THE EFFECT OF UTILIZING FORAGE PEA FOR HAY ON FEED INTAKE, RUMINAL FERMENTATION, AND DIGESTIBILITY WHEN FED TO BEEF CATTLE

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ABSTRACT

The purpose of this research was to evaluate field pea (*Pisum sativum* L.; c.v. CDC Horizon) harvested as hay on feed intake, ruminal fermentation, and total tract digestibility in beef heifers. In the first study, pea hay was mixed with barley (CDC Maverick) or oat (CDC Haymaker) hay at 0, 15, or 30% of the hay dry matter (DM), and offered *ad libitum* to ruminally-cannulated Hereford crossbred heifers in a 6 × 6 Latin square design. In the second study, field pea hay (CDC Horizon) was harvested at early, mid, or late stages of maturity. Pea hay was included at 40% of the dietary DM, and the diet was offered ad libitum to ruminally-cannulated Speckle Park heifers in a duplicate 3 × 3 Latin square design. In Study 1, dry matter intake increased with pea hay inclusion rate relative to 0% inclusion ($P = 0.03$). Ruminal fermentation was altered as mean ruminal pH increased with pea inclusion relative to 0% inclusion ($P \leq 0.013$). There was no difference in total short-chain fatty acid (SCFA) concentration ($P \geq 0.55$) while pea hay inclusion rate linearly increased butyrate and decreased propionate ($P \leq 0.013$); furthermore, ruminal ammonia increased quadratically with inclusion rate ($P < 0.001$). Pea hay inclusion rate did not affect microbial protein synthesis or nitrogen retention ($P \geq 0.77$). In Study 2, advancing maturity of pea hay resulted in numerically greater forage DM yield, but did not affect dry matter intake, ruminal SCFA concentration, or total tract digestibility. Advancing maturity decreased rumination ($P \leq 0.016$), ruminal pH ($P = 0.005$), and ruminal passage rate ($P = 0.022$). The data from these two studies suggest that CDC Horizon field pea is a potential forage source for beef cattle that may increase CP content of the forage and increase dry matter intake without compromising ruminal fermentation. When field pea is grown in combination with cereal forage, the whole-crop pea may be harvested based upon the maturity of the cereal hay without concern of reduced feed intake or digestibility given that pea hay maturity had only minimal effects on cattle responses.

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LIST OF ABBREVIATIONS

ADF	acid detergent fiber
ADG	average daily gain
$aNDF_{OM}$	ash-free neutral detergent fiber
BP	barley-pea mixture
BW	body weight
CDC	Crop Development Centre
CP	crude protein
DE	digestible energy
DM	dry matter
DMI	dry matter intake
EARLY	early maturity pea hay
EE	ether extract
GDD	growing degree days
k_d	rate of ruminal degradation
k_p	rate of ruminal passage
LATE	late maturity pea hay
MID	mid maturity pea hay
NDF	neutral detergent fiber
NFC	non-fibrous carbohydrates
OM	organic matter
OP	oat-pea mixture
pdNDF	potentially degradable neutral detergent fiber
SCFA	short-chain fatty acids
SEM	standard error of mean
uNDF	undigestible neutral detergent fiber

1.0 GENERAL INTRODUCTION

Feed costs account for a large proportion of total costs of cattle production with estimates as high as 60% of the total cost (Kaliel and Kotowich, 2002). In order to increase efficiency, reducing feed cost without affecting productivity is critical for cow-calf producers. One of the cheapest and most feasible methods of providing forage to beef cows, specifically in winter when pastures may not be growing fresh forage, is through the use of dry-preserved forage. In western Canada, cow-calf producers are able to provide a forage-based diet to their cattle year-round by utilizing a combination of summer pasture grazing with fresh forages, and winter-feeding systems with dry-preserved forage. These winter-feeding systems have allowed producers to shift from a more intensive drylot management system and may include winter-feeding methods such as: stockpiled forage; swath grazing; bale grazing; bale processing in the field; and feeding baled hay.

In order to ensure production of dry preserved forages is optimized, it is important to consider both forage yield and forage quality. Recent research has demonstrated that forage DM yield is increased by delaying harvest of annual cereals from late milk to hard dough or ripe stages (Rosser et al., 2013; Rosser et al., 2016). Forage yield may also be increased by the addition of legumes into the cereal forages; however, the data are variable with reports of increased total DM yield in response to cereal-legume blends (Carr et al., 2004), while others have reported no difference in DM yield with blends as compared to the sole cereal crops (Walton, 1975; Berkenkamp and Meeres, 1987; Aasen et al., 2004; Strydhorst et al., 2008). As such, while the addition of legumes into cereal forages may not always improve DM yield, it is clear that legume incorporation does not compromise DM yield. Legume species have a symbiotic relationship with *Rhizobium* bacterial species which allows for biological nitrogen fixation and can improve soil fertility in areas producing cereal crops, particularly increasing yield of crops following a legume harvest in the same field (Zahran, 1999). Furthermore, including legumes into a cereal diet improve forage quality with increased CP concentration (Berkenkamp and Meeres, 1987; Carr et al., 2004), decreased fiber concentration, and improved digestibility (Thornton and Minson, 1973; Bruno-Soares et al., 1999; Mustafa et al., 2000).

While alfalfa (*Medicago sativa* L.) is a commonly utilized and studied legume source for cattle diets, field pea (*Pisum sativum*) is gaining popularity as well. Field pea has often been used as a grain source for protein supplementation (Khorasani et al., 2001; Reed et al., 2004; Anderson et al., 2007; Vander Pol et al., 2008; Vander Pol et al., 2009; Soto-Navarro et al., 2012). As such, field pea cultivars were developed for grain characteristics. Recently; however, pea has been increasingly used as a forage source. Traditional forage pea cultivars may be problematic to harvest as a forage crop because they have tall, weak stems, making them prone to lodging. In order to address these production and harvest issues, the Crop Development Centre at the University of Saskatchewan developed several cultivars of forage-type field pea. Cultivars in particular include CDC Tucker, CDC Leroy, and CDC Horizon (Warkentin et al., 2012). The CDC Horizon cultivar was developed to improve forage quality and production (Warkentin et al., 2012). This cultivar was also developed to produce greater forage DM yield, and resistance to powdery mildew losses. Furthermore, CDC Horizon is a semi-leafless type forage pea with medium stature and strong stems, improving its lodging resistance. Currently there are no studies evaluating the responses of cattle when fed CDC Horizon. Being that this cultivar was selected as a forage during growth and harvest, it is possible that these same characteristics which are beneficial for crop production will actually have a countereffect on palatability and digestibility. For this research, CDC Horizon was evaluated in combination with cereal forage and at varying harvest maturities for use in feeding trials with beef cattle.

2.0 LITERATURE REVIEW

2.1 Feeding Management Systems for Beef Cattle During Winter

2.1.1 Shifting from intensive to extensive winter-feeding systems

Managing beef cattle throughout the winter requires many considerations. Such considerations involve ensuring adequate shelter is provided to protect cattle from the wind and providing fresh water. Cattle selection is also required as cattle must be appropriately adapted to the cold, as well as of an adequate breed, age, health status, and body condition score to thrive through harsh winter conditions. Furthermore, digestible energy requirements may increase as much as 20% for cattle grazing in cold, snowy conditions (NASEM, 2016). Winter feeding for beef cattle comprises up to 60% or more of total production costs (Kaliel and Kotowich, 2002). As such, solutions to reduce cost and increase efficiency through nutritional management are necessary. While a dairy cow in lactation or a growing steer have high energy and protein demands, wintering beef cows out on pasture do not require the same intensive feeding programs that would be found in these other production operations (NASEM, 2016). Because of their lower production requirements, beef cows can thrive on a forage-based diet with little supplementation of mineral or protein.

Providing silage as the main forage source for these cows comes at a steep requirement for equipment, time, labor, and resources to achieve adequate production and feed-out management; to feed silage to pastured cattle requires either gathering them up to the feeding area every day or delivering the silage to the cattle where they are in the pasture.

2.1.2 Winter-feeding systems

With a need for cost-efficient forage to feed cattle through the winter, producers often turn to dry-preserved forages. These forages can be provided in a number of winter-feeding systems, including dry-lot feeding, baled hay, bale grazing, bale processing, swath grazing, and stockpiled forage grazing. Each of these systems have different requirements regarding management, equipment, yardage, labor, and input cost. As such, these systems also allow for different carrying capacities.

2.1.2.1 Dry lot feeding

A traditional feeding system for wintering beef cattle is through the use of dry lot systems. In this system, cattle are housed in group pens and provided shelter, water, and feed in a bunk, bale feeder, or other feed delivery system. Compared to swath grazing, bale grazing, and straw chaff grazing, drylot feeding of barley hay in western Canada had the highest feed cost ($0.86/cow/d vs $0.31, $0.83, and $0.16, respectively) and a higher total cost ($1.07/cow/d) than bale grazing ($0.98/cow/d) or swath grazing ($0.76/cow/d; Kelln et al. 2011). This system has higher feed, feeding, and pen maintenance costs and is the only one of the four compared which requires manure removal. However it is important to note that a major benefit of this system includes consistent BW gain of cows throughout the winter, as opposed to bale grazing, swath grazing, or straw chaff grazing cows which lost BW and BCS during the first 21 d of the study, though they did have a positive overall ADG between d 1 and d 78 of the study (Kelln et al., 2011).

2.1.2.2 Baled hay

Preserving forages for hay or green feed is another option for winter feeding that is utilized around the world, particularly in North America. Hay and green feed are terms used synonymously. For consistency throughout this thesis, all baled dry preserved forages will be referred to as hay. Hay may be produced using grasses, cereals, or legumes. Perennial grass hay varies in species depending on regional grass production. For annual cereal hay, the most predominant crops used are barley (*Hordeum* vulgare) and oat (*Avena sativa*). For legumes, the most predominant crops are alfalfa (*Medicago sativa*), clover (*Trifolium*), and pea (*Pisum sativum*). It is recommended that barley and oat hay be harvested in the hard dough stage of maturity (Rosser et al., 2013; Rosser et al., 2016). Hay production requires more input than stockpiling or swath grazing, as it requires the crop to be cut, cured in the field, baled, and stored. During the curing phase, forage is susceptible to nutrient loss via leaching, particularly if the swath is exposed to precipitation. The nutrients lost to leaching are soluble nutrients such as protein, sugars, and water-soluble carbohydrates. Nutrient leaching increases the relative NDF and ADF content of the forages. However, when stored under cover and sheltered from weathering, forages harvested as hay can retain nutritional composition with minimal losses for months or even years (Fahey et al., 1994).

2.1.2.3 Bale grazing

In bale grazing systems, hay is harvested using the same methods as described above, with the bales placed throughout the fields in the desired locations in the fall, and then allowing cattle to graze the bales throughout the winter (Kelln et al., 2011). In instances where the field has a large number of bales, temporary fences may be set up to restrict cattle to certain areas to limit grazing potential to a certain number of bales at a time and reduce waste. Compared to dry lot feeding, bale grazing had an 8% lower total system cost for the entire winter, at $0.98/cow/d compared to $1.07/cow/d (Kelln et al., 2011). However, bale grazed cattle lost BW during the first 21 d of the feeding period. This may be due to naïve cattle being exposed to bale grazing for the first time, highlighting the importance of adapting cattle to feeding systems.

2.1.2.4 Bale processing

Bales of hay may be further processed using a bale processing apparatus which chops, shreds, or grinds bales. This process may be done in the field where the cattle are, delivering feed from the processor onto the ground for the cattle. However, this system comes with substantial forage losses of up to 26% (McCartney, 2015), with legumes having greater nutrient loss in fines than cereals (Alberta Agri-Facts, 2007). There are limited studies comparing feed utilization and cattle performance when fed with a bale processor

2.1.2.5 Swath grazing

Producers also have the option of implementing a swath grazing system in which forage is swathed, dried, and left in the field for later grazing. Swath-grazing is an economically efficient system; due to less harvest processing, and utilizing swath grazing systems cost 37% less than baling hay (Volesky et al., 2002). In another study, swath-grazed cows averaged an input cost $70 less than traditional-fed cows (McCartney et al., 2004). By incorporating swath-grazing, not only is the need for manure removal and spreading eliminated, but manure in the field is able to continue the nitrogen cycle and benefit soil environments as well as plant growth.

One option often recommended to producers to reduce field losses of forage associated with increased time in the swath is to delay seeding in order to obtain a later harvest; however, Baron et al. (2012) reported a decrease in forage DM yield for whole crop barley and oat seeded as seeding dates were delayed throughout May to June. While seeding later is still often recommended to reduce nutrient leaching, producers must be aware that minimizing the time forage spends in swath prior to grazing by later seeding will also reduce the overall yield.

2.1.2.6 Stockpiled forage

Stockpiled forage is the term for forage which is allowed to grow following the first hay harvest. This regrowth forage is not harvested but instead left standing to be grazed later in the season (Baron et al., 2016). This system requires the least input cost as the labor and equipment usage are low as is the infrastructure required for forage storage. Unless the need for protein or mineral supplementation arises, stockpiled forage also does not require frequent trips to the pasture to deliver forage, as the cattle are out grazing the field. However, nutrient quality of stockpiled forages may deteriorate as the grazing period progresses (Baron et al., 2004), particularly for legumes susceptible to weathering damage (Burns and Chamblee, 2000). Therefore, stockpiled forages may come with the added cost of supplementation to meet nutrient requirements.

2.2 A Comparison of Barley and Oat for Green Feed

2.2.1 Agronomic management

For cereal forages produced in the Dark Brown soil region of Saskatchewan (Saskatoon), it is recommended to seed at a rate of 108 kg/ha for feed type barley and 123 kg/ha for oat (Government of Saskatchewan, 2019). Barley should be seeded 3 to 5 cm, and oat at 2 to 3 cm (Government of Saskatchewan, 2019). In western Canada, barley and oat should be seeded when soil temperature at the seed depth is between 10 and 20°C. Barley and oat mature to the hard dough stage at similar rates, with barley requiring 1193 to 1438 growing degree days (GDD) and oat requiring 1261 to 1447 GDD (Miller, 2018).

