	SEM	*P* value
Average daily gain, kg/d	0.9	1.1	1.1	0.24	0.52
Cumulative gain, kg/24 d	20.5	27.4	26.5	5.70	0.51
DM					
Intake, kg/d	8.1	7.8	8.3	0.34	0.26
Omasal flow, kg/d	3.3	3.3	3.5	0.17	0.78
Ruminal digestibility, %	57.6	57.5	58.3	0.55	0.59
Total tract digestibility, %	67.0	68.7	68.5	1.81	0.78
OM					
Intake, kg/d	7.3[ab]	7.0[b]	7.5[a]	0.09	0.023
Omasal flow, kg/d	2.5	2.5	2.7	0.13	0.58
Ruminal digestibility, %	64.8	64.2	64.0	0.47	0.43
Total tract digestibility, %	70.3	71.6	70.9	1.64	0.84
NDF					
Intake, kg/d	4.1[a]	3.4[c]	3.8[b]	0.08	< 0.001
Omasal flow, kg/d	1.0	0.9	1.0	0.07	0.75
Ruminal digestibility, %	60.1	56.2	57.9	2.68	0.61
Total tract digestibility, %	71.1	75.2	78.1	2.68	0.058
ADF					
Intake, kg/d	2.7[a]	2.2[b]	2.6[a]	0.06	< 0.001
Omasal flow, kg/d	0.7	0.6	0.7	0.05	0.45
Ruminal digestibility, %	53.5	49.4	52.4	3.14	0.65
Total tract digestibility, %	74.2	72.3	73.7	0.62	0.11
Starch					
Intake, kg/d	1.1[c]	1.7[a]	1.6[b]	0.01	< 0.001
Omasal flow, kg/d	0.1	0.1	0.2	0.03	0.19
Ruminal digestibility, %	92.6[a]	92.2[b]	90.0[c]	0.03	< 0.001
Total tract digestibility, %	95.8[a]	95.4[ab]	94.8[b]	0.27	0.043
CP					
Intake, kg/d	1.1[b]	1.1[c]	1.2[a]	0.01	< 0.001
Omasal flow, kg/d	0.6	0.7	0.7	0.05	0.50
Ruminal digestibility, %	43.9[a]	42.0[b]	43.1[a]	0.27	< 0.001
Total tract digestibility, %	70.5	70.6	72.0	1.56	0.74
Gross energy					
Intake, Mcal/d	33.79	32.74	35.40	2.120	0.69
Apparent digestibility, %	68.12	69.61	69.35	1.341	0.72
Digestible energy					
Intake, Mcal/d	23.00	22.79	24.57	1.502	0.68
Intake, Mcal/kg	2.84	2.94	2.96	0.070	0.50

[abc]Means within a row with the same superscript are not significantly different ($P > 0.05$).

decreased with advancing maturity ($P < 0.001$), whereas the ruminal digestibility of CP was similar between LM and RP (average 43.5%), but least for HD (42.0%; $P < 0.001$). Total tract digestibility of DM, OM, ADF and CP were not affected by maturity ($P \geq 0.11$). The total tract digestibility of NDF tended to increase with advancing maturity ($P = 0.058$), whereas the total tract digestibility of starch decreased with advancing maturity ($P = 0.043$).

The amount of whole-crop forage offered, refused, percentage of refusals relative to the amount offered and DM intake as a percent of BW were not affected by maturity at the time of harvest (Table 4.5; $P \geq 0.29$). Selection indices for DM, OM, CP and starch were not affected by maturity ($P \geq 0.11$). Heifers fed HD and RP selected against NDF and ADF ($P \leq 0.026$), however there was no sorting of NDF or ADF when heifers were fed LM.

Minimum ruminal pH was greatest for LM, least for HD, and intermediate for RP (Table 4.6; $P = 0.012$), whereas for mean ruminal pH there was a decrease between LM and HD. There were no differences for minimum pH between HD and RP ($P = 0.003$). Maximum ruminal pH and total ruminal SCFA concentration were not affected by harvest maturity ($P \geq 0.21$). The concentration of acetate decreased between LM and HD and then slightly increased at RP ($P < 0.001$). With advancing maturity there was a decrease in propionate concentration, but an increase in butyrate concentration ($P < 0.001$). Isobutyrate and isovalerate concentrations were least for LM, greatest for HD, and intermediate for RP ($P < 0.001$). Valerate concentrations were similar between LM and RP (average 0.89 m*M*), and greater for HD (0.91 m*M*; $P < 0.001$). Rumen osmolality was greater for RP compared to LM and HD ($P < 0.001$), whereas ruminal ammonia concentrations were intermediate for LM, least for HD and greatest for RP ($P < 0.001$).

Nitrogen intake and output (g/d) were not affected by maturity (Table 4.7; $P \geq 0.24$). Nitrogen balance was intermediate for LM, least for HD and greatest for RP (47.5, 37.1 and 53.2 g/d, respectively; $P = 0.022$).

4.5 Discussion

The current recommendation is to harvest oat at the LM stage when used in green feed or swath grazing systems (Saskatchewan Ministry of Agriculture, 2008). However, this recommendation is based on characteristics that optimize fermentation of the fresh forage into high quality silage

Table 4.5. Nutrient selection for heifers fed whole-crop oat (*Avena sativa*; cv. CDC Weaver) harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages.