The current recommendations for harvesting forage for hay are early dough for barley (Juanita Kopp, Alberta Agriculture and Rural Development) and late milk for oat (Government of Saskatchewan, 2017). These recommendations are the same for silage and hay harvest. However, it has recently been reported that harvesting cereal crops at a later stage of maturity such as hard dough and ripe can increase forage yield (Rosser et al., 2013; Rosser et al., 2016; Rosser et al., 2017) as well as digestible energy yield due to similar energy content in both the early dough and hard dough stages (Kilcher and Troelson, 1973). Rosser et al. (2013) evaluated the effects of harvest maturity on yield and chemical composition of wheat (*Triticum aestivum*), barley, and oat, and reported that harvesting whole-crop cereals at the hard dough and mature stages may actually increase effectively degradable DM (EDDM) yield, as well as increasing DM, OM, and NFC, without a change in the CP concentration. Delaying harvest until more advanced stages of cereal maturation may offset the need to delay seeding and increase the efficiency of the harvest, producing more t/ha of forage.

Comparative forage yield between oat and barley is highly variable with some authors reporting that oat forage out-yielded barley (Berkenkamp and Meeres, 1987; Baron et al., 1992; Baron et al., 2012), while others report barley out-yielding oat (Chapko et al., 1991; Khorasani et al., 1997; May et al., 2007), or no difference between the two cereal types (McCartney and Vaage, 1994). This variability is a result of the cumulative factors affecting crop production including, *inter alia*, cultivar selection, soil type, temperature, precipitation, fertilizer application, seeding date, seeding rate, allotted growing degree days, and weed management.

2.2.2 Quality characteristics

While differences in forages will vary depending on cultivar, generally speaking, barley hay is higher in CP and starch, while oat hay is higher in NDF and ADF (NASEM, 2016). Harvesting at a later maturity has been suggested to result in decreased digestibility, decreased intake, and increase the ability for cattle to sort for kernels and against fibrous stems. However, it has been shown in several studies that delaying harvest does not affect DMI (Beck et al. 2009; Rosser et al. 2016). In fact, Rosser et al. (2016) evaluated the effects of harvest maturity of whole crop barley and oat for swath grazing on intake, digestibility, and sorting behaviors of beef cattle. Increasing maturity at harvest beyond the recommended stages did not affect DMI, with only a slight reduction in NDF and ADF digestibility. It should be noted that in spite of

Table 2.1 Nutrient composition of barley and oat hay.

Nutrient[1]	**Barley Hay**	**Oat Hay**
Digestible energy, Mcal/kg	2.65 ± 0.25	2.64 ± 0.18
CP, % DM	10.95 ± 3.84	8.73 ± 2.56
NDF, % DM	56.88 ± 8.59	59.13 ± 6.40
ADF, % DM	33.88 ± 6.47	37.08 ± 4.66
Starch, % DM	5.66 ± 5.52	3.97 ± 2.57
Fat, % DM	2.41 ± 0.88	2.22 ± 0.59

[1] Values listed as mean ± SD, derived from the National Academy of Science, Engineering, and Medicine (NASEM, 2016).

reduced NDF and ADF digestibility, starch was more digestible in later maturity. Overall, DE remained unaffected by stage of maturity at harvest, indicating later harvested forages may provide greater yield without compromising the nutritive aspects of the forage.

2.2.3 Intake responses

It is widely understood that voluntary feed intake and eating behaviors are not regulated by one or two specific factors, but are the combined effect of a multitude of variables based on feed type and composition (Allen, 2000), feed digestibility (Oba and Allen, 1998), environmental factors such as individual versus group feeding (Grant and Albright, 2001), and animal characteristics such as age (NASEM, 2016), size (NASEM, 2016) breed and genetics (Nkrumah et al., 2007), and stage of production such as growth, gestation, or lactation (NASEM, 2016). One such variable affecting feed intake is dietary fiber. Increasing NDF consumption has been shown to decrease voluntary feed intake due to the associated increased bulk and ruminal fill compared to low-fiber concentrate-based diets (Dado and Allen, 1995). Being that it has less NDF and ADF than oat (NASEM, 2016), barley would be more likely to result in an increased DMI over an oat forage diet. Not only does NDF concentration affect feed intake, but the digestibility of that NDF can alter intake as well. As the digestibility of NDF increases, intake is observed to increase in response (Oba and Allen, 1998). This a result of a decreased retention time in the rumen. As NDF is more digestible, less time is required in the rumen for bacterial degradation and digestion of the fiber; as a result, passage rate, or k_p, increases, meaning more digesta is leaving the rumen, distension of the rumen is reduced, and more feed can be consumed. In order to calculate k_p and k_d, the equations outlined in Dado and Allen (1995) may be used, assuming that ruminal pool size and flux remains constant, there is equal passage rate of digestible and indigestible NDF, and the 120-h *in vitro* method of analyzing indigestible NDF is accurate.

Early research reported barley silage resulting in a lower DMI in dairy cows than oat silage (Christensen et al., 1977). It was concluded that awned forage species such as barley are less palatable to cattle than non-awned species, such as oat, due to the irritation caused by awns in the mouth of the animal. This could also be attributed to the NDF and ADF differences discussed above. However, barley forage harvested in dough stages will not have fully developed awns and be more palatable (Bauer et al., 2012). Furthermore, some newer varieties of barley developed for forage are of awnless varieties and therefore more palatable. When fed as a whole crop silage, barley created a greater intake response than oat in dairy cows (Khorasani et al., 1996; Wallsten et al., 2009) and sheep (McCartney and Vaage, 1993), but resulted in no difference in intake in beef cattle (McCartney and Vaage, 1993).

2.3 Use of Field Pea as a Forage Source for Cattle

2.3.1 Grain-type vs. forage-type cultivars

Field pea (*Pisum sativum* L.) is a crop which can be utilized in both beef and dairy production operations (Khorasani et al., 2001; Reed et al., 2004; Vander Pol et al., 2008; Vander Pol et al., 2009; Soto-Navarro et al., 2012; Anderson et al., 2014). Pea is more commonly grown and incorporated into diets in western Canada and the northern United States, particularly Montana and North Dakota, as it thrives in cool environments with temperatures as low as -3^{o}C (Anderson et al., 2014). The majority of field pea production is used as grain for human food markets, while some grain is fed to monogastric animals, and some used for ruminants. Forage production of pea generally preserved as silage (Borreani et al., 2007). While pea is often used as a grain source to increase protein concentration, some cultivars have been specifically selected for forage production. Traditionally, forage-type cultivars were long stemmed, rather weak stemmed, with small seeds selected to reduce seed cost (Warkentin et al., 2011). These types also produced a large biomass. However, more recent breeding efforts have focused on incorporating grain type qualities into the forage type cultivars in order to improve crop quality and production ease (Warkentin et al., 2012). Developed at the University of Saskatchewan Crop Development Centre (CDC), these forage type cultivars, such as CDC Horizon and CDC Leroy, were selected for semi-leafless traits with stronger, more durable stems to reduce shattering loss during harvest (Borreani et al., 2007; Warkentin et al., 2012).

In continuance with the recent breeding selections for forage-type pea cultivars, a new cultivar of pea was developed for potential incorporation into beef cattle feeding systems. The University of Saskatchewan’s Crop Development Center (CDC) has developed CDC Horizon (*Pisum sativum* L.). This semi-leafless forage pea, developed in 2010 (Warkentin et al., 2012), was selected for superior lodging resistance to the commonly utilized forage pea cultivars

Trapper and 40-10, high biomass quality and production, resistance to powdery mildew (caused by *Erysiphe pisi Syd*.), and increased DM production over forage pea cultivars CDC Leroy and CDC Tucker. CDC Horizon is a semi-leafless type that is significantly shorter and stronger-stemmed than the commonly used Trapper and 40-10 pea varieties. These characteristics allow for greater quality retention rate of the pea during harvest and baling processes. However, it is important to note that currently the only research on the effectiveness of CDC Horizon as a forage has been on monoculture stands, and none of these studies have evaluated palatability and cattle performance.

2.3.2 Agronomic management

It is recommended by the Saskatchewan Pulse Growers Association (2019) to seed field pea when the soil temperature reaches 5°C. In western Canada, this generally occurs between mid-April to mid-May. Seeding as early as possible will aid in preventing heat damage to the crop during the flowering stage (typically in July), as pea and many other crops are susceptible to yield losses due to heat at flowering. Peas should be seeded 3 to 8 cm deep into moist soil, at a rate of 75 to 85 plants per square meter. Increasing seeding rate from 75 to 150 plants per square meter increased forage yield and decreases lodging, but decreased seeds per plant as well as overall CP concentration of the forage (Türk et al., 2011). An inoculant treatment of *Rhizobium* species may be beneficial to enhance N fixation, and N fertilizers are not required except in soils with less than 17 kg/ha N. However, peas are less competitive against weeds than cereal grain species (Aasen et al., 2004). Farmers in central Alberta reported 67% of the region's pea crop was affected by weeds, whereas only 27% of the barley crop was affected (Harker, 2001). Therefore, peas may require a more aggressive herbicide treatment protocol than cereal grain species produced under the same conditions.

2.3.3 Growth stages

The stages of growth are defined in detail by Knott (1987). In this detailed coding system, there are over 20 defined stages of pea development (depending on cultivar), categorized into four main stages: germination and emergence (0), vegetative (1), reproductive (2), and senescence (3). For the remainder of this thesis, stages of development discussed will be referred to as early, mid, and late. All three of these stages pertain to the reproductive and senescence stages of the plant, described as principle stage codes 2 and 3 in the Knott staging system (Knott, 1987). The early stage was associated with Knott stages 205 and 206, when the first flat pods were present at one or more nodes. The mid stage was associated with Knott stages 207 through 209, when the pods were filled with seeds at one or more nodes, the plant was yellowing, and the lower pods turned to a yellow or brown. The late stage was associated with Knott stage 301 to 302, when all pods were filled with yellow, dry seeds. These stages are pictured in Figure 2.1.

As the plant develops throughout each stage, there are many changes occurring that affect nutrient composition. Pod filling, as a result of seed development, increases starch concentration (Knott, 1987). Furthermore, stem development increases NDF and ADF concentrations (Ammar et al., 2010). The culmination of these two developmental effects leads to the decrease in CP concentration within the crop. However, overall forage yield increases with maturity, so while forage CP concentration decreases, overall forage CP yield increases with advanced maturity (Turk and Albayrak, 2007).

2.3.4 Harvest recommendations

Research conducted in the mid-1940s found that Washington-grown peas with advancing harvest maturity decreased in crude protein concentration as well as protein digestibility (Daniel et al., 1946). In this study, sheep were reported to have an increased intake with advancing maturity, regardless of whether the pea forage was fed fresh or dry-preserved. Harvest maturity of field peas for use in silage was studied by Borreani et al. (2007), reporting an increase in overall forage DM yield as well as grain contribution to DM. In this study, the digestibility of NDF decreased with maturity, though this effect was counteracted by the increased proportion of highly digestible pea grain, resulting in no difference in overall OM digestibility, evaluated *in vitro*. Similarly, these results were supported by numerous other studies in pea (Fraser et al., 2001; Salawu et al., 2002; Mustafa and Seguin, 2004). However, digestibility of pea silage was greatest in early and mid-stages at harvest, compared to silage harvested at either flowering or ripe stages (Brundage et al., 1979). Little recent research has evaluated the maturity of field pea harvested for hay and its effects on animal intake, performance, eating behavior, or metabolism. The current harvest recommendations for field pea forage are at the first pod wrinkle (Knott Stage 208) for both silage and hay forage (Government of Saskatchewan, 2017).

Figure 2.1. Early (left), mid (center), and late (right) stages of field pea (*Pisum sativum*) development.

2.3.5 Eating behavior and intake

As discussed previously in Section 2.3.3, NDF content and digestibility can limit voluntary feed intake in ruminants. The potentially degradable NDF in legumes, specifically pea NDF, is generally more digestible than the potentially degradable NDF found in cereal feeds (Bruno-Soares et al., 1999). As a result, the cumulative effects of decreased fiber content and increased digestibility of legume-based fiber leads to increased feed intake. These effects have also been observed in Oba and Allen (1998) and Hayashi et al. (2007; Table 2.2). However, replacing cereal forage with field pea hay did not affect intake when fed to sheep (Bastida Garcia et al., 2011). Furthermore, in a study by Poland et al. (2003), gestating ewes offered grass pea (*Lathyrus sativus)* hay or alfalfa hay (control) *ad libitum* did not differ in intake. Grass pea, sometimes referred to as chickling vetch, is a legume species nutritionally similar to *Pisum sativum* field pea. Another study comparing field pea silage with barley or alfalfa silage reported no difference in intake when offered to dairy cows (Mustafa et al., 2000). Pea-wheat intercropped silages resulted in greater intake over grass silage when fed to sheep (Adesogan et al., 2002; Salawu et al., 2002). Moreover, when pea was offered as a grain source rather than a whole-crop forage, there were no reported effects on intake (Khorasani et al., 2001; Reed et al., 2004) or digestibility of fiber (Reed et al., 2004). While there is some discrepancy as to whether pea increases intake or not, there have yet to be reports in which pea had a negative effect on intake.

2.3.6 Cattle performance

Another important factor to consider in feed evaluation for ruminants is the fermentative characteristics of the feed. Comparing alfalfa, a legume, against cereal forages, it was reported that alfalfa fed to dairy cows resulted in lower mean ruminal pH, greater total SCFA concentrations, and higher acetate to propionate and butyrate ratios than in cereal forage diets (Khorasani et al., 1996). These findings indicate that legume forages allow for a greater extent of ruminal fermentation than cereal forages. This is supported by grain-based studies as well; for instance, replacing a barley or soybean meal grain source with pea in dairy cow diets resulted in a decreased ruminal pH, increased acetate concentration, and increased ruminal ammonia-N concentration (Khorasani et al., 2001). Another study evaluating peas as a grain source for

Table 2.2. Summary of experiments evaluating animal intake, performance, and digestibility in response to field pea.