	Stage of maturity				
	LM	HD	RP	SEM	*P* value
Forage offered, kg	5.3	5.3	5.6	0.32	0.76
Forage refused, kg	0.8	1.1	0.9	0.21	0.32
Refusal, % of offered	15.7	21.0	15.8	4.08	0.47
Forage intake, kg	4.3	4.0	4.5	0.48	0.74
Supplement intake, kg	4.1	4.1	4.1	0.01	0.89
DM intake, kg	8.1	7.8	8.3	0.34	0.26
DM intake, % BW	1.9	1.9	2.0	0.06	0.29
Selection index, %[1]					
DM	100.3	100.6	100.6	0.24	0.47
OM	100.1	100.2[z]	100.0	0.07	0.11
CP	102.5	104.1[z]	104.0[z]	0.82	0.32
NDF	99.5[a]	97.6[bz]	97.9[bz]	0.39	0.013
ADF	99.1[a]	96.0[bz]	97.3[abz]	0.68	0.026
Starch	106.4	110.5[z]	107.1[z]	2.05	0.31

[ab]Means within a row with the same superscript are not significantly different ($P > 0.05$).

[z]Values with a superscript indicate that value is different than 100.0 ($P < 0.05$)

[1]Selection index calculated as [(actual nutrient intake)/(theoretical nutrient intake)] × 100 according to Leonardi and Armentano, (2003).

Table 4.6. Rumen characteristics of heifers fed whole-crop oat (*Avena sativa*; cv. CDC Weaver) harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages.

	Stage of maturity				
	LM	HD	RP	SEM	*P* value
Ruminal pH					
Minimum	5.99[a]	5.84[b]	5.94[ab]	0.030	0.012
Mean	6.35[a]	6.30[b]	6.28[b]	0.013	0.003
Maximum	6.81	6.90	6.79	0.156	0.87
Ruminal SCFA, m*M*					
Total	118.68	116.37	117.10	0.84	0.21
Acetate	71.29[a]	69.55[c]	70.21[b]	0.035	< 0.001
Propionate	16.74[a]	16.17[b]	14.72[c]	0.016	< 0.001
Isobutyrate	0.66[c]	0.76[a]	0.70[b]	0.002	< 0.001
Butyrate	9.27[c]	11.05[b]	11.96[a]	0.016	< 0.001
Isovalerate	1.07[c]	1.34[a]	1.20[b]	0.009	< 0.001
Valerate	0.88[b]	0.91[a]	0.89[b]	0.003	0.001
Osmolality, m*Osm*	300.2[b]	299.9[b]	302.7[a]	0.42	< 0.001
Rumen ammonia, mg/dL	17.6[b]	16.7[c]	18.8[a]	0.10	< 0.001

[abc]Means within a row with the same superscript are not significantly different ($P > 0.05$).

Table 4.7. Nitrogen balance of heifers fed whole-crop oat (*Avena sativa*; cv. CDC Weaver) harvested at the late milk (LM), hard dough (HD) and ripe (RP) stages.

	Stage of maturity				
	LM	HD	RP	SEM	*P* value
N intake, g/d	183.5	179.7	198.9	8.00	0.24
N output, g/d					
Feces	54.1	52.8	55.8	3.82	0.86
Urine	81.9	89.8	89.9	4.22	0.39
Total N	136.0	142.6	145.7	7.07	0.64
N balance, g/d	47.5[ab]	37.1[b]	53.2[a]	6.29	0.022

[ab]Means within a row with the same superscript are not significantly different ($P > 0.05$).

(Acosta et al., 1992; McCartney and Vaage, 1994, Khorasani et al., 1997) instead of optimizing DM yield and nutrient digestibility of dry-preserved forage (Baron et al., 1992). A concern for harvesting whole-crop oat beyond the LM stage is the potential reduction in palatability and digestibility of the fibrous fractions (Linn and Martin, 1989). Moreover, concerns for whether the starch contained within the kernels will be available are prominent in industry.

Delaying the maturity at the time of harvest beyond that currently recommended (i.e. LM) resulted in an increase in DM yield. This finding supports past work showing that harvesting oat forage after LM results in increased DM yield (Kilcher and Troelsen, 1973; Bergen et al., 1991; Rosser et al., 2013). These data suggest that delaying the stage of maturity at harvest might help to improve forage yield and therefore reduce cost of forage production. Along with the increase in DM yield, there were notable increases in the concentration of starch, and a reduction in NDF concentration as plants advanced in maturity from the LM to RP. Similar responses have been previously observed for whole-crop oat (Rosser et al., 2013) that further suggests that the current recommendations may not optimize DM and nutrient yield. However, allowing plants to achieve full maturity may not optimize yield as we observed a slight reduction in DM yield between HD and RP stages from 4.7 to 4.2 t/ha, respectively. While this study was not designed to evaluate the reason for the loss in yield, we speculate that kernel loss at the time of cutting and baling were the primary causes (Smith, 1960, Edwards et al., 1968, Edmisten et al., 1998a and Stacey et al., 2006).

Harvesting whole-crop oat forage at LM and RP stages did not affect DMI, but harvesting at HD reduced it by 0.3 to 0.5 kg/d. The reduction in HD forage intake may be due to a reduction in palatability, or an increase in time required to breakdown HD forage compared to LM and RP forage. Palatability of forages can be affected by many different variables, ranging from chemical composition of forage to the physical characteristics. Aderibigbe et al. (1982) determined that the palatability of ryegrass varieties increased when the starch content of the plant increased from 14 to 25%. Ulyatt (1983) found that as forages mature there was an increase in the fragility of the forage, which resulted in an improvement in particle size reduction. The change in fragility of the forage could potentially explain the decreased DMI at HD compared to RP forage. The forage in the refusals from RP appeared to be more brittle compared to HD, however forage brittleness was not quantified. An increase in the rate for the reduction in particle

size could increase passage rate from the rumen, reducing ruminal fill, and potentially improving DMI (Allen, 1996). While improvements in passage rate and a reduction in ruminal fill could be possible explanations, there were no differences in DM or OM disappearance or flow from the rumen.

Harvesting at more advanced maturities results in increases in starch content, which could potentially result in decreased ruminal pH if the starch is available. It is clear that processing cereal grains such as barley and oat is required to optimize digestibility (Moran et al., 1986). For example, Moran et al. (1986) reported that rolled oat had an in situ 24 h DM disappearance rate of 64.9% compared to 11.1% when the oat was not processed. However, Morgan and Campling (1978) suggested that barley should be rolled before feeding to cattle, but that rolling oat would only be beneficial if being fed to mature cattle. If the starch is available, the increase in starch availability may reduce rumen pH, negatively affecting NDF digestibility (Krajcarski-Hunt et al., 2002). Results from the current study suggest that delaying the maturity at harvest does not negatively affect total tract DM or NDF digestibility. These findings support previous *in situ* work (Rosser et al., 2013) reporting that advancing maturity had no negative effect on *in situ* NDF degradability. In contrast, Beck et al. (2009) harvested wheat hay at the boot and HD stage and included it at 40% of the total diet DM. Beck et al. (2009) observed that delaying harvest resulted in reduced DM and NDF apparent total tract digestibility. The differential response between the current study and that of Beck et al. (2009) may be due to the wide range in maturity stages that they measured (boot and hard dough). The NDF and NFC content between these two diets had more drastic differences (-14, and 16%, respectively for NDF and NFC) compared to the maturities that were utilized in the current study (-10 and 9%, for NDF and NFC concentration).

Although there was an increase in starch for HD and RP compared to LM, there was a small but detectable reduction in ruminal and total tract starch digestibility of starch. The decrease in ruminal and total tract starch digestibility with advancing maturity suggests that increasing starch content present in the forage, specifically due to the grain, has a decreased availability with advanced maturity. That said, the total tract digestibility of starch was still approximately 95%, which is greater than the approximately 80% total tract starch digestibility found by Morgan and Campling (1978) when they provided whole oat grain at 50% of the diet. While the starch

digestibility decreased, the total amount of starch digested in the rumen (calculated as starch intake × ruminal digestibility) was 1.02, 1.56 and 1.44 kg starch in the rumen for LM, HD and RP, respectively. The reduction in minimum pH with advanced stages of maturity further confirms availability of starch in the rumen. It is important to note that the minimum ruminal pH for HD was only 5.84 indicating that while it was lower than the other treatments, the severity of pH depression would not be expected to negatively affect NDF digestibility (Krajcarski-Hunt et al., 2002). The combined effect of increased starch content but slightly reduced starch digestibility equated to DE values of 5.50, 5.40 and 5.75 Mcal/kg for LM, HD, and RP, respectively. Thus, delaying the maturity at harvest did not negatively affect energy content of the forage resource.

Due to suboptimal forage yield and the consequential availability, specifically at LM, the supplementation level of the diet (1.6% BW) was higher than producers would typically offer. This level was selected to ensure that there were adequate levels of forage present to complete the study. As shown in Table 4.5 supplement intake was 46.1 to 49.4% of the total diet, therefore at least half of DMI was from the whole-crop oat forage. Beck et al. (2009) provided 40% of the total diet as whole-crop wheat forage harvested at either the boot or hard dough stage and were able to see differences in DM and NDF total tract digestibility. Moreover, 25% of the supplement that was provided to the heifers consisted of alfalfa pellet in an attempt at increasing the overall forage content of the diet. Lintzenich et al. (1995) showed that even though alfalfa pellets were more available than unprocessed alfalfa it does not negatively impact either forage intake or digestibility.

4.6 Conclusion

These data suggest that harvesting whole-crop oat forage at the HD stage allows for increased DM yield, and DMI compared with the currently recommended stage, late milk. Harvesting at the mature stage also did not result in a reduction in DM digestibility, and only a minor decrease in starch digestibility, without negatively affecting ruminal fermentation characteristics or digestible energy intake. Future research is required to evaluate the effect of delaying harvest maturity of oat forage in a field setting, with minimal supplementation level.

5.0 EFFECT OF FEEDING WHOLE-CROP FORAGE DAILY OR IN 3-DAY ALLOCATIONS ON DRY MATTER INTAKE AND FERMENTATION CHARACTERISTICS

5.1 Abstract

It is currently recommended to allocate forage on a 3-d basis for swath grazing systems. However, 3-d allocations of forage might allow cows to increase selective consumption early in the forage allocation period and may increase the risk for ruminal acidosis with forages that contain sufficient quantities of starch. The objective of this study was to determine whether the feeding frequency of whole-crop oat forage harvested at two maturities affects forage intake and ruminal fermentation. Whole-crop oat forage (c.v. CDC Weaver) was harvested at the hard dough (HD) and ripe (RP) stages and offered ad libitum either daily (1-D) or once every 3 d (3-D) to 4 ruminally cannulated heifers. Treatments were arranged in a 2 × 2 factorial arrangement within a 4 × 4 Latin square design. However, due to low forage availability, 1 period was omitted resulting in an incomplete Latin square. Diets were supplemented to ensure CP was balanced across treatments. Dry matter and forage intake were not affected by harvest maturity or feeding frequency ($P \geq 0.649$). Minimum ruminal pH averaged over 3 days was lower in heifers fed 3-D (5.53) compared to heifers fed 1-D (5.89; $P < 0.001$). Mean pH throughout the 3-d feeding cycle increased from 5.81 to 5.99, and 6.35 for d 1, 2, and d 3, respectively, for heifers fed 3-D (frequency × day; $P = 0.002$). However, mean pH did not differ among days for heifers fed 1-D (average pH of 6.32). Total ruminal SCFA concentrations did not differ among days of the feeding cycle for heifers fed 1-D (122.17 ± 1.21 m*M*), but decreased from d 2 (135.51 m*M*) to d 3 (117.34 m*M*; $P = 0.038$) for heifers fed 3-D. These data suggest that feeding 3-D may not affect forage intake, but increases the risk for decreased ruminal pH occurring on the day of feeding, and reduces ruminal SCFA concentrations across the 3-D cycle.