Reference	**Comparison**	**Animal**	**Summary of results**
Adesogan et al., 2002	Wheat-pea silage with differing harvest maturity and pea inclusion rate	Sheep	Pea increased intake and digestibility. High pea was more digestible than low pea. No effect on N retention.
Bastida Garcia et al., 2011	Pea hay replaced oat straw at 0, 25, 50, and 75% of forage.	Sheep	No effect on intake, digestibility, or ruminal fermentation.
Hayashi et al. 2007	Pea hay replaced rice straw at 0, 0.5, and 1% of BW.	Murrah buffalo	Pea increased DMI relative to 0%pea diets. Pea inclusion increased ADG and CP intake
Khorasani et al. 2001	Ground pea replaced SBM at 0, 33.3, 66.7, and 100% of concentrate DM.	Dairy cows	Pea did not affect intake, milk yield, or bacterial N; inclusion rate of pea decreased ruminal pH, altered SCFA concentration.
Mustafa et al. 2000	Pea, alfalfa, and barley silages	Dairy cows	Forage type did not affect DMI or milk yield. Legumes were more degradable than barley. Pea increased milk fat and decreased milk protein compared to alfalfa.
Poland et al. 2003	Grasspea and alfalfa hay	Sheep	No difference in intake, ADG, or production.
Salawu et al. 2002	Pea and pea-intercrop silages cut at increasing maturity	Sheep	Pea-intercrop silages decreased in all variables compared to pea silage.
Vahdani et al. 2014	Grasspea hay and alfalfa hay	Sheep	Grasspea had a lower palatability index (87% of alfalfa). No difference in digestibility.

feedlot cattle reported similarly, with an increase in SCFA concentration and ruminal ammonia-N in response to increasing pea levels in the diet (Reed et al., 2004). However, when pea hay replaced oat straw as a forage source for sheep, ruminal fermentation was not affected; there were no differences in ruminal pH, total SCFA, or relative SCFA molar proportions in response to pea levels in the diet (Bastida Garcia et al., 2011). As stated previously, pea forage is more ruminally degradable than cereals, as well as higher in protein and starch with lower fiber concentrations. Greater dietary protein content is associated with increased ruminal ammonia-N concentration (Pritchard and Males, 1984). Furthermore, increasing starch while decreasing fiber will modify the ruminal microbiome, shifting the population towards amylolytic bacteria rather than cellulolytic. Changing the dietary composition, in turn altering the ruminant microbiome population, will affect the rate and end-products of ruminal fermentation (Belanche et al., 2012).

Being a legume species, field pea has a greater protein concentration than cereal species. Assuming equal feed intakes, animals consuming field pea forage will, by default, have a greater nitrogen consumption than those fed cereal forages. However, this increased nitrogen consumption does not necessarily imply an increased nitrogen utilization. While Salawu et al. (2002) reported an increased nitrogen retention in sheep fed whole pea silage compared to those fed a pea-wheat blended silage, Khorasani et al. (2001) found no change in bacterial nitrogen output in dairy cows in response to pea, and Andesogan et al. (2002) found no difference in nitrogen retention in response to increasing pea inclusion in sheep diets. If pea forage is oversupplying protein, there is no further benefit of that protein supplementation and, in turn, nitrogen excretion may increase. Depending on the production scenario, this may be a costly dietary decision.

2.4 Intercropping Cereals and Legumes

2.4.1 Agronomic management

Production of cereal-legume mixtures introduces new variables to crop management that monoculture production does not require. Initially, field arrangement presents several options: will the two crops be seeded together as a mixture, in separate but very close rows, or in alternating, separate rows? Being that pea is less competitive than cereal grains (Aasen et al., 2004), it is recommended to seed in separate intercropped rows to allow for optimal pea production without losing pea yield due to direct competition with the cereal crop (Chen et al., 2004). Walton et al. (1979) compared oat and barley in mixtures and intercrops with pea or soybean, reporting mixtures to out-yield intercrops. However, in that study, only a 3:1 cereal to legume seeding ratio was used in only alternating row arrangement, and there is no mention of fertilizer treatment. Chen et al. (2004) compared 4 rows barley × 4 rows pea, 2 rows barley × 2 rows pea, and mixtures, reporting that increasing row space between crops allowed for greater pea contribution to the overall crop. However, there are many production scenarios involving mixtures seeded together (Berkenkamp and Meeres, 1987; Chapko et al., 1991; Aasen et al., 2004; Asci et al., 2015). In these instances, it is important to consider seeding practices that allow both plant species to thrive in production. Seeding a higher ratio of legume to cereal allowed for greater competition of pea in oat mixtures, but decreased overall forage yield (Neugschwandtner and Kaul, 2014). It is important to consider seeding depth of each component of the mixtures; for example, barley should be seeded 3 to 5 cm, oat at 2 to 3 cm, and pea at 3 to 8 cm (Government of Saskatchewan, 2019). Legumes are more susceptible to competition with weeds (Aasen et al., 2004) so additional herbicides may be necessary in mixture production.

2.3.2 Harvest maturity

Being that the cereal species is generally the largest contributor to an intercrop or mixture system, it is recommended that harvest decisions are based upon the maturity of the cereal, rather than the legume (Government of Saskatchewan, 2017). Recommended harvest maturity for both barley and oat for hay is at the hard dough stage (Rosser et al., 2013; Rosser et al., 2016). At this stage, nutritional quality is high and forage DM yield is greater than at the early dough or late milk stages.

2.4.3. Yield

When looking at an overall DM yield perspective, data is quite variable (Table 2.3). Based on a number of studies reporting a decrease in DM yield, intercropping cereals with legumes may seem disadvantageous. It has been shown that intercropping legumes with cereal grains does not increase DM yield when compared to the individual species produced in monoculture

Table 2.3. Summary of experiments evaluating forage yield effects of cereal-pea mixtures or intercrops.

Reference	Comparison	Summary of Results
Aasen et al., 2004	Barley, oat, and field pea in monocrop and intercrop	Yields of barley, oat, and pea were similar. Blends did not out-yield monocrops.
Berkenkamp and Meeres, 1987	Barley, oat, wheat, and triticale mixed with field pea, faba bean, and sunflowers	Mixtures yielded the same or less than monocrops and had greater CP than cereal monocrops.
Brundage et al., 1979	Barley, oat, and field pea monoculture and intercrops harvested for silage at 4 dates	Advancing maturity increased DM yield in all crops. Intercrops decreased DM yield but increased CP yield
Carr et al., 1998	Various barley and oat cultivars in monoculture and intercropped with pea	Effects of intercropping varied depending on cereal seeding rate. CP concentration increased with pea.
Carr et al., 2004	Various barley and oat cultivars produced in monoculture and intercropped with pea	Intercrops yielded greater DM and CP.
Rosser et al., 2013	Barley, oat, millet, and wheat harvested at advancing maturity	Advancing maturity increased forage DM yield in all species but did not affect CP yield.
Strydhorst et al., 2008	Barley produced as monoculture and intercropped with pea, lupin, and faba bean with increasing legume inclusion	Barley-pea blend did not affect DM yield. Inclusion of faba bean or lupin with barley decreased DM yield. All intercrops increased CP yield.
Walton et al., 1975	Barley, oat, and wheat produced in monoculture and intercropped with pea, soybean, and rape	Delaying harvest increased DM yield. Intercrops decreased DM yield. Intercrops had greater CP yield.

(Walton, 1975; Berkenkamp and Meeres, 1987; Aasen et al., 2004; Strydhorst et al., 2008). In fact, Walton (1975) compared barley, oat, and wheat monocultures to cereal mixtures with pea, soybean, and rapeseed at various seeding rates and seed ratios, reporting a consistent decrease in yield in the mixed crops regardless of plant species used in the combinations. In Berkenkamp and Meeres (1987), barley, oat, wheat, and triticale were grown in monoculture and in mixture with either field pea, faba bean, or sunflower in two different soil regions. The cereal-legume mixtures consistently yielded amounts between the yields of the individual monoculture species. Strydhorst et al. (2008) reported a decrease in DM yield when barley was intercropped with faba bean or lupin. In that same study; however, there was similar DM yield between barley monoculture and barley-pea mixtures, highlighting the differences in compatibility between species. Aasen et al. (2004) evaluated barley, oat, and field pea grown in monoculture, in combination with each other, and in combination with ryegrass and fall rye. Cereal-pea mixtures contained 100% seeding rate of field pea and 25% seeding rate of the cereal. Furthermore, plots with cereal monocultures were fertilized with 42 kg N/ha, while pea mixtures and pea monoculture plots received 24 and 6 kg N/ha, respectively. They reported no differences in DM yield between the cereal-pea mixtures and their respective monocultures. It is important to note that in this study, production of field pea mixtures required a much greater input cost than monoculture crop production. This was attributed not only to higher seed costs but to increased need for herbicides as well, since field peas are less competitive than cereal grains and therefore more susceptible to weeds.

However, in contradiction to the previous studies, Carr et al. (2004) evaluated various unfertilized cultivars of barley and oat grown in combination with field pea at approximately a 3:1 cereal to pea ratio, with each plant species in the mixture seeded at 50% of its monoculture seeding rate. In that study, there was increase in DM yield for both oat and barley when mixed with pea compared to respective monoculture yields.

Another study evaluated barley, oat, and wheat grown in monoculture and in combination with field pea, soybean (*Glycine max* L.), or rape (*Brassica napus* L.), reporting that oat-pea combination outperformed oat-rape, whereas barley-rape out yielded barley-pea (Walton, 1975). These data suggest there may be compatibility differences between cereal type and legume type which needs to be considered when planning a cereal-legume mixture.

2.4.4 Forage quality

Legume forages are known for being higher in protein than cereal grains. While maybe too expensive to feed alone, legumes such as pea are often intercropped with cereal forages. Compared with other commonly used protein sources such as soybean meal (53% CP), canola meal (41%), cottonseed meal (45%), dried corn distillers' grains (31%), and fish meal (66%; NASEM, 2016), legumes are considerably lower in protein concentration. For example, some commonly utilized legume forages are alfalfa (20%; NASEM, 2016), field pea (25.3%; Anderson et al., 2007), and red clover (15%; NASEM, 2016). However, in beef cow diets where CP requirements range between 7 and 11% (NASEM, 2016), legumes are a quality forage source capable of meeting protein requirements. One study reported cereal-legume mixtures averaging 62% greater CP than just sole cereal crop (Strydhorst et al., 2008). Therefore, when legumes are grown in forage mixtures with cereals, producers are able to provide adequate protein and eliminate the need to deliver a second feed or use a ration mixer. Legumes also possess a unique ability to fix nitrogen in the soil due to a symbiotic relationship with *Rhizobium* species of bacteria (Zahran, 1999). This nitrogen fixation allows for a potential decrease in fertilizer application and associated costs, as well as increasing overall soil quality by providing higher nitrogen levels (Anil et al., 1998).

Berkenkamp and Meeres (1987) reported that incorporating different species of legumes into cereal forage production consistently resulted in higher protein content at harvest than the straight cereal crop, regardless of the legume species used in the blend Carr et al. (2004) observed pea-barley and pea-oat forage mixtures had 35 g/kg CP greater than in their respective monocultures, without a significant change in forage yield, indicating that intercropping pea may be a feasible potential solution to increasing protein in forage diet. Along with the increased CP yield, overall N yields in this study were observed to be 32 kg/ha higher for barley-pea when compared with monoculture barley, and 37 kg/ha for oat-pea compared with monoculture oat. This is due to the increased N-fixation found in legume plant species (Zahran, 1999). The study by Carr et al. (2004) also reported a decrease in NDF concentration, increase in Ca concentration, and no effect on P concentration for both barley-pea and oat-pea mixtures when compared to their respective monocultures. This data is significant to producers because cereal based diets so often lack the necessary calcium to maintain an ideal Ca:P ratio of at least 2:1 in cattle diets. Increasing Ca in the forage would potentially allow for producers to save money on calcium supplements while sustaining wintering cattle on a mostly green feed diet. The increase in protein concentrations ensures the cows' protein requirements during gestation will be adequately met.

2.4.5 Eating behavior and intake

As previously discussed, addition of legumes such as pea forage into cattle diets has potential to increase intake (Oba and Allen, 1998; Hayashi et al., 2007), though there are many contraindicative studies reporting no difference in voluntary intake when fed peas in lieu of another feed ingredient (Khorasani et al., 2001; Poland et al., 2003; Bastida Garcia et al., 2011).

2.4.6 Cattle performance

When evaluating a feed source, it is important to consider not just feed intake, but how that feed is utilized within the animal. It is well established that legume species are more digestible than other forage sources such as cereals or grasses (Thornton and Minson, 1973; Bruno-Soares et al., 1999; Mustafa et al., 2000). Pea increased digestibility over grasses in wheat-pea blended silages fed to sheep, with greater digestibility associated with a higher pea ratio in the blends (Adesogan et al., 2002). Furthermore, whole-crop pea silage was more ruminally degradable and overall digestible for sheep than pea-wheat blended silage (Salawu et al., 2002). Therefore, it can be concluded that an increase in pea content in the diet can increase total tract digestibility in ruminants.

When rice straw was replaced with field pea hay at an increasing inclusion rates from 0 to 1% BW, lactating Murrah buffalo (*Bubalus bubalis)* responded with improved ADG along with improved intake (Hayashi et al., 2007). While the buffalo on the highest pea inclusion treatment had a seemingly low ADG of 0.48 kg/d, it is important to note that this is still greatly improved over the 0% pea treatment ADG of -0.63 kg/d. As well, these are mature, lactating, dairy Murrah buffalo and therefore it cannot be assumed the same higher rates of gain will be identically exhibited in North American beef breeds of cattle, specifically *Bos taurus* breeds prominent in western Canada. However, the results of this study still demonstrate a potential benefit of utilizing field pea in beef cattle diets.

Contrary to the results of Hayashi et al. (2007), a study conducted on gestating ewes reported no difference in ADG when fed grasspea hay (referred to as chickling vetch) or alfalfa hay (Poland et al.; 2003). The contradicting results between Hayashi et al. and Poland et al. may derive from differences in animal species, production type (fiber versus dairy), stage of production, pea species, as well as pea inclusion rates in the diet. Furthermore, the study with Murrah buffalo compared intake to a rice straw diet, while the control diet for the ewes was alfalfa, another legume species. The difference between two legumes may not be as drastic as the difference between a legume such as pea with a different plant type, such as a cereal or grass.

2.5 Conclusions

Inclusion of legume forages, specifically field pea (*Pisum sativum)*, is an important agronomic method to potentially increasing forage yield of DM and CP while decreasing N fertilization costs. When fed to ruminants, legumes are a readily digestible feed source which will not compromise or may even improve voluntary feed intake. Field pea may potentially alter the end-products of ruminal fermentation, but it does not inhibit overall animal production.