5.2 Introduction

Implementation of extensive winter feeding practices, such as swath grazing, have been reported to reduce the cost of production relative to feeding cattle in confinement without affecting production responses for mature beef cattle (Volesky et al. 2002; McCartney et al. 2004). For

swath grazing, it has been suggested to provide a 3-d allocation of the forage to reduce labor costs and feed wastage (Saskatchewan Ministry of Agriculture, 2009c). However, it is not clear whether altering the forage allocation frequency from 1 to 3-d impacts voluntary intake or ruminal fermentation of the cattle fed 3-d allocations instead of daily forage allowances.

While there is no doubt that 3-d allocations of forage will reduce labor cost, providing multiple days of forage may increase the selective consumption of the higher quality portions of the whole-crop forage, such as the grain and leaf material on the first day. With this selective consumption there may be a decrease in the utilization of the forage, increasing the amount of forage that will be needed over the winter feeding period. Those higher quality portions are generally more digestible than the stems (Kilcher and Troelsen, 1973; Chow et al., 2008), which in the case of the grain could result in drastic a drop in ruminal pH and the onset of ruminal acidosis. Exposure to ruminal acidosis could potentially reduce DMI, as well as the digestibility of fiber components of the forage (Calsamiglia et al., 2002). Sorting for grain in the initial part of the forage allocation period would most likely result in decreased feed quality (DeVries et al., 2005) and availability for the second and third day of the feeding period. Smith (1974) found that as forage allocation was increased from daily to once every 4 days there was an increase in forage that was refused as a percentage of offered.

As shown in Section 3.0 and 4.0 it is possible to harvest whole-crop barley and oat forage at maturity stages that are later than currently recommended to improve DM yield without major negative effects on feed intake and digestibility. Harvesting at more mature stages resulted in increases in starch content, but the minimum ruminal pH was never below 5.5, which would suggest SARA. However, in Chapters 3.0 and 4.0, forage was offered twice daily (0800 and 1600 h) which differs from industry practice and may reduce the ability of the cows to sort through the forage for the grain. Thus, the objective of this study was to determine whether the frequency of forage allocation and harvest maturity of whole-crop oat forage influences voluntary DMI over a 3-d period and ruminal fermentation characteristics both daily and over a 3-d period.

5.3 Materials and methods

5.3.1 Agronomic practices

Forage that remained after the experiment described in Chapter 4 was utilized in this experiment. For a description of the agronomic practices and harvesting method refer to Section 4.3.1 and 4.3.2. However, for this study only forage harvested at the HD and RP stages were utilized. The HD and RP stages were utilized because allowing forage to mature past LM provided more forage without large decreases in forage intake and digestibility (Rosser et al., 2013). The environmental conditions during the harvest year, and the harvest dates are shown in Table 4.1.

5.3.2 Experimental design

Four ruminally cannulated heifers (441 ± 16 kg) were used for this study. The experimental design consisted of a 4 × 4 Latin square with a 2 × 2 factorial treatment arrangement. Periods were 15 d including 9 d of adaptation and 6 d for data and sample collection. The main treatment factors evaluated were the maturity of whole-crop oat at the time of harvest (**HD** vs. **RP**) and the frequency of feed allocation [once daily (**1-D**) vs. once every 3 d (**3-D**)]. The whole-crop oat forage was allocated for ad libitum intake, targeting approximately 20% refusal of forage offered. Each heifer was also provided a supplement at a fixed rate of 1.6% of BW in a separate feeder. The supplement consisted of (DM basis) 25% alfalfa pellet, 20% vitamin and mineral supplement and 55% rolled barley and canola meal combination (Table 4.2). The proportion of rolled barley and canola meal were formulated in an attempt to make diets isonitrogenous. The supplement was offered daily to all of the heifers, regardless of treatment, at 0900 h. The whole-crop oat forage was fed at 0900 h for 1-D and at 0900 h on d 1, 4, 7, 10 and 13 for 3-D. All experimental procedures involving heifers were pre-approved by the University of Saskatchewan Animal Research Ethics Board (protocol no. 20100021) and followed the guidelines of the Canadian Council of Animal Care (2009).

5.3.2.1 Animal performance and dry matter intake

Heifers were weighed on two consecutive days before 0800 h at the start and end of each period. Average daily gain was calculated based on weight gain over the 15-d period. Voluntary DMI was determined during d 10 to 15. On each d of feed provision, the amount of feed allocated was weighed. Refusals were weighed prior to the morning feeding (daily for 1-D, and on d 13 and d 1

of next period for 3-D) and a sample equating to 10% of the refusal weight was collected at each sampling day and stored at -20 °C for later analysis. The DMI was calculated by subtracting the weight of the refusal from the weight of feed offered once corrected for DM content. Feed samples were collected daily throughout d 10 to 15 and, within heifer were composited by period.

5.3.2.2 Ruminal fermentation

On d 10 to 12, ruminal pH was measured every 5 min using an indwelling pH system described by Penner et al. (2006). The pH systems were standardized with pH buffers of 4 and 7, as described in Section 3.3.3. Standardization occurred prior to being inserted into the rumen on d 10 and the morning of d 13 of each period after removal from the rumen. Minimum, mean and maximum ruminal pH was then calculated both daily and over the 3-d measurement.

Rumen digesta was collected from the cranial central, central and caudal central regions (250 mL each) at 1400 and 2000 h on d 13, at 0200, 0800, 1400 and 2000 h on d 14, at 0200, 0800, 1400 and 2000 h on d 15, and 0200 and 0800 on d 1 of next period, but prior to feeding the subsequent treatment. The samples collected at 1400 and 2000 h on d 13, 0200 and 0800h on d 14 were composited to represent day 1; 1400 and 2000 h on d 14, 0200 and 0800h on d 15 were composited to represent day 2; 1400 and 2000 h on d 15, 0200 and 0800h on d 1 were composited to represent day 3. Digesta from each region was combined and strained through 2 layers of cheesecloth. For short chain fatty acid (SCFA) and ruminal ammonia analysis, 10 mL of rumen fluid was added to 2 mL of 25% (w/v) metaphosphoric acid, and 2 mL of 1% sulfuric acid, respectively. For osmolarity analysis 10 mL of the rumen fluid was collected at each sampling point. The rumen fluid samples were then stored at -20 °C until further analysis.