2.6 Hypotheses

Increasing inclusion rate of field pea into barley and oat cereal blends will reduce NDF concentration, increase CP concentration, alter ruminal fermentation, increase DMI, and improve overall digestibility, but cereal type will not alter the effects of pea inclusion rate. Delaying harvest of field pea grown in monoculture to later stages of maturity will result reduce DMI, palatability, digestibility, and rate of passage through the GI tract.

2.7 Objectives

The objectives of this research project were to evaluate the effects of feeding field pea hay (*Pisum sativum* L.; c.v. CDC Horizon) to beef cattle using two separate studies. The first study evaluated the effects of incorporating pea into cereal green feed on DMI, nutrient sorting, ruminal fermentation, nitrogen retention, and apparent total tract digestibility. The second study evaluated the stage of harvest maturity of pea green feed and its effects on forage yield, intake, eating behavior, ruminal fermentation, ruminal passage rate, and apparent total tract digestibility when fed to beef cattle.

3.0 EFFECT OF INCORPORATING FORAGE PEA (*PISUM SATIVUM* L.) INTO CEREAL HAY ON INTAKE, RUMINAL FERMENTATION, AND APPARENT DIGESTIBILITY WHEN FED TO BEEF HEIFERS[1]

3.1 Abstract

The objective of this study was to evaluate the pea hay inclusion rate in diets for beef cattle based on barley or oat hay. Six ruminally-cannulated heifers (407 ± 38 kg) were used in a 6 × 6 Latin square (25-d periods) with a 2 × 3 factorial design. Treatments included whole-crop barley or oat hay with pea hay blended in to achieve inclusion rates of 0, 15, or 30% (DM basis) of the forage. Cattle were adapted to their respective diets from d 1 through d 20. On d 21, jugular catheters, urinary catheters, and continuous indwelling ruminal pH probes were inserted to enable measurements from d 22 through d 25. Ruminal fluid and blood samples were also collected every 4 h over a 24-h duration beginning at 0800 h on d 22. Statistical analyses were conducted using the mixed model of SAS with polynomial contrasts to determine the effect of cereal type, pea inclusion, the cereal × inclusion interaction, and the linear and quadratic effects of pea inclusion. Pea inclusion increased dry matter intake (DMI; $P = 0.03$) by 0.75 kg/d relative to diets without pea hay, but the response was not linear or quadratic. Inclusion of pea linearly increased mean ruminal pH ($P = 0.039$), the concentration of butyrate in ruminal fluid ($P = 0.013$), and plasma urea-N concentration ($P = 0.001$), and quadratically increased ruminal ammonia concentration ($P < 0.001$). The molar proportion of propionate in ruminal fluid decreased linearly ($P < 0.001$) with increasing pea hay inclusion. Generally speaking, cattle fed cereal-only diets tended to sort for CP and against NDF, but cattle did not sort for or against CP or NDF when pea hay was included ($P \leq 0.006$). Pea hay inclusion reduced CP digestibility by 2.87% relative to cereal-only treatments ($P = 0.025$), but did not affect N intake, microbial N, or N excretion. DMI, ruminal pH, total SCFA, and blood metabolites were not affected by cereal hay type, although barley resulted in greater ruminal ammonia concentration than oat (3.27 vs. 2.18 mg/dL; $P < 0.001$). Oat hay-based diets were more digestible than barley hay-based diets ($P = 0.028$). Microbial N was not affected by cereal hay type ($P = 0.62$), although fecal N was

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[1] Pursley, A.A., B. Biligetu, T. Warkentin, H.A. Lardner, and G.B. Penner. 2019. Effect of incorporating forage pea (*Pisum sativum* L.) into cereal hay on intake, ruminal fermentation, and apparent total tract digestibility when fed to beef heifers. Translational Anim. Sci. (in review).

greater in barley hay-based treatments while urinary N was greater in oat (P = 0.025). Total N balance was greater for cattle fed oat (41.9 g/d) than barley hay (30.4 g/d; P = 0.033). Overall, pea hay inclusion increased DMI, increased ruminal butyrate concentration, but reduced CP digestibility without affecting N balance. Oat hay resulted in less sorting behavior and improved digestibility over barley hay.

3.2 Introduction

Cereal hay is a commonly utilized winter feed source for gestating beef cows (Volesky et al., 2002). Incorporating legumes, such as pea (*Pisum sativum* L.), with cereals increases the CP concentration of the hay at harvest relative to a monoculture cereal crop (Aasen et al., 2004; Strydhorst et al., 2008). Intercropping legumes with cereals has been reported to increase forage DM yield (Berkenkamp and Meeres, 1987; Carr et al., 2004) and N yield (Carr et al., 2004). Furthermore, the ability of legumes to fix nitrogen may have the potential to reduce the cost of production by reducing or even eliminating the need for added N fertilizer (Zahran, 1999).

While there are potential benefits of pea inclusion within cereal crops, lodging of pea when grown as a monoculture or in mixtures with cereal grains has been a concern (Asci et al., 2015). However, pea breeding efforts have resulted in a new pea cultivar, CDC Horizon, developed to have greater lodging resistance relative to CDC Trapper (Warkentin et al., 2012) and to have improved forage quality, resistance to powdery mildew, and increased DM yield over CDC Leroy and CDC Tucker (Warkentin et al., 2012). As a semi-leafless type pea, CDC Horizon is also shorter and broader-stemmed than CDC Trapper and 40-10, allowing for greater quality retention during harvest by reducing fragility-related losses from pod and leaf shatter. However, only one study has evaluated cattle responses to CDC Horizon, and in that study, it was grown for hay in a monoculture (Pursley et al., 2019).

It was hypothesized that increasing pea inclusion into cereal hay would increase DMI and total tract digestibility, with similar effects occurring when included with barley or oat. The objectives of this study were to evaluate intake, ruminal fermentation, and total tract digestibility in beef cattle in response to barley and oat hay-based diets with increasing levels of pea hay inclusion.

3.3 Materials and Methods

3.3.1 Forage Production

Monocultures of barley (*Hordeum vulgare* L.; c.v. CDC Maverick), oat (*Avena sativa;* c.v. CDC Haymaker), and pea (*Pisum sativum* L.; c.v. CDC Horizon) were seeded (Great Plains no-till drill, Salina, KS) in individual 0.81-ha plots on May 26, 2017 at the University of Saskatchewan (Saskatoon, SK, Canada). In addition, pea was seeded together with either barley or oat to produce cereal-legume blends using 0.81-ha plots for each crop type and combination. The seeding rate was 319 kg/ha for barley, 240 kg/ha for oat, and 247 kg/ha for pea. For blends, the seeding rates for each of the crops was 50% of the monoculture seeding rate equating to 160 kg/ha of barley with 123 kg/ha of pea, and 120 kg/ha of oat with 123 kg/ha of pea. Due to inability to adequately mix the cereal and pea within the seeder, the pea was seeded using a second pass. All plots received 35 kg/ha to target 60 kg/ha soil N concentration, based on soil samples collected in the spring. No herbicide, fungicide, or insecticide were applied.

Forage plots were monitored for stage of maturity and swathed at the hard dough stage for the cereal grain according to Rosser et al. (2013). The monoculture pea forage was swathed on the same date as for the barley monocrop and barley-pea mixture (swathing date: August 4th, 2017; baling date: August 13th, 2017). Oat-based plots were swathed on August 11th, 2017 and baled August 22nd, 2017. All forages were cut with a Case IH 8825 (CNH, Racine, WI) at a targeted stubble height of 10 cm. Swaths were monitored daily for DM content and baled with a Massey Ferguson 1839 baler (AGCO, Duluth, GA) when DM content was >85%. Bales were stored under a covered shelter until being used in feeding studies.

Prior to cutting, 0.5-m^2 quadrat clippings (10-cm stubble height) were collected from 5 random locations in each plot (Table 3.1). The total wet weight and DM content of the sample was used to determine forage yield. In the case of cereal-pea mixtures, the cereal and pea forages were hand-separated to determine their contribution to the forage yield. Clippings were then cut to a length of 5 cm and dried at 135°C until a constant weight was reached to determine DM content. In addition, a sub-sample from the collected pre-harvest samples was frozen and stored for determination of chemical composition as described below. At time of baling, a representative sample of the forage was collected for chemical analysis (Table 3.2).

Table 3.1. Environmental conditions pre- and post-swathing of barley (*Hordeum vulgare* L.; c.v. CDC Maverick), oat (*Avena sativa* L.; c.v. CDC Haymaker), and pea (*Pisum sativum* L.; c.v. CDC Horizon) monocultures, and barley-pea (BP) and oat-pea (OP) mixtures.

	Crop type				
Agronomic management[1]	Barley	BP	Oat	OP	Pea
Pre-swathing[2]					
Days from seeding	71	71	77	77	71
Growing degree days[3]	934	934	1033	1033	934
Mean ambient temperature, °C	17.5	17.5	17.6	17.6	17.5
Precipitation, mm	57.0	57.0	86.9	86.9	57.0
Date of swathing, 2017	4-Aug	4-Aug	11-Aug	11-Aug	4-Aug
Predicted yield, T/ha (DM)	9.6	10.7	9.8	13.8	12.8
Post-swathing[4]					
Mean ambient temperature, °C	19.6	19.6	18.4	18.4	19.6
Precipitation, mm	29.9	29.9	7.5	7.2	29.9
Date of baling, 2017	13-Aug	13-Aug	22-Aug	22-Aug	13-Aug
DM at baling, %	86.4	87.6	90.0	90.5	81.9

[1] Data derived from SRC Climate Research Station 4057180 (Saskatoon, SK).

[2] Data is calculated from seeding date until date of swathing.

[3] Daily growing degree days were calculated as: (maximum temperature + minimum temperature)/2 – 5°C.

[4] Data were calculated from date of swathing until date of baling.

Table 3.2. Nutrient composition of barley hay (*Hordeum vulgare* L.; c.v. CDC Maverick), oat hay (*Avena sativa* L.; c.v. CDC Haymaker), pea hay (*Pisum sativum* L.; c.v. CDC Horizon), barley-pea hay mixture, oat-pea hay mixture, and mineral supplement.

	Ingredient					
Variable	Barley	Barley-Pea[1]	Oat	Oat-Pea	Pea	Supplement[3]
DM	88.83 ± 2.24[2]	89.37 ± 2.19	87.99 ± 2.56	85.90 ± 7.42	88.26 ± 2.21	94.01 ± 0.42
Nutrient, % DM						
OM	93.81 ± 0.31	93.55 ± 1.99	93.95 ± 0.71	94.26 ± 0.75	93.80 ± 0.52	54.59 ± 0.70
CP	10.25 ± 1.03	9.82 ± 0.67	11.22 ± 0.74	9.70 ± 1.84	15.47 ± 2.23	8.00 ± 0.11
aNDF_{OM}	50.95 ± 2.11	48.68 ± 1.72	52.82 ± 3.31	51.38 ± 1.83	15.47 ± 2.75	18.88 ± 0.87
NDF	52.22 ± 2.02	50.70 ± 2.50	53.48 ± 3.29	52.02 ± 2.12	37.97 ± 2.79	28.13 ± 4.85
ADF	31.33 ± 2.50	30.12 ± 2.82	30.37 ± 1.81	29.98 ± 3.05	28.70 ± 2.91	8.87 ± 0.50
Starch	14.30 ± 2.02	16.27 ± 2.80	13.33 ± 3.79	13.42 ± 6.26	19.48 ± 3.10	11.80 ± 0.38
EE	2.79 ± 0.60	2.57 ± 0.46	3.42 ± 0.34	3.59 ± 0.45	1.90 ± 3.10	2.29 ± 0.34
Ca	0.46 ± 0.03	0.40 ± 0.08	0.40 ± 0.05	0.35 ± 0.03	1.41 ± 0.12	9.59 ± 0.11
P	0.25 ± 0.03	0.21 ± 0.03	0.22 ± 0.03	0.23 ± 0.02	0.27 ± 0.04	3.91 ± 0.05

[1] Barley-Pea consisted of 1.62% pea DM, Oat-Pea consisted of 1.65% pea DM.

[2] Values are listed as mean ± SD.

[3] Supplement composed (DM basis) of wheat middlings (62.66%), molasses (3.63%), Ca (8.55%), P (3.58%), Mg (3.43%), K (0.70%), Na (2.37%), Cl (3.63%), S (0.51%), Mn (53,574 ppm), Cu (4,498 ppm), Fe (2,044 ppm), Sn (7,553 ppm), I (1.8 ppm), Co (1.7 ppm), Se (3.3 ppm), Vitamin A (55,691.6 IU/kg), Vitamin D (6,772.1 IU/kg), Vitamin E (1,485.1 IU/kg), melengestrol acetate (MGA; 0.0019%; Federated Co-operatives Limited; Saskatoon, SK, Canada), and monensin (0.19%; Elanco Division of Eli Lilly Canada Inc., Guelph, ON, Canada).

Unexpectedly, the pea only represented 1.62% and 1.65% (DM basis) for the barley and oat blends, respectively.

3.3.2 Experimental Design

Six ruminally-cannulated Hereford-cross heifers were used in a 6 × 6 Latin square design, with 25-d periods. Each period included 21 d of dietary adaptation and 4 d of data and sample collection. As the pea contribution in the cereal-pea blends was low (1.62% and 1.65% of DM for the barley and oat blends, respectively), the monoculture pea was used to create treatments that differed in the pea inclusion rate by hand mixing. Thus, treatments consisted of 92% forage (DM basis) and 8% of a supplement providing minerals and vitamins (Table 3.3). The forage DM was composed of either: 1) 100% barley hay; 2) 85% barley hay with 15% pea hay; 3) 70% barley hay with 30% pea hay; 4) 100% oat hay; 5) 85% oat hay with 15% pea hay; or 6) 70% oat hay with 30% pea hay. The percentage of pea present in the cereal-pea blend hays was accounted for when calculating pea hay inclusion. Diets were fed once daily with the mineral and vitamin supplement offered at 0730 h and the forage at 0800 h. Heifers had unrestricted access to fresh water throughout the study. Feed refusals were collected and weighed each day at 0700 h.

3.3.3 Heifer BW and DMI

Heifers were weighed at 0700 h on d 1 and 2 of each period, as well as the on the 2 consecutive days following completion of the experiment. DMI was recorded during the 4-d sampling period based on the difference between the amount of feed offered and the amount refused when corrected for the DM content of the feed offered and the feed refused. Samples of the feed ingredients and refusals were collected daily and DM was determined by drying at 55°C until achieving a constant weight.

3.3.4 Ruminal Fermentation and Total Tract Digestibility

Ruminal digesta was collected every 4 h for 24 h, beginning at 0800 h on d 22. At each collection time point, a 250-mL sample of digesta was collected from each the cranial, central, and caudal regions of the rumen at the rumen-fluid rumen-mat interface. The sample was

Table 3.3. Dietary ingredient inclusion rate and dietary composition for beef heifers fed barley (*Hordeum vulgare* L; c.v. CDC Maverick) or oat (*Avena sativa;* c.v. CDC Haymaker) hay with pea hay (*Pisum sativum;* c.v. CDC Horizon) comprising 0, 15, and 30% of the hay DM.

	Treatment					
	Barley			Oat		
Variable	0	15	30	0	15	30
Ingredient inclusion rate, % DM						
Barley	92.00	-	-	-	-	-
Barley-Pea[1]	-	79.69	65.87	-	-	-
Oat	-	-	-	92.00	-	-
Oat-Pea[2]	-	-	-	-	79.72	65.92
Pea	-	12.31	26.13	-	12.28	26.08
Supplement[3]	8.00	8.00	8.00	8.00	8.00	8.00
DM, %	90.69	89.73	89.70	90.28	90.83	90.61
Nutrient Composition, % DM						
OM	91.65	91.44	91.47	91.77	92.00	91.94
CP	10.29	10.59	11.37	11.18	10.50	11.29
$aNDF_{OM}$	48.90	45.45	43.93	50.62	47.61	45.72
ADF	29.69	28.39	28.20	28.80	28.29	28.11
Starch	14.40	16.60	17.05	13.51	14.33	15.17
Ether extract	2.81	2.51	2.42	3.38	3.33	3.10
Ca	0.96	1.03	1.17	0.91	1.00	1.14
P	0.47	0.44	0.45	0.44	0.46	0.46

[1] Barley-Pea hay consisted of 98.38% barley DM and 1.62% pea DM.

[2] Oat-Pea hay consisted of 98.35% oat DM and 1.65% pea DM.

[3] Supplement composed (DM basis) of wheat middlings (62.66%), molasses (3.63%), Ca (8.55%), P (3.58%), Mg (3.43%), K (0.70%), Na (2.37%), Cl (3.63%), S (0.51%), Mn (53,574 ppm), Cu (4,498 ppm), Fe (2,044 ppm), Sn (7,553 ppm), I (1.8 ppm), Co (1.7 ppm), Se (3.3 ppm), Vitamin A (55,691.6 IU/kg), Vitamin D (6,772.1 IU/kg), Vitamin E (1,485.1 IU/kg), melengestrol acetate (MGA; 0.0019%; Federated Co-operatives Limited; Saskatoon, SK, Canada), and monensin (0.19%; Elanco Division of Eli Lilly Canada Inc., Guelph, ON, Canada).

strained through 2 layers of cheesecloth and 10 mL of the strained ruminal fluid was transferred into a 15-mL vial containing 2 mL of metaphosphoric acid (25% wt/v). This subsample was used Research Centre Ruminal pH Measurement System (Dascor Inc., Escondido, CA) as described by Penner et al. (2006). The pH system was standardized at 39°C prior to insertion and upon removal from the rumen. The loggers recorded data in mV and the beginning and ending regressions determined by calibrating the pH meters in pH 7 and 4 buffers were used to convert mV to pH with the assumption of linear drift over time.

Urinary catheters were inserted into each heifer on d 21 with urine collection initiated on d 22. Urine was collected into 25-L carboys containing 200 mL of 12-*M* HCl and urine excretion was measured every 24-h for 96 h starting at 0600 h each day. Urine pH was recorded daily to ensure the collected urine had a pH < 3.0. Each day, a 35-mL representative sample was collected and stored at -20°C. The daily samples were combined to yield a 4-d composite for each heifer. Urinary N excretion was evaluated using the Kjeldahl procedure (Method 984.13, AOAC, 1994). Microbial CP supply was estimated using the calculations described by Chen and Gomes (1992) utilizing total urine output and the concentrations of allantoin (Chen and Gomes, 1992) and uric acid (kit 700320, Cayman Chemical, Ann Arbor, MI).

Fecal samples were collected every 6 h over 96 h beginning at 0600 h on d 22. At each collection, feces were scraped from the pen floor and the wet weight of the feces was measured. A representative sample equating to 5% of the fecal weight from each collection point was stored in order to create a 4-d fecal composite sample for each heifer. The composite sample was stored at -20°C between sampling time points, was dried at 55°C until achieving a constant weight and was sent to Cumberland Valley Analytical Services (Waynesboro, PA) as described below. Apparent total tract digestibility was determined by expressing the difference between nutrient intake and nutrient output relative to nutrient intake on a DM basis.

3.3.5 Plasma and Serum Metabolites

Jugular catheters were inserted on d 21 to enable frequent blood collection. Blood samples were collected every 4 h for 24 h starting at 0800 h on d 24. At each collection time-point, 10 mL of blood was collected into tubes containing 158 IU of Li-heparin (BD Vacutainer, BD and Company, Franklin Lakes, NJ) to enable separation of plasma. Tubes for plasma were immediately placed on ice and centrifuged at 1,800 × *g* for 15 min at 4°C. Plasma was then transferred to a 5-mL vial and stored at -20°C until being analyzed for plasma urea nitrogen (Fawcett and Scott, 1960) and plasma glucose (product numbers P7119 and number F5803, Sigma Aldrich, Oakville, ON, Canada) concentrations. In addition, 10 mL of blood was collected into tubes containing clot activators (BD Vacutainer, BD and Company, Franklin Lakes, NJ) and allowed to fully clot for 30 min before centrifugation at 1,800 × *g* for 15 min at 4°C to separate serum. Serum was then transferred to 5-mL vials and stored at -20°C until being used to determine the concentration of β-hydroxybutyric acid (BHBA) according to Williamson et al. (1962).

3.3.6 Chemical Analysis

All feed, refusal, and fecal samples were dried at 55°C in a forced-air oven for 3 d and then ground to pass through a 1-mm screen using a hammer-mill (Christy and Norris Ltd., Chelmsford, UK). Ground samples were sent to Cumberland Valley Analytical Services (Waynesboro, PA) and analyzed for organic matter (OM), crude protein (CP), neutral detergent fiber (NDF), ash corrected NDF ($aNDF_{OM}$), acid detergent fiber (ADF), starch, ether extract, Ca, and P. Crude protein was analyzed using a Leco FP-528 Nitrogen Combustion Analyzer (LECO Corp., St. Joseph, MI). Neutral detergent fiber (NDF) was determined according to Van Soest et al. (1991) using Whatman 934-AH glass micro-fiber filters with 1.5-µm particle retention (GE Healthcare Life Sciences, Piscataway, NJ) utilizing α-amylase and sodium sulfite. The residue remaining from the NDF analysis was also used to determine $aNDF_{OM}$ by ashing the residue at 535°C for 2 h. Acid detergent fiber was determined according to AOAC method 973.18 (AOAC, 2000) using Whatman 934-AH glass micro-fiber filters with a 1.5-µm particle retention instead of glass crucibles. Starch was determined according to Hall (2009) and ether extract was determined according to AOAC method 2003.05 (AOAC, 2006). Ethanol-soluble carbohydrate was analyzed according to Dubois et al. (1956). Ash was determined according to AOAC method 942.05 (AOAC, 2000), with the modification that a 1.5-g sample was ashed for 4 h at 600°C. Calcium and P concentrations were determined according to AOAC method 985.01 (AOAC, 2000) by ashing samples for 1 h at 535°C followed by a digestion using 15% nitric acid.

Samples were then adjusted to 50 mL and analyzed on a PerkinElmer 5300 inductively-coupled plasma optical emission spectrometer (PerkinElmer, Shelton, CT).

3.3.7 Statistical Analysis

Data were analyzed using the Mixed Model procedure of SAS (version 9.4; SAS Inst. Inc., Cary, NC). The model included the fixed effects of cereal type, pea inclusion, cereal-pea interaction, and the linear and quadratic effects of pea inclusion. Heifer and period were included as random effects. Significance was declared when $P < 0.05$.

3.4 Results

3.4.1 Forage Production and Treatments

Barley, barley-pea, and pea were swathed 71 d after seeding; whereas, the oat and oat-pea crops were swathed 77 d after seeding (Table 3.1). The mean ambient temperature was 17.5°C and precipitation during crop growth ranged from 57 to 87 mm depending on swathing date. Barley, barley-pea, and pea required 9 d in the swath for curing prior to baling, while oat and oat-pea required 11 d.

Although statistical analysis could not be conducted, increasing pea hay inclusion in the diet numerically increased the dietary CP slightly in barley treatments, increased starch concentrations in both cereal types, and reduced aNDF_{OM} (Table 3.2 and 3.3). Barley-based diets were numerically greater in starch concentration and oat diets were greater in aNDF_{OM}, NDF, and ether extract.

3.4.2 BW, DMI, and Ruminal Fermentation

BW and ADG were not affected by cereal hay type or pea hay inclusion ($P > 0.26$; Table 3.4). However, including pea increased DMI relative to 0% pea hay without detectable linear or quadratic effects. There were no effects of cereal hay or pea hay inclusion on minimum or maximum ruminal pH ($P \geq 0.14$), although mean ruminal pH increased linearly with pea inclusion ($P = 0.039$). There was no effect of cereal hay or pea hay inclusion on total ruminal SCFA concentration; however, molar proportions were affected by both cereal hay type and inclusion rate of pea. For the molar proportion of acetate, there was an interaction among cereal

Table 3.4. ADG, DMI, ruminal fermentation, and blood metabolite concentrations in beef heifers fed barley (*Hordeum vulgare* L; c.v. CDC Maverick) or oat (*Avena sativa;* c.v. CDC Haymaker) hay with pea hay (*Pisum sativum;* c.v. CDC Horizon) comprising 0, 15, and 30% of the hay DM.

	Barley			Oat				*P*-value^{1}				
Variable	0%	15%	30%	0%	15%	30%	SEM^{2}	C	I	C×I	L	Q
Initial BW, kg	445	440	446	457	454	440	10.7	0.57	0.33	0.65	0.90	0.94
Final BW, kg	448	444	446	457	459	438	11.2	0.37	0.32	0.44	0.76	0.92
ADG, kg/d	0.18	0.13	0.00	0.02	0.18	0.31	0.120	0.26	0.63	0.44	0.46	0.55
DMI, kg/d	7.18	7.98	7.72	7.20	7.75	7.93	0.360	0.98	0.03	0.71	0.13	0.32
Ruminal digesta, kg	48.5	50.9	51.9	47.8	49.7	49.4	3.14	0.35	0.38	0.87	0.43	0.75
Ruminal pH												
Minimum	6.52	6.52	6.58	6.43	6.55	6.60	0.056	0.89	0.14	0.35	0.091	0.93
Maximum	6.96	7.00	6.94	6.91	6.96	6.99	0.056	0.99	0.59	0.62	0.67	0.58
Mean	6.72	6.74	6.79	6.67	6.74	6.80	0.037	0.60	0.039	0.57	0.024	0.96
Ruminal Fermentation												
Ammonia, mg/dL	2.96	2.87	4.05	1.48	1.98	3.09	0.32	<0.001	<0.001	0.20	<0.001	0.011
SCFA, m*M*	88.07	84.18	83.93	89.32	84.53	87.76	3.71	0.55	0.59	0.88	0.31	0.42
SCFA, mol/100 mol												
Acetate	68.69^{ab}	68.13^{ab}	68.65^{b}	68.13^{b}	69.62^{ab}	70.20^{a}	0.533	0.005	0.074	0.024	<0.001	0.67
Propionate	17.82	16.65	15.82	18.67	16.59	15.76	0.390	0.96	<0.001	0.61	<0.001	0.40
Isobutyrate	0.77	0.81	0.86	0.81	0.85	0.85	0.025	0.44	0.19	0.79	0.009	0.70
Butyrate	10.70	11.25	11.47	8.74	9.87	10.62	0.374	<0.001	0.013	0.34	<0.001	0.55
Isovalerate	1.07	1.10	1.17	1.02	1.09	1.24	0.037	0.95	0.073	0.64	0.001	0.38
Valerate	1.38^{ab}	1.23^{ab}	1.27^{a}	0.91^{d}	1.05^{c}	1.19^{bc}	0.177	<0.001	0.014	0.023	0.52	0.79
Caproate	0.37	0.43	0.46	0.32	0.42	0.45	0.014	0.06	<0.001	0.97	<0.001	0.037

Table 3.4 (continued). ADG, DMI, ruminal fermentation, and blood metabolite concentrations in beef heifers fed barley (*Hordeum vulgare* L; c.v. CDC Maverick) or oat (*Avena sativa;* c.v. CDC Haymaker) hay with pea hay (*Pisum sativum;* c.v. CDC Horizon) comprising 0, 15, and 30% of the hay DM. Continued.

	Barley			Oat				*P*-value[1]				
Variable	0%	15%	30%	0%	15%	30%	SEM[2]	C	I	C×I	L	Q
Metabolite, mg/dL												
Plasma glucose	53.0	49.8	51.5	50.7	51.7	52.0	2.22	0.99	0.78	0.47	0.64	0.56
Serum BHBA	5.6	6.9	6.3	6.3	7.0	6.5	0.45	0.20	0.028	0.55	0.22	0.025
Plasma urea-N	7.5	6.7	8.9	7.8	7.7	8.1	0.32	0.66	0.001	0.37	0.062	0.26

[a-f] means within a row with uncommon superscripts differ ($P < 0.05$) with cereal-inclusion interaction.

[1] *P*-value categories are abbreviated as C = cereal, I = inclusion, C×I = interaction of cereal and inclusion, L = linear contrast of inclusion rate, and Q = quadratic contrast of inclusion rate.