5.3.4 Chemical analysis

Samples were analyzed as described in section 3.3.4.

5.3.5 Statistical analysis

Due to a shortage in forage, only the first 3 periods were completed, resulting in an incomplete Latin square. Data were analyzed using Mixed Model procedure of SAS (Version 9.3, Cary, NC). For analysis of intake data, fixed effects were maturity, allocation frequency and the

interaction of maturity and allocation. Heifer was considered to be a random effect. To analyze ruminal fermentation characteristics fixed effects included in the model were maturity, allocation frequency and day, as well as the 2-way and 3-way interactions. Heifer was considered a random effect. Day within period, was analyzed as a repeated measures. When significant ($P < 0.05$), means were separated using the Bonferroni post-hoc mean separation test. Significance was declared when $P \leq 0.050$.

5.4 Results

Total and forage DMI over 3 days was not affected by maturity, allocation or the interaction of maturity and allocation (Table 5.1; $P \geq 0.41$) averaging 34.5 and 26.2 kg, respectively. Mean and minimum ruminal pH were less when forage was allocated 3-D instead of 1-D ($P \leq 0.010$). Minimum ruminal pH was decreased when forage was harvested at RP compared to HD. Duration and area that pH < 5.8 was significantly higher for 3-D, compared to 1D ($P = 0.004$). Whole-crop oat forage that was harvested at RP had a larger area pH was below 5.8 ($P = 0.041$) compared to HD. Total ruminal SCFA concentration was not affected by harvest maturity or allocation averaging 126 m*M* ($P \geq 0.14$). Propionate concentration tended to increase ($P = 0.066$) and isovalerate and valerate concentrations increased ($P \leq 0.016$) for 3-D compared to 1-D. Ruminal ammonia concentration was greater for HD compared to RP (averaging 7.6 and 6.3 mg/dL, respectively; $P = 0.040$).

There were no interactions between maturity and day on any ruminal fermentation characteristics measured (Table 5.2; $P \geq 0.13$). Over the 3-d measurement, maximal ruminal pH was intermediate for cows that were allocated forage 1-D, whereas 3-D had the greatest maximum pH on d 1 and 3, and the lowest pH on d 2 ($P = 0.010$). Mean ruminal pH was not different between days for 1-D cows, and was at an intermediate level (average 6.33). The mean ruminal pH of cows allocated 3-D increased from d 1 to 3 ($P = 0.001$). Minimum ruminal pH was greatest for 1-D on d 1, intermediate for 3-D on d 2 and 3 and for 1-D cows throughout measurement, and lowest for 3-D cows on d 1 ($P = 0.014$). The duration and area that ruminal pH was below 5.8 was greatest for 3-D compared to 1-D, and for 3-D it decreased with days ($P = 0.003$). Total ruminal SCFA concentrations were intermediate for 1-D, and 3-D on d 2 (average 125 m*M*), greatest for 3-D on d 1 (138 m*M*), and least for 3-D on d 3 (117 m*M*; $P = 0.046$).

Table 5.1. Intake and ruminal fermentation characteristics of heifers fed whole-crop oat (*Avena sativa*; cv CDC Weaver) harvested at hard dough (HD) and ripe (RP) stages, and either fed daily (1-D) or in 3-day (3-D) allocations.

	HD		RP			*P* values		
	1-D	3-D	1-D	3-D	SEM	Maturity	Allocation	Maturity × Allocation
DMI, kg/3 d								
Total	33.5	36.1	34.3	34.2	2.36	0.79	0.54	0.52
Forage	25.1	27.9	26.0	25.8	2.14	0.74	0.47	0.41
Supplement	8.4	8.2	8.3	8.4	0.28	0.86	0.87	0.64
Ruminal pH								
Maximum	6.77	6.69	6.76	6.74	0.064	0.72	0.37	0.78
Mean	6.36^{a}	6.10^{b}	6.30^{a}	5.99^{b}	0.082	0.32	0.010	0.75
Minimum	5.93^{a}	5.64^{ab}	5.84^{a}	5.43^{b}	0.079	0.088	0.002	0.44
Duration < 5.8, min/d	1.1^{b}	273.3^{ab}	77.2^{ab}	502.8^{a}	87.36	0.119	0.004	0.41
Area < 5.8, pH × min/d	0.1^{b}	44.7^{ab}	6.1^{b}	158.5^{a}	24.65	0.041	0.004	0.060
Ruminal SCFA, m*M*								
Total	123.25	129.36	120.81	131.34	5.269	0.95	0.14	0.62
Acetate	90.51	81.33	84.43	78.50	3.697	0.28	0.20	0.68
Propionate	20.38	33.11	22.15	36.81	3.836	0.43	0.066	0.82
Isobutyrate	0.71	0.86	0.83	0.87	0.149	0.64	0.65	0.78
Butyrate	11.68	11.72	12.26	11.58	3.061	0.93	0.94	0.93
Isovalerate	1.32^{b}	2.23^{a}	1.33^{b}	2.12^{a}	0.427	0.81	0.007	0.83
Valerate	0.75^{b}	1.03^{a}	0.86^{b}	1.11^{a}	0.113	0.22	0.016	0.84
Ruminal ammonia, mg/dL	7.1^{a}	8.1^{a}	6.1^{b}	6.4^{b}	0.37	0.040	0.20	0.52
Osmolality, m*Osm*	286.2	284.5	305.5	322.4	16.34	0.11	0.65	0.58

^{ab}Means within a row with the same superscript are not significantly different ($P > 0.05$).