[2] SEM of the cereal-inclusion (C×I) interaction.

hay type and pea hay inclusion rate (*P* = 0.024), with acetate being greatest for 30% pea hay inclusion with oat hay and least for 30% inclusion of pea hay in barley hay. Propionate concentration decreased linearly with increasing pea inclusion. Use of barley hay resulted in lesser concentrations of butyrate ($P < 0.001$) than oat and pea hay inclusion linearly increased the butyrate concentration. Pea hay inclusion also linearly increased the concentrations of isobutyrate and isovalerate, ($P < 0.013$), while decreasing molar proportion of caproate ($P < 0.001$). Total ruminal ammonia was 1.08 mg/dL greater for heifers fed barley hay relative to oat hay and increased at an increasing rate as pea hay inclusion (*P* = 0.011).

3.4.3 Blood metabolites

No interactions between cereal hay type and pea inclusion rate were detected (Table 3.4). Moreover, there was no effect of cereal hay type for blood metabolite concentrations ($P \geq 0.20$). Serum BHBA quadratically increased and then decreased with pea inclusion (*P* = 0.028). Plasma urea-N decreased and then increased in response to pea inclusion (*P* = 0.001)

3.4.4 Eating behavior

Heifers fed oat hay selectively sorted for CP (*P* = 0.022; Table 3.5) and against aNDF_{OM} when compared to those fed barley hay. However, unlike the oat hay treatments, the barley hay treatments resulted in aversion against starch (*P* = 0.002). Inclusion of pea linearly decreased selection of CP ($P < 0.001$), linearly decreased the selection against aNDF_{OM} and ADF, and linearly increased selection for ether extract ($P \leq 0.006$) with increasing pea hay inclusion.

3.4.5 Apparent Total Tract Digestibility and Nitrogen Balance

Dry matter, OM, and CP digestibility were greater for heifers fed oat hay than barley hay (Table 3.6). While DM and OM digestibility were not affected by pea hay inclusion, CP digestibility decreased quadratically with increasing inclusion. There were no effects of cereal

Table 3.5. Sorting behavior for beef heifers fed barley (*Hordeum vulgare* L; c.v. CDC Maverick) or oat (*Avena sativa;* c.v. CDC Haymaker) hay with pea hay (*Pisum sativum;* c.v. CDC Horizon) comprising 0, 15, and 30% of the hay DM.

	Barley			Oat				*P*-value[2]				
Sorting Index[1]	0%	15%	30%	0%	15%	30%	SEM[3]	C	I	C×I	L	Q
OM	100.15	100.32^{z}	100.13	100.17	100.15	100.16	0.073	0.55	0.49	0.37	0.91	0.30
CP	102.91	97.90	98.30	105.46^{z}	100.31	99.80	0.963	0.022	<0.001	0.87	<0.001	0.028
aNDF$_{OM}$	98.87	101.98^{z}	101.55	97.81^{z}	99.51	99.90	0.726	0.010	0.006	0.64	0.017	0.14
ADF	94.85	100.18	99.48	96.29^{z}	98.00	97.61	1.008	0.25	0.002	0.11	0.024	0.066
Starch	97.10	95.01^{z}	96.55	103.69	100.77	99.12	1.807	0.002	0.25	0.42	0.38	0.83
Ether extract	73.37	103.72^{z}	103.68^{z}	98.06	95.23	98.7	8.054	0.67	0.29	0.24	0.025	0.073

[1] Sorting index was calculated as [(actual nutrient consumed)/(theoretical nutrient consumed)] × 100%, as described in Leonardi and Armentano (2006).

[2] *P*-value categories are abbreviated as C = cereal, I = inclusion, C×I = interaction of cereal and inclusion, L = linear contrast of inclusion rate, and Q = quadratic contrast of inclusion rate.

[3] SEM of the cereal-inclusion (C×I) interaction.

[a-f] means within a row with uncommon superscripts differ ($P < 0.05$) with cereal-inclusion interaction.

[z] Means with a superscript differ from 100.0 ($P < 0.05$) based on a 2-tailed t-test.

Table 3.6. Apparent digestibility of nutrients for beef heifers fed barley (*Hordeum vulgare* L; c.v. CDC Maverick) or oat (*Avena sativa;* c.v. CDC Haymaker) hay with pea hay (*Pisum sativum;* c.v. CDC Horizon) comprising 0, 15, and 30% of the hay DM.

	Barley			Oat				*P*-value^1				
Digestibility, %	0%	15%	30%	0%	15%	30%	SEM^2	C	I	C×I	L	Q
DM	61.14	63.21	65.31	67.89	67.65	67.64	0.875	<0.001	0.32	0.23	0.13	0.95
OM	61.63	63.76	63.3	69.48	61.92	62.07	0.883	0.002	0.24	0.32	0.090	0.97
CP	61.07	56.51	62.01	72.36	67.78	67.53	1.143	<0.001	0.025	0.082	0.27	0.014
aNDF_{OM}	59.68	62.19	61.87	69.55	60.77	61.21	1.159	0.95	0.93	0.28	0.79	0.93
ADF	54.72	56.98	57.26	65.71	56.23	57.74	1.249	0.19	0.79	0.17	0.85	0.50
Starch	67.60^a	72.76^a	79.06^a	98.01^b	90.45^b	89.11^b	1.319	<0.001	0.97	0.001	0.84	0.90
Ether extract	68.01	63.94	64.87	75.97	76.00	70.58	2.371	0.028	0.61	0.14	0.88	0.49

[1] *P*-value categories are abbreviated as C = cereal, I = inclusion, C×I = interaction of cereal and inclusion, L = linear contrast of inclusion rate, and Q = quadratic contrast of inclusion rate.

[2] SEM of the cereal-inclusion (C×I) interaction.

$^{a\text{-}f}$ means within a row with uncommon superscripts differ ($P < 0.05$) with cereal-inclusion interaction.

hay type, pea inclusion, or their interaction on fiber digestibility (aNDF$_{OM}$ and ADF; $P \geq 0.17$). An interaction between cereal hay type and pea inclusion was detected for starch digestibility, with barley treatments being more digestible than oat, but starch digestibility numerically increasing as pea hay inclusion increased for the barley hay treatments while starch digestibility numerically decreased with increasing pea hay inclusion for the oat hay treatments. Ether extract digestibility was greater for oat hay than for barley hay but was not affected by inclusion rate of pea hay.

Nitrogen intake was not affected by cereal hay type or pea hay inclusion. While fecal output was not affected, fecal N output was greater for heifers fed barley hay than those fed oat hay. Urine output and urinary N excretion were greater for heifers fed treatments with oat hay than barley hay but there were no effects of pea hay inclusion. There were no differences in the excretion of allantoin but feeding barley hay resulted in greater urinary uric acid excretion compared to oat hay ($P = 0.034$; Table 3.7) without affecting total purine derivative excretion. As such, there no differences in the predicted daily microbial nitrogen supply ($P = 0.24$) were observed.

Table 3.7. Nitrogen intake, excretion, and balance for beef heifers fed barley (*Hordeum vulgare* L; c.v. CDC Maverick) or oat (*Avena sativa;* c.v. CDC Haymaker) hay with pea hay (*Pisum sativum;* c.v. CDC Horizon) comprising 0, 15, and 30% of the hay DM.

	Barley			Oat				*P*-value[1]				
Variable	0%	15%	30%	0%	15%	30%	SEM[2]	C	I	C×I	L	Q
Intake N, g/d	119.4	127.0	138.7	134.6	129.9	143.9	7.68	0.24	0.14	0.74	0.17	0.48
Fecal output, kg	2.7	2.8	2.7	2.3	2.5	2.6	0.17	0.067	0.78	0.67	0.69	0.71
Fecal N output, g/d	48.5	46.8	42.9	29.3	35.7	39.0	8.93	0.001	0.79	0.11	0.95	0.94
Urine output, kg	7.4	7.1	7.9	8.7	8.9	9.0	0.83	0.004	0.63	0.81	0.25	0.99
Urinary N output, g/d	50.9	47.8	57.1	56.4	57.3	65.2	4.85	0.025	0.056	0.87	0.17	0.32
Urinary PD, mmol/d[3]												
Allantoin	54.6	65.4	64.9	60.7	71.3	63.0	7.42	0.71	0.66	0.91	0.56	0.44
Uric acid	11.5	13.0	14.2	10.1	8.4	7.1	1.73	0.034	0.99	0.47	0.87	0.93
Total	66.3	78.3	79.1	70.8	67.7	70.1	8.00	0.62	0.88	0.81	0.63	0.89
Microbial N[4], g/d	48.2	56.9	57.5	51.5	49.3	50.9	5.82	0.62	0.88	0.81	0.63	0.89
N retained, g/d	20.0	32.4	38.7	48.9	36.9	39.8	9.20	0.033	0.77	0.071	0.65	0.97

[1] *P*-value categories are abbreviated as C = cereal, I = inclusion, C×I = interaction of cereal and inclusion, L = linear contrast of inclusion rate, and Q = quadratic contrast of inclusion rate.

[2] SEM of the cereal-inclusion (C×I) interaction.

[3] PD = purine derivatives

[4] Predicted according to Chen and Gomes (1992).

3.5 Discussion

While the intention was to evaluate the effect of pea inclusion when grown in combination with barley or oat for hay, the proportion of pea in the forage when grown as a binary mix only equated to 1.62% and 1.65% of the DM for the barley-pea and oat-pea blends, respectively. These results were unexpected and differ from past research showing successful inclusion of pea when grown with barley (Strydhorst et al., 2008), oat (Uzun and Asik, 2012), and triticale (Asci et al., 2015). While it cannot be confirmed, the low inclusion rate may have been affected by factors such as seeding depth and drier than normal growth conditions. Nevertheless, the original treatment approach was modified by mixing pure pea hay with barley or oat hay to create pea hay inclusions of 0, 15, and 30% as a proportion of the total barley or oat hay.

3.5.1 Effect of Pea Inclusion in Cereal Hay

Previous research has reported that feeding pea hay to cattle increases DMI relative to cereal-only diets (Soto-Navarro et al., 2012). Similar results were observed in this study, where inclusion of pea at either 15 or 30% increased DMI, regardless of whether it was incorporated with barley or oat hay. The improvement in DMI may be attributed to lower NDF concentration in pea hay compared to the cereal hay in the present study. DMI is negatively impacted by NDF intake due to the greater ruminal distension and slower passage rate associated with high NDF diets (Dado and Allen, 1995; Oba and Allen, 1998; Allen, 2000). Moreover, the filling effect of NDF is negatively related to NDF digestibility (Oba and Allen, 1998). The pea hay used in this study contained a numerically less NDF (37.97%) than barley (52.22%) and oat (53.48%) hay and given that apparent total tract NDF digestibility was similar among treatments, the lesser dietary NDF concentration with increasing pea inclusion likely explains the greater DMI. Additionally, cattle selected against fibrous components in straight cereal diets while such sorting was not observed in the blended diets further supporting that the reduced NDF concentration in pea hay may explain the greater DMI observed when pea was included.

It was observed that heifers sorted for CP and against NDF and ADF in the cereal-only treatments while sorting against CP and selecting less against fiber in cereal-pea blend diets. As previously stated, cereal hay contains greater fiber and less protein than pea hay (NASEM, 2016). Therefore, the behavioral patterns exhibited indicate that when pea was included in a cereal-based diet, cattle may select for the cereal component over the pea. Furthermore, it was observed that despite greater CP concentration and increased DMI, pea inclusion did not increase CP intake, microbial protein supply, or nitrogen balance. The lack of a positive effect on CP intake and N-balance is supported by previous studies (Khorasani et al., 2001; Vander Pol et al., 2008; Vander Pol et al., 2009). The increase in DMI without a corresponding increase in N intake further supports the explanation that cattle selected against the pea component of the hay as pea inclusion rate increased.

As expected based on findings by Reed et al. (2004), increasing pea hay concentration in the diet increased mean ruminal pH, due to the high ruminal buffering effect of legumes compared to cereals through cation exchange capacity (Jasaitis et al., 1987; Van Soest, 1994). Despite increased ruminal pH, ruminal SCFA concentration was not affected by pea hay inclusion, but inclusion of pea hay at 15 or 30% relative to 0% increased the molar proportions of acetate, isobutyrate, and butyrate at the expense of propionate. Moreover, there was a quadratic response for BHBA concentration in serum with concentration increasing between 0 and 15% and decreasing between 15 and 30%. The increase in serum BHBA is likely in response to greater ruminal butyrate and greater ruminal ketogenesis, particularly since the concentration of BHBA does not necessarily increase linearly with increasing ruminal butyrate concentration (Krehbiel, 1992) and it is believed that quadratic pattern of change may reflect differing use of glucose, butyrate, and propionate by ruminal epithelial cells for oxidation (Wiese et al., 2013).

3.5.2 Comparing Barley and Oat Hay

Barley and oat are two common cereals used for hay production in the Northern Great Plains (Volesky et al., 2002). When offered as a whole crop silage, barley produced a greater DMI response than oat in dairy cattle (Khorasani et al., 1996) and sheep (McCartney and Vaage, 1994), with no intake difference observed in beef heifers (McCartney and Vaage, 1994). In accordance with the results of McCartney and Vaage (1994), this study found no difference in intake between barley and oat hay treatments when fed to beef heifers.

Cereal hay source did not affect minimum, maximum, or mean ruminal pH. This response could be expected given the lack of difference for DMI and similar dietary starch concentrations. However, based on greater total tract starch digestibility and lower ruminal ammonia concentrations for cattle fed oat hay relative to barley hay, it is likely that ruminal starch degradability was greater for oat than barley hay. In accordance with these results, Herrera-Saldana et al. (1990) reported greater starch degradability in oat compared to barley. That said, the lack of difference for ruminal pH could also be related to the relatively low dietary starch concentration, that ruminal pH had a relatively narrow range in the present study, and that ruminal pH was maintained at a relatively high level.

Our results show that cereal hay type impacts N utilization with greater N retention for cattle fed oat hay relative to barley hay. However, N retention was greater than would be expected for cattle given the measured ADG. For example, assuming 26 g of N retained equates to approximately 1 kg BW gain (Kohn et al., 2005) cattle with the N retention levels reported in this study would have an ADG predicted to range from 0.77 to 1.88 kg/d depending on treatment. However, the measured ADG was much lower than these predictions. Experimental methods of collecting N balance data are prone to overestimation of N intake and underestimation of N output (Spanghero and Kowalski, 1997) and the bias associated with N-balance measurement accuracy should have affected all treatments equally.