Table 5.2. Daily ruminal fermentation characteristics of heifers fed whole-crop oat (*Avena sativa*; cv CDC Weaver) either daily (1-D) or in 3-day (3-D) allocations.

	Day 1		Day 2		Day 3			*P* values		
	1-D	3-D	1-D	3-D	1-D	3-D	SEM	Day	Allocation × Day	Maturity × Day
Ruminal pH										
Maximum	6.77^{ab}	6.81^{a}	6.77^{ab}	6.51^{b}	6.76^{ab}	6.81^{a}	0.060	0.012	0.010	0.29
Mean	6.34^{ab}	5.81^{c}	6.31^{ab}	5.99^{bc}	6.33^{ab}	6.35^{a}	0.071	0.001	0.001	0.79
Minimum	5.96^{a}	5.29^{c}	5.84^{ab}	5.45^{bc}	5.86^{ab}	5.86^{ab}	0.091	0.049	0.014	0.91
Duration < 5.8, min/d	5.0^{b}	736.7^{a}	79.2^{b}	361.7^{b}	33.3^{b}	65.8^{b}	83.68	0.007	0.003	0.82
Area < 5.8, pH × min/d	0.0^{b}	214.4^{a}	7.0^{b}	79.5^{b}	2.2^{b}	10.9^{b}	26.06	0.004	0.003	0.13
Ruminal SCFA, m*M*										
Total	122.14^{ab}	138.37^{a}	123.18^{ab}	135.43^{ab}	120.76^{ab}	117.26^{b}	3.925	0.027	0.046	0.94
Acetate	87.02	83.65	88.47	80.84	86.92	75.26	3.187	0.23	0.28	0.92
Propionate	21.09	37.61	21.47	38.13	21.25	29.15	3.695	0.16	0.19	0.99
Isobutyrate	0.84	0.83	0.75	0.88	0.70	0.88	0.094	0.45	0.087	0.86
Butyrate	12.51	12.92	11.95	12.28	11.46	9.76	2.675	0.43	0.67	0.76
Isovalerate	1.43	1.23	1.31	2.35	1.23	1.68	0.468	0.14	0.38	0.95
Valerate	0.83	1.14	0.80	1.21	0.78	0.86	0.136	0.13	0.20	0.99
Ruminal ammonia, mg/dL	6.60	6.55	6.61	6.55	6.59	8.74	0.526	0.13	0.12	0.93
Osmolality, m*Osm*	318.1	285.0	287.7	340.0	281.6	285.4	32.69	0.66	0.41	0.72

[abc]Means within a row with the same superscript are not significantly different ($P > 0.05$).

Ruminal ammonia and osmolality were not affected by forage allocation or day ($P \geq 0.12$).

5.5 Discussion

To reduce costs associated with winter-feeding, especially labor it has been suggested to provide forage in 3-d allocations. Providing forage in 3-d allocations instead of daily can result in reduced costs associated with labor (McCartney et al., 2004). When dairy cows were offered feed once daily instead of twice daily there was an increase in the NDF concentration of the refusal (DeVries et al., 2005). Smith (1974) found that when the forage allocation was increased from daily to once every 4 days there was an increase in forage refusals as percentage of offered. To our knowledge there have not been any studies that have determined feeding behavior of cattle in swath grazing systems comparing various allocation periods (e.g. daily vs. 3 d vs. 7 d). Increased sorting and altered feeding behavior could potentially result in changes in intake over the allocation period, which would impact rumen fermentation patterns especially within the allocation period.

Increasing forage allocation period can potentially result in high quality components of the forage being consumed the first day, leaving lower quality components on subsequent days. This could result in reduced intakes the subsequent days, variation in nutrient availability and supply among days, and could result in reduced utilization of the forage. Feeding allocation did not have an effect on the voluntary DMI in our experiment, which was also found by Kolver et al. (1998), Krehbiel et al. (1998) and Atkinson et al. (2010). This could potentially be due to a change in feeding behavior of the cows. Ruiz and Mowat (1987) suggested that when feed was provided ad libitum, feeding frequency did not have an effect on DMI. Phillips and Rind (2001) reported that feeding cows a total mixed ration (TMR) on alternate days, compared to daily resulted in increased time spent eating and ruminating. McCartney et al. (2004) found that providing silage on alternate days instead of daily resulted in deceased DE intake/cow/d, compared with providing silage daily. This suggests that allocating forage over longer periods of time can have variable effects on feeding behavior and changes in fermentation patterns.

Feeding a 3-d allocation of forage instead of providing it daily resulted in the heifers sorting through the forage, and consuming the grain component of the forage on the first 2 d of the 3-d feeding cycle. DeVries et al. (2005) formulated a diet to have a forage:concentrate ratio of 49:51,

which was offered either once a day, or twice a day, then measured the forage to concentrate ratio of the refusals. They found that when the TMR was only provided daily the forage to concentrate ratio was 63:37, instead of 55:45 for the refusals from the cows fed twice daily. Extrapolating the TMR sorting characteristics to our model, it could be suggested that heifers that were provided forage 3-D would have sorted their forage to a greater extent than 1-D heifers. This suggestion is supported by the interaction between allocation frequency and day of measurement with 3-D heifers having ruminal pH values that were lowest on d 1 and increased to d 3. In the current study heifers were provided supplement daily, suggesting that the difference in ruminal pH from d 1 to 3 was due to the forage and the subsequent sorting of the forage, not the amount of concentrate that was provided to them daily.

Minimum ruminal pH was lowest and the duration and area pH < 5.5 was greatest when 3-D forage allocation was utilized. This is likely due to increased sorting since ruminal pH increased over the 3-d period, suggesting they consumed large quantities of grain the first 2 d, then had to consume lower quality forage on d 3. The severity of the ruminal pH drop was increased when the forage was harvested at RP compared to HD. This is contrary to the results shown in Chapter 4, where oat forage harvested at HD had lower ruminal pH when compared with RP. A potential reason for the difference observed may be differences in heifer maturity affecting starch digestibility (Morgan and Campling, 1978).