Barley hay had lesser total tract digestibility for most nutrients than oat hay. In particular, starch digestibility was low for barley hay and this differed from a previous study where barley hay was harvested at a similar stage of maturity resulting in total tract digestibility of >90% (Rosser et al. 2015). It is unclear why starch digestibility for barley hay was less than expected in the present study, but it may be related to barley variety selection. When comparing barley and oat hay, oat hay had greater starch digestibility. Whole oats have greater starch digestibility than barley, which requires processing to improve digestibility (Campling, 1991). Furthermore, oat grain was more degradable than barley grain when ground for *in situ* degradation experiments (Herrera-Saldana et al., 1990). However, our results contradict studies reporting overall greater digestibility in whole-crop barley forage than oat forage (Cherney and Marten, 1982; Hingston and Christensen, 1982; McCartney and Vaage, 1994), which may be a result of the variation in forage characteristics between cultivar types within a species.

3.6 Conclusion

Incorporating pea hay with cereal hay may improve DMI, modify ruminal fermentation, and decrease CP digestibility without affecting nitrogen balance. In this study, oat hay induced less sorting behavior by cattle and had greater total tract digestibility than barley hay. However, our data suggest that barley encourages more nitrogen recycling in the cattle. Future research is needed to assess growth performance and feed efficiency of cattle fed pea-cereal hay blends, as well as the effects of barley-pea and oat-pea blends on nitrogen recycling.

4.0 EFFECT OF STAGE OF MATURITY AT HARVEST FOR FORAGE PEA (*PISIUM SATIVUM* L.) ON EATING BEHAVIOR, RUMINAL FERMENTATION, AND DIGESTIBILITY WHEN FED AS HAY TO YEARLING BEEF HEIFERS[2]

4.1 Abstract

The objective of this study was to evaluate the stage of maturity at harvest for pea hay (*Pisum sativum* L., c.v. CDC Horizon) on DMI, eating behavior, ruminal fermentation, and digestibility when fed to beef heifers. Pea hay was cut at EARLY, MID, and LATE stages of maturity, dried in the field, and baled. The EARLY maturity was defined to occur when flat pods were on one or more nodes, the MID stage was defined when seeds filled the pods at one or more nodes and the leaves were changing from green to gold, and the LATE stage was defined when yellow dry seeds filled pods on most or all of the nodes and the pods and leaves had a yellow color. Six ruminally-cannulated Speckle Park heifers were used in a replicated 3 × 3 Latin square design with three 18-d periods including 12 d for adaptation, 2 d for measurement of ruminal pool sizes, and 4 d for collection of eating behavior, ruminal pH, ruminal fluid, and feces. For all treatments, the respective pea hay was included at 40% of the dietary DM. Stage of maturity at harvest for pea hay did not affect DMI or ruminal total SCFA concentration with averages of 3.2 kg/d and 96.55 m*M*, respectively. The duration of time spent ruminating decreased with advancing pea hay maturity when reported as min/d, min/kg DMI, and min/kg NDF ($P \leq 0.01$). Mean ruminal pH also decreased with advancing pea maturity ($P < 0.01$). The ruminal DM and uNDF_{OM} pools were not affected by stage maturity ($P \geq 0.55$) nor was the rate of digestion for NDF. However, NDF passage rate decreased by 0.21%/h with advancing pea hay maturity ($P = 0.02$). Apparent total tract digestibility of NDF (average = 16.30%, $P = 0.41$) was not affected, but starch digestibility decreased from 96.10 to 93.08% with advancing pea hay maturity ($P = 0.07$). Overall, stage of maturity at harvest for pea hay does not appear to affect DMI or NDF digestibility, but decreases chewing activity, apparent total tract starch digestibility, ruminal pH, and ruminal NDF passage rate.

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[2] Pursley, A.A., B. Biligetu, T. Warkentin, H.A. Lardner, and G.B. Penner. 2019. Effect of stage of maturity at harvest for forage pea (*Pisum sativum* L.) on eating behavior, ruminal fermentation, and digestibility when fed as hay to yearling beef heifers. Translational Anim. Sci. Accepted.

4.2 Introduction

Incorporation of legumes such as field pea into cereal crops can enhance nitrogen fixation, decrease requirement for fertilizer application, and increase protein concentration of hay (Berkenkamp and Meeres, 1987; Aasen et al., 2004; Carr et al., 2004; Strydhorst et al., 2008). However, cereals and field pea mature at differing rates. Harvest timing of cereal-pea blends is currently based on cereal maturity (Uzun and Asik, 2012); however, it is not clear how maturity at harvest for pea hay affects cattle responses.

Delaying maturity at swathing for annuals used for hay has been shown to improve yield without compromising quality for small grain cereals (Rosser et al., 2013, 2016), intercrops (Pikul et al., 2004), and pea (Borreani et al., 2007). Moreover, harvesting cereal hay at hard dough relative to soft dough does not compromise ruminal or total tract digestibility (Rosser et al., 2013; 2016) or DMI in beef cattle (Rosser et al., 2016; 2017). Recent research evaluating pea hay harvest maturity on cattle performance is limited; however, it has been reported that allowing peas to advance in maturity increased DMI in sheep (Daniel et al., 1946). On the other hand, digestibility of pea silage was greatest when cut at EARLY and MID stages rather than when flowering or ripe (Brundage et al., 1979). New forage pea cultivars have been developed with improved lodging resistance (Warkentin et al., 2012), which may allow for more delayed maturity at harvest without compromising digestibility.

It was hypothesized maturity of field pea at harvest would not affect DMI or total tract digestibility, but the greater starch concentration in advanced maturity would increase sorting and alter ruminal fermentation.

4.3 Materials and Methods

4.3.1 Forage Production

CDC Horizon, a semi-leafless forage pea cultivar (Warkentin et al., 2012), was planted May 15, 2018 in a 0.81-ha plot at the University of Saskatchewan Livestock and Forage Centre of Excellence (Clavet, SK, Canada). Seeds were treated with 0.033 mL/kg mefenoxam and 0.0219 mL/kg fludioxonil (Apron Max RTA; Syngenta, Guelph, ON, Canada) and 0.958 g/kg ethaboxam (Intego Solo; Nufarm, Calgary, AB, Canada), and seeded at a rate of 112 kg/ha with a

Great Plains no-till drill (Great Plains, Salina, KS). During seeding, the crop was inoculated with 3.33×10^{12} viable cfu/kg *Rhizobium leguminosarum* (TagTeam; Monsanto Company, St. Louis, MO) and 23-22-0-10 fertilizer at 131 kg/ha. Chemical application during growth occurred 3 times. On May 5, 2018, 109.8 mL/ha polyalkylenedioxide (AIM; AgPro, Big Sandy, TX) and 880.2 g ae/ha of glyphosate (RoundUp; Monsanto Company, St. Louis, MO) was applied. On June 5, 2018, 15.04 ae/ha of imazamox and 15.04 ae/ha of imazethapyr (Odyssey; BASF Canada Inc., Mississauga, ON, Canada), 166.5 g/ha of sethoxydim (Poast; BASF Canada, Mississauga, ON, Canada), and 0.25 L/100L of petroleum hydrocarbons (Merge; BASF Canada, Mississauga, ON, Canada) were applied. On June 18, 2018, 19.753 g/ha of imazamox (Viper; BASF Canada, Mississauga, ON, Canada) and 2 L/ha of 28-0-0 fertilizer was applied.

Peas were harvested at 3 stages of maturity based upon those outlined by the Northern Pulse Growers Association (Knott, 1987). The EARLY (EARLY) was defined as stage R3, when pea plants had flat unfilled pods at one or more nodes. The MID (MID) stage was defined as stages R4 and R5, which occurred when seeds filled the pods at one or more nodes and leaves were changing from green to gold. The LATE (LATE) stage was defined as stage R6, which occurred when yellow dry seeds filled the pods on most or all of the nodes and the leaves and pods were yellow. Forage was swathed using a Case IH 8825 swather (CIH, Racine, WI) on July 15, July 25, and August 9, 2018 for the EARLY, MID, and LATE stages, respectively. All stages of pea green feed were baled using a Massey Ferguson 1839 baler (AGCO, Duluth, GA) on August 10, 2018, when DM was ≥ 85%. However, the EARLY and MID pea swaths had precipitation fall on them during the curing process (Table 4.1). Bales were stored under shelter until use for the feeding study.

Table 4.1. Environmental conditions prior to and after swathing for pea (*Pisum sativum* L.; c.v. CDC Horizon) harvested for hay at EARLY, MID, and LATE maturity.

	Stage of Maturity[5]		
Agronomic Management	EARLY	MID	LATE
Environmental conditions[1], pre-swathing			
Days from seeding	62	72	87
Growing degree days[2]	761	887	1115
Mean ambient temperature, °C	17.6	17.7	18.1
Precipitation, mm	109.8	111.6	141.8
Date of swathing (2018)	15-Jul	25-Jul	9-Aug
Environmental conditions, post-swathing			
Mean ambient temperature, °C	19.4	19.8	19.6
Precipitation, mm	33.8	32.0	1.8
Date of baling	10-Aug	10-Aug	10-Aug
Time required for curing, d	26	16	1
Forage DM at baling, %	87.28	87.88	87.14
Actual yield[4], T/ha	1.869	4.350	4.421

[1] Data derived from University of Saskatchewan Department of Civil and Geological Engineering.

[2] Growing degree days were calculated as (maximum temperature + minimum temperature)/2 – base temperature, with the base temperature being 5°C.

[3] Predicted DM yield calculated based on an average yield of 5 random 0.5-m^2 quadrat samples with 10-cm stubble height collected throughout the swath.

[4] Actual DM yield calculated as (number of bales harvested per harvest maturity × average bale weight of that harvest maturity × DM coefficient of bales) / (ha used per harvest).

[5] Harvest maturities consisted of EARLY (plants with flat pods at one or more nodes), MID (filled pods at one or more nodes and leaves that were turning from green to gold), and LATE (yellow dry seeds filled pods on most nodes, and the leaves and pods were yellow).

4.3.2 Experimental Design

Six Speckle Park heifers previously fit with a ruminal cannula (model 9C; Bar Diamond Inc., Parma, ID) were used in a replicated 3×3 Latin square design. Heifers were housed indoors in individual 3×3 m pens with rubber mat flooring. Pens were cleaned twice daily. Water was provided ad libitum and heifers were fed once daily at 0900 h. Diets (DM basis) consisted of 40% pea hay, 43.56% of a high-fiber oat pellet, and 16.44% of a vitamin and mineral supplement (Table 4.2). Pelleted feeds and the pea hay were provided in separate bunks to allow for accurate calculation of forage intake.

Each square had a unique treatment sequence and, when considering both squares, were designed to balance for carryover effects. Periods were 18 d in duration. Within each period, d 1 through 12 were used to adapt heifers to their respective treatment. Rumen evacuations were conducted on d 13 and 14, in which a subsample of the solid fraction of digesta was collected for chemical analysis. Behavior monitoring and sample collection of feed, refusals, feces, ruminal fluid, and ruminal pH occurred from d 15 through 18.

4.3.3. Heifer Body Weight and Dry Matter Intake

Heifers were weighed on d 1 and 2 of each period, as well as the 2 days following completion of the experiment. The amount of feed offered and refused (pea hay and concentrate were measured individually) were weighed daily to determine feed intake. During sampling periods, 500-g of each feed ingredient and a representative sample equating to 20% of the feed refusals from each heifer were collected daily and dried to constant weight at 55°C to determine the DM content. The amount of feed offered and refused was corrected for DM and used to determine DMI. Feed and refusal samples were composited by heifer within period for chemical analysis.

4.4.4 Ruminal Pool Size and Turnover Rate

The reticulo-ruminal digesta was completely evacuated 3 h post-feeding on day 13 and 3 h prior to feeding on day 14 to evaluate ruminal NDF turnover. The weight of the contents was recorded, mixed, and a 4-L sample was collected from each heifer. The digesta sample was weighed and separated into liquid and solid fractions using a wine press (Harvest Bounty Wine

Table 4.2. Inclusion rates and nutrient composition of treatment diets consisting of pea hay (*Pisum sativum* L.; c.v. CDC Horizon) harvested at EARLY, MID, and LATE maturity for beef cattle diets.

Variable	Treatment[1]		
	EARLY	MID	LATE
Ingredient inclusion rate, % DM			
Early Pea	40.00	-	-
Mid Pea	-	40.00	-
Late Pea	-	-	40.00
Mineral[2]	16.44	16.44	16.44
Oat Pellet[3]	43.56	43.56	43.56
Chemical Composition, % DM			
DM, %	89.1	90.2	89.4
OM	95.26	95.52	95.71
CP	15.32	14.15	14.20
$aNDF_{OM}$	41.98	42.15	37.67
ADF	29.59	29.54	25.49
ESC	3.71	3.54	3.77
Starch	13.15	15.10	18.40
Ether extract	1.85	1.83	1.81
Ca	0.68	0.72	0.62
P	0.30	0.28	0.30

[1] Harvest maturities consisted of EARLY (plants with flat pods at one or more nodes), MID (filled pods at one or more nodes and leaves that were turning from green to gold), and LATE (yellow dry seeds filled pods on most nodes, and the leaves and pods were yellow).

[2] Mineral was composed of ground wheat (69.3%), porcine tallow (9.3%), molasses (8.3%), and urea (5.0%). The supplement provided 2.1% Ca, 1.1% P, 0.2% Mg, 0.6% K, 0.4% Na, 0.8% Cl, 0.2% S, 86.2 ppm Mn, 182.2 ppm Cu, 555.5 ppm Fe, 282.7 ppm Zn, 2.9 ppm I, 0.6 ppm Co, 0.6 ppm Se, 14,543.6 IU/kg Vitamin A, 1,872.5 IU/kg Vitamin D3, 424.4 IU/kg Vitamin E, 0.10% monensin (Elanco Division of Eli Lilly Canada Inc., Guelph, ON, Canada), and 0.11% melengestrol acetate (MGA; Federated Co-operatives Limited; Saskatoon, SK, Canada).

[3] Pellet was composed of oat hulls (50%), wheat middlings (40%), and molasses (10%).

proportions of individual SCFA ($P \geq 0.24$) with the exception of caproate that was greater for LATE than for EARLY or MID ($P < 0.001$).

Press, Pleasant Hill Grain LLC, Hampton, NE; Karnati et al., 2007). The arising solid and liquid fractions were weighed, a representative 500-g samples from each fraction were collected, and samples were dried in a forced-air oven at 55°C until a constant weight was achieved for determination of DM. Solid samples were ground through a hammer mill with a 1-mm screen, and sent to Cumberland Valley Analytical Services (Waynesboro, PA) for analysis.