Total SCFA concentration was higher for heifers that were fed 3-d allocation of the whole-crop oat forage. This was similar to the results found by Kartchner and Adams (1982), where cows that were supplemented with grain on alternate days had higher ruminal SCFA concentration when compared to the cows that were supplemented daily. In the current study the increased SCFA concentrations on d 1 and 2 is likely due to the heifers preferentially sorting for grain, which is high in energy (Kilcher and Troelsen, 1973).

5.6 Conclusions

Providing forage in 3-d allocations did not negatively impact DMI, but did cause fluctuations in rumen fermentation characteristics. These fluctuations, especially for duration and area that pH < 5.5, were more extreme when the forage was harvested at RP. Providing forage in larger

allocations results in the potential risk of SARA occurring, which is a management issue for producers.

6.0 GENERAL DISCUSSION

The global objective of this thesis was to determine the optimal stages of maturity at the time of harvest for barley and oat when used for swath grazing or green feed. It was hypothesized that harvesting whole-crop barley and oat forage after the soft dough and LM stages, respectively, would allow producers to increase forage yield without negative effects on forage intake, fermentation characteristics or total tract digestibility. Supporting the hypothesis, the data indicates that to optimize the yield, quality, and intake of forage, ruminal fermentation and total tract-digestibility the optimal harvest maturity of whole-crop barley and oat forage is HD.

Allowing barley and oat forage to advance in maturity has been reported to increase forage yield (Baron et al., 1992; Rosser et al., 2013) without negatively affecting forage intake, ruminal fermentation or digestibility (see chapter 3 and 4). Rosser et al., (2013) used the same harvest maturities grown in the same soil zone and found that harvesting barley and oat whole-crop forage resulted in linear increases in DM yields. Collectively, harvesting whole-crop barley and oat forage at the HD stage would result in increased forage yields (Rosser et al., 2013) without negative impacts on forage intake, ruminal fermentation or total-tract digestibility.

While there appears to be a major advantage for yield when allowing whole-crop cereal grains to become more advanced at the time of harvest, allowing plants to achieve full maturity is not recommended. Baron et al., (1992) found that whole-plant yield became more variable when harvested around the fully ripe stage, and suggested that this variability may be due to kernel loss and leaves senescing. This could be a potential reason for the decrease in DM yield observed in Chapter 4 for oat forage harvested at RP compared to HD. Smith (1960) suggested that the amount of kernel loss that takes place when forage is harvested around the ripe stage is dependent on year but risk for kernel loss increases with advancing maturity. Variation in kernel losses across years could also help to explain why Rosser et al. (2013) found that harvesting RP forage did not decrease DM yield for barley and oat, as well as the fact that they were harvesting forage by hand, not mechanically, which may reduce risk for kernel loss.

The increase in available forage when harvesting at later maturities could have a significant impact on the cost of production, especially considering that DMI, selective consumption, and total tract digestibility were not negatively affected. The 10-yr average price for green feed in

Saskatchewan (Saskatchewan Ministry of Agriculture, 2013) is $57.62/t of DM, assuming 85% DM. Using the 10-yr average price, delaying harvest from LM to HD could result in increased forage revenue of $84.71/ha and $149.24/ha for barley and oat. Alternatively, producers could increase the number of head grazing that particular area of land by 23 and 57% for barley and oat, respectively. Assuming a utilization rate of 71.7% (Baron et al., 2014), and 550 kg cow, that consumes 2.5% of BW, the carrying capacity would increase from 183 cow d/ha to 260 cow d/ha for barley harvested at LM and HD, respectively. Using the same assumption, delaying oat harvest from LM to HD would result in an increase from 110 cow d/ha to 245 cow d/ha.

Harvesting barley and oat forage at later maturities increased the amount of starch, and therefore grain component of the forage. For both barley and oat forage, the starch content of the forage increased from approximately 2.9% at LM to 25% and 14.5%, respectively at HD. Increasing the grain content within the forage could result in some potential issues for producers if they wish to adopt harvesting annual forages at later maturities. The increase in grain content did not result in a large decrease in ruminal pH in Section 3 and 4, with the lowest minimum ruminal pH 6.08 and 5.84, for barley and oat, respectively. However, forage was provided twice daily which would reduce the amount of sorting that would occur and may not truly reflect field feeding conditions. In a swath grazing system where forage was provided in larger allocations, the increase in grain content in combination with increased sorting potential could result increased risk for SARA. As such, future studies are needed to determine whether the risk for SARA is real or just a perceived risk when fed under field feeding conditions.

To partially address the frequency and quantity of forage allocation, a study was conducted to compare providing 1-d of forage or 3-d of forage to beef heifers. Providing a 3-d allocation of forage did not negatively affect forage intake, but increased fluctuations in ruminal fermentation. The increased daily fluctuations in ruminal fermentation may indicate a greater risk for SARA early on in a 3-d forage allocation period. The rumen fermentation data suggests that on the final day of the feeding period the heifers were left with the lower quality forage, which may have reduced their intakes. Low feed intake (Albornoz et al., 2013a,b; Zhang et al., 2013a,b) followed by high consumption of starch is a significant risk factor for ruminal acidosis (Schwaiger et al., 2013). Thus, if producers are interested in increasing forage yield by allowing the forage to be more advanced in maturity at the time of harvest they should ensure that forage allocations do

not exceed 3 d. More research is required to determine an optimal forage allocation schedule in a swath grazing system.

It has been suggested that forages utilized in swath grazing systems should be harvested as close to the first frost as possible to reduce nutrient leaching from the swaths (Aasen et al., 2004). However, delaying seeding of barley and oat can result in decreased yields (Baron et al., 1994; Kibite et al., 2002; May et al., 2007; Baron et al., 2012). One potential option to reduce the amount of weathering that would happen to the swaths without reducing forage yield would be to harvest at later maturities. Harvesting at later maturities would allow producers to seed at similar times to produce optimal forage yields and reduce the time swaths are in the field before the first frost. The effect of harvest maturity on the amount of leaching that will occur has not been investigated. However, delaying harvest of barley and oat forage from the milk to dough stage resulted in a decrease in WSC (Bergen et al. 1991). This could suggest that leaching losses may be lower for whole-crop barley and oat forage that is harvested at later maturities.

While the results of the studies within this thesis support those of Rosser et al. (2013) and Baron et al. (1992) and appear very positive, research is needed to determine the impact of harvest maturity on forage utilization under field-based conditions. In the studies in this thesis, heifers were supplemented with alfalfa pellet, barley grain, canola meal and a vitamin and mineral pellet at a rate of 0.8 and 1.6% of BW, which is higher than levels most producers would utilize in swath grazing systems. Providing high levels of supplementation has the potential to reduce the ability to pick up on response differences that are directly related to harvest maturity of the forage. Supplementation levels were determined to ensure that we had adequate forage throughout the entire length of the studies. For the barley (Chapter 3) and oat harvest maturity studies (Chapters 4 and 5) heifers were supplemented at 0.8 and 1.6% of BW, respectively. For the barley experiment, the supplementation level equated to 37.5 to 43.1% of the diet, and for the oat experiments the supplementation equated to 46.1 to 49.4% of the diet. While these are high rates of supplementation, it should be noted that 16.6 and 25% of the supplement for barley and oat respectively, consisted of alfalfa pellets and therefore the ‘concentrate’ level was only 31.3% and 32.3% of the total diet for barley and oat. The approach to provide alfalfa pellets as part of the supplement was to ensure that total diet contained a high forage to concentrate ratio. It is acknowledged that pelleted alfalfa is highly available but past studies have shown that pelleted

alfalfa does not negatively influence forage intake or digestibility (Lintzenich et al., 1995). Thus, it is concluded that the level of supplementation was justified and is not likely to bias the results or conclusions drawn from the data. Moreover, Beck et al. (2009) fed wheat forage harvested at boot and HD stages, and found that only providing the forage at 40% of total DM resulted in no difference in DMI, but differences in DM and NDF digestibility. This suggests that even though the forage was only provided at 40% of the total diet they could still observe a difference in DM and NDF digestibility between whole-crop wheat forage harvested at the boot and hard dough maturity stages.

A second consideration is that this research was conducted in individual pens within a barn setting, where it was possible to measure more variables than would be possible within a field-feeding setting. Some of these variables include total urine and fecal collections, as well as site of digestion which utilized 10 d of continual intra-ruminal marker infusions to ensure steady marker state. However, a weakness of the research is that the effects of animal interactions, or the effects of environment during the grazing season could not be evaluated. It has been suggested that when cattle are on pasture winter grazing their maintenance energy requirements can increase by 10 to 20% compared to cattle that are in a barn (NRC, 2000). McCartney et al. (2004) found that cattle that were over-wintered in swath grazing systems required 18 to 21% more DE for maintenance compared to cattle that were fed in a dry-lot setting. Both temperature and precipitation can have a significant impact on intakes and performance of cattle in winter-grazing systems. When it is colder, and there is more snow it is assumed that there will be a reduction in forage intake (Adams et al., 1986) due to a change in feeding behavior.

Delaying harvest of barley and oat could result in an increased incidence of some plant diseases, such as ergot, which could have a significant impact on production and management. While this is a concern, barley and oat are less susceptible to ergot contamination compared to other crops like rye, but harvesting at later maturities does increase the potential risk of ergot. When barley and oat are contaminated with ergot some of the grain is replaced with ergot bodies, which produce ergot alkaloids (Gilles et al., 1972). Consumption of ergot alkaloids can result in reduced performance, as well as abortion (Strickland et al., 2011). Allowing the forage to advance in maturity can potentially increase the amount of alkaloids that are produced. This is a potential concern that producers would have to recognize if they adopt later harvest maturities.

With the increased risk producers should scout their crops looking for ergot bodies to determine their management strategy. Whatley (2014) suggested that if the presence of ergot bodies is noted it may be favorable to harvest at later maturities, allowing wind to remove the ergot bodies from the cereal heads. If this is the strategy implemented it would be suggested that that field not be seeded with cereals the next 2 years, since the ergot bodies can survive for up to 2 years in the soil (Whatley, 2014). If only part of the field was infected with ergot it may be suggested to remove that forage from the swath grazing site to avoid the negative consequences associated with ergot alkaloids. Another management strategy could be to provide supplemental forage with the ergot-infected forage to dilute the ergot concentration in the forage.

Finally, different types of cattle have different nutrient requirements and eating behavior, which means recommendations for harvest maturity will be different. Calves are still growing and therefore require more protein and energy than a mature beef cow, and they have different eating behaviors. Immature cattle tend to chew their feed more (Morgan and Campling, 1978), resulting in increased damage to grain pericarp making starch more available to rumen microbes. Starch digestibility of a 50:50 hay and whole barley diet decreased from 61.6% to 58.5% as heifers matured from 7 to 16 months respectively, (Morgan and Campling, 1978). This increased accessibility to the grain could potentially result in a reduction in ruminal pH, causing ruminal acidosis. Harvesting forage at earlier maturities would decrease the amount of starch that is present in the whole-crop forage, reducing the risk of acidosis.

7.0 CONCLUSION

Harvesting barley and oat forage at the hard dough stage results in improvements in forage yield without negatively impacting intake, digestibility or fermentation characteristics relative to the late milk stage. However, producers should be cautious when providing cattle with high quantities of whole-crop forage as providing forage in 3-d allocations may increase the risk for ruminal acidosis, especially when forage is advanced in maturity.

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