4.4.5 Eating Behavior

The particle size distribution of the forage and forage refusals were measured in duplicate using Penn State Particle Size Separator with 19, 8, and 4-mm sieves, and a bottom pan (Nasco, Newmarket, ON, Canada). From these data, the sorting index was determined according to Leonardi and Armentano (2003). Briefly, the sorting index was calculated using the quantity of each fraction consumed relative to the amount that would have been consumed if no sorting had occurred. Values greater than 100 were considered to indicate selective consumption, while any value less than 100 indicate selective avoidance.

Eating behavior was evaluated using Rumi-Watch halters (ITIN + HOCH GmbH, Liestal, Switzerland). The noseband of the halter included an oil-filled flexible silicone tube. Jaw movements were recorded by a pressure sensor on the noseband of the halter and halters were programmed to record the time spent eating, drinking, and ruminating from 0900 h on d 15 and to extend for 96 h (Zehner et al., 2012). Differentiation between eating, ruminating, and drinking was derived based upon the pressure patterns and length of time of behavioral bouts.

4.4.6 Ruminal Fermentation

Ruminal pH was recorded every 5 min for 96 h, from 0900 h on d 15 until 0855 h on d 1 of the following period using the Lethbridge Research Centre Ruminal pH Measurement System (Dascor Inc., Escondido, CA) as described by Penner et al. (2006). The pH system was standardized in pH buffers 7 and 4 before insertion into the rumen and upon removal. The starting and ending regressions were used to convert the mV data to pH assuming a linear drift over time while accounting for temperature effects on pH.

Ruminal digesta samples were collected every 12-h with a 3-h offset among the 4 d of collection. This approach resulted in 8 samples representing every 3 h of a 24-h cycle when compressed. During collection, three 250-mL samples of digesta were collected from the caudal, cranial, and ventral sacs of the rumen. Digesta were strained through 2 layers of cheesecloth and a 10-mL sample of the strained ruminal fluid was added to 2 mL of 25% (w/v) metaphosphoric acid. Samples were stored at -20°C. Ruminal fluid samples were used to measure the concentration of short-chain fatty acid (**SCFA**) using gas chromatography (Agilent 6890; Agilent Technologies Canada Inc., Mississauga, ON, Canada) according to Khorasani et al. (1996).

4.4.7 Apparent Total Tract Digestibility

Fecal samples (100 g/sample) were collected directly from the rectum at the same time as ruminal digesta collection and samples were composited for each heifer by period. Fecal composite samples were dried at 55°C in a forced-air oven until achieving a constant weight and then ground to pass through a 1-mm screen using a hammer-mill (Christy and Norris Ltd., Chelmsford, UK). Fecal output was determined using undigested aNDFom (uNDF$_{OM}$) as a marker. Digestibility (% DM) was then determined by expressing the difference between nutrient intake and nutrient output when divided by nutrient intake.

4.4.8 Chemical Analysis

All feed ingredient, refusals, solid ruminal digesta, and fecal samples were dried to constant weight at 55^{o}C in a forced-air oven, ground through a 1-mm screen using a hammer mill (Christy and Norris Ltd, Chelmsford, UK) prior to being sent to Cumberland Valley Analytical Services (Waynesboro, PA) for analysis. Samples were analyzed for CP, NDF, ash-free NDF (aNDF$_{OM}$), undigestible NDF (uNDF$_{OM}$), ADF, starch, ethanol-soluble carbohydrate (ESC), ether extract (EE), ash, Ca, and P.

Crude protein was analyzed using a Leco FP-528 Nitrogen Combustion Analyzer (LECO Corp., St. Joseph, MI). Neutral detergent fiber (NDF) was determined according to Van Soest et al. (1991) using Whatman 934-AH glass micro-fiber filters with 1.5-µm particle retention (GE Healthcare Life Sciences, Piscataway, NJ) utilizing α-amylase and sodium sulfite. The residue remaining from the NDF analysis was also used to determine aNDF$_{OM}$ by ashing the residue at 535°C for 2 h. Acid detergent fiber was determined according to AOAC method 973.18 (AOAC, 2000) using Whatman 934-AH glass micro-fiber filters with a 1.5-µm particle retention instead of glass crucibles. Starch was determined according to Hall (2009) and ether extract was determined according to AOAC method 2003.05 (AOAC, 2006). Ethanol-soluble carbohydrate was analyzed according to Dubois et al. (1956). Ash was determined according to AOAC method 942.05 (AOAC, 2000), with the modification that a 1.5-g sample was ashed for 4 h at 600°C. Calcium and P concentrations were determined according to AOAC method 985.01 (AOAC, 2000) by ashing samples for 1 h at 535°C followed by a digestion using 15% nitric acid. Samples were then adjusted to 50 mL and analyzed on a PerkinElmer 5300 inductively-coupled plasma optical emission spectrometer (PerkinElmer, Shelton, CT).

4.4.9 Calculations and Statistical Analysis

The degradation rate of aNDFom (k_d) was calculated according to Dado and Allen (1995). The rate of degradation for digestible aNDFom was calculated as k_d = (hourly digestible aNDFom intake)/(rumen pool size of digestible aNDFom) – k_p, with k_p being the fractional ruminal passage rate of digestible aNDFom. This model is based on the assumption that passage rate for digestible and indigestible aNDFom fractions are equivalent and that the ruminal pool size of aNDFom was constant.

Data were analyzed using the Mixed Model procedure in SAS (version 9.4, SAS Inst. Inc., Cary, NC). The model included the fixed effect of treatment, with the random effect of period and cow nested within square. Mean separation was conducted using the Bonferroni means separation test. Sorting behavior was also evaluated using a 2-tailed t-test to determine if individual treatment means differed from 100. In all analyses, significance was declared when $P < 0.05$.

4.5 Results

4.5.1 Forage Production and Treatments

EARLY, MID, and LATE pea hay were swathed 62, 72, and 87 d after seeding, respectively (Table 4.1). The mean ambient temperature for during the growing season was 17.8°C, and precipitation ranged from 109.8 to 141.8 mm between treatments. To ensure adequate DM concentration for baling, EARLY hay required 26 days of curing in the swath, MID hay required 16 days, and LATE hay only required 1 day. While statistical analysis could not be conducted for yield or composition data, harvest yield numerically increased with maturity relative to the EARLY cut hay, with the MID and LATE stages yielding similarly. Starch concentration numerically increased with advancing pea maturity at the expense of CP and fibrous components (aNDFom and ADF; Table 4.2 and 4.3).

4.5.2 BW, DMI, and Eating Behavior

No effect of pea hay maturity was observed on BW, pea hay DMI, or total DMI ($P > 0.54$; Table 4.4). There were no differences among treatments for time spent eating or drinking ($P > 0.095$). However, rumination time (min/d) decreased with advancing pea hay maturity ($P < 0.001$) and decreased relative to EARLY maturity when expressed as min/kg DM and min/kg $aNDF_{OM}$ ($P \leq 0.016$). Heifers fed the EARLY harvested pea hay sorted more against particles retained on the 4 mm sieve and those on the pan ($P \leq 0.024$; Table 4.4) than those fed the MID and LATE pea treatments.

4.5.3 Ruminal fermentation, NDF Turnover, and Apparent Total Tract Digestibility

Maturity of pea hay at swathing did not affect minimum or maximum ruminal pH ($P \geq 0.074$; Table 4.5), but mean pH decreased from 6.59 for EARLY to 6.30 for LATE pea hay ($P = 0.005$). Total SCFA concentration was not affected by pea hay maturity, nor were the molar The ruminal pool sizes of DM, aNDFom, uNDFom, and potentially degradable NDF were not different ($P \geq 0.32$; Table 4.6) among treatments. However, the rate of passage (k_p) was slowest for the LATE maturity pea hay treatment (1.89%/h) and fastest for the MID maturity pea ha (2.24%/h, $P = 0.022$) with the EARLY maturity being intermediate but not different from the other treatments (2.10%/h). While passage rate differed, the k_d for aNDFom did no differ among treatments ($P = 0.15$). Likewise, apparent total tract digestibility of OM, CP, NDF, aNDFom, ADF, starch, and ether extract were not affected by stage of pea hay maturity ($P \geq 0.051$; Table 4.7). However, ESC digestibility was greater for EARLY maturity compared to MID and LATE ($P = 0.013$).

Table 4.3. Nutrient composition of ingredients used in treatment diets of consisting of forage pea (*Pisum sativum* L.; c.v. CDC Horizon) harvested for green feed at EARLY, MID, and LATE maturities, mineral supplement, and pellet supplement for beef cattle.

Nutrient Composition[1], % DM	EARLY [2]	MID	LATE	Mineral[3]	Pellet[4]
DM	87.28 ± 0.72	87.88 ± 1.97	87.14 ± 1.07	91.98 ± 1.29	88.11 ± 0.78
OM	94.11 ± 2.80	94.57 ± 2.68	95.12 ± 2.32	94.07 ± 4.65	96.78 ± 2.11
CP	16.30 ± 1.39	13.37 ± 5.20	13.50 ± 0.46	27.75 ± 0.81	9.80 ± 0.80
aNDFom	49.97 ± 1.46	50.40 ± 2.49	39.20 ± 1.87	11.53 ± 0.70	46.13 ± 2.05
ADF	42.50 ± 0.20	42.37 ± 2.12	32.23 ± 2.71	5.77 ± 0.25	26.73 ± 1.38
ESC	3.90 ± 0.35	3.47 ± 0.75	4.03 ± 0.76	3.53 ± 2.19	3.73 ± 2.19
Starch	2.00 ± 1.23	6.87 ± 5.59	15.12 ± 12.59	27.64 ± 23.14	17.92 ± 14.96
Ether extract	1.11 ± 0.70	1.07 ± 0.64	1.02 ± 0.54	5.29 ± 4.00	1.22 ± 0.71
Ca	0.83 ± 0.52	0.93 ± 0.64	0.67 ± 0.43	1.63 ± 1.21	0.19 ± 0.02
P	0.18 ± 0.14	0.12 ± 0.08	0.17 ± 0.12	0.89 ± 0.43	0.19 ± 0.06

[1] Values stated as mean ± SD.

[2] Harvest maturities consisted of EARLY (plants with flat pods at one or more nodes), MID (filled pods at one or more nodes and leaves that were turning from green to gold), and LATE (yellow dry seeds filled pods on most nodes, and the leaves and pods were yellow).

[3] Mineral was composed of ground wheat (69.3%), porcine tallow (9.3%), molasses (8.3%), and urea (5.0%). The supplement provided 2.1% Ca, 1.1% P, 0.2% Mg, 0.6% K, 0.4% Na, 0.8% Cl, 0.2% S, 86.2 ppm Mn, 182.2 ppm Cu, 555.5 ppm Fe, 282.7 ppm Zn, 2.9 ppm I, 0.6 ppm Co, 0.6 ppm Se, 14,543.6 IU/kg Vitamin A, 1,872.5 IU/kg Vitamin D3, 424.4 IU/kg Vitamin E, 0.10% monensin, and 0.11% melengestrol acetate (MGA; Federated Co-operatives Limited; Saskatoon, SK, Canada).

[4] Pellet was composed of oat hulls (50%), wheat middlings (40%), and molasses (10%).

Table 4.4. Effect of harvesting pea hay (*Pisum sativum* L.; c.v. CDC Horizon) at EARLY, MID, and LATE maturities on body weight, DMI, and eating behavior for yearling beef heifers.

Variable	EARLY[1]	MID	LATE	SEM	*P*-Value
Body weight, kg					
Initial	346	343	343	17.2	0.66
Final	368	366	366	19.3	0.91
ADG, kg/d	1.2	1.3	1.2	0.07	0.57
DMI (total diet), kg/d	8.5	8.3	9.1	0.52	0.59
DMI (pea hay only), kg/d	3.0	3.3	3.4	0.22	0.54
Behavior[1]					
Eating time, min/d	442	479	484	15.4	0.17
Eating time, min/kg DM	53.9	58.2	53.3	4.65	0.69
Eating time, min/kg $aNDF_{OM}$	127.7	130.5	148.0	11.04	0.095
Ruminating time, min/d	403^{a}	366^{b}	321^{c}	7.7	<0.001
Ruminating time, min/kg DM	49.3^{a}	44.3^{ab}	36.4^{b}	3.63	0.016
Ruminating time, min/kg $aNDF_{OM}$	116.6^{a}	98.8^{b}	97.4^{b}	7.77	0.006
Drinking time, min/d	8	10	11	21.3	0.91
Sorting index[2] %					
> 19 mm	114.85	101.24	99.52	4.616	0.089
< 19, > 8 mm	101.80	100.38	98.80	5.480	0.62
< 8, > 4 mm	61.25^{b}	99.8^{a}	101.89^{a}	9.249	0.024
< 4	28.54^{b}	95.30^{a}	94.27^{a}	14.34	0.017

[1] Harvest maturities consisted of EARLY (plants with flat pods at one or more nodes), MID (filled pods at one or more nodes and leaves that were turning from green to gold), and LATE (yellow dry seeds filled pods on most nodes, and the leaves and pods were yellow).

[2] Sorting index was calculated as (actual consumed)/(theoretical consumed) × 100, as described by Leonardi and Armentano (2003).

[a,b,c] Means within a row with uncommon superscripts are different ($P < 0.05$).

[z] Means with this superscript are different from 100 in a 2-tailed t-test.

Table 4.5. Effect of harvesting pea hay (*Pisum sativum* L.; c.v. CDC Horizon) at EARLY, MID, and LATE maturities on ruminal pH and SCFA concentrations in beef cattle.

Variable	EARLY[1]	MID	LATE	SEM	*P*-value
pH					
Minimum	5.87	5.72	5.67	0.126	0.074
Maximum	7.06	6.99	6.87	0.062	0.11
Mean	6.59^a	6.40^b	6.30^c	0.118	0.005
Total SCFA, m*M*	91.2	101.2	97.3	9.97	0.24
SCFA, mol/100 mol					
Acetate	63.68	63.65	62.28	1.545	0.78
Propionate	19.88	21.32	21.67	2.721	0.87
Isobutyrate	0.88	0.85	0.77	0.093	0.73
Butyrate	11.85	11.08	11.35	1.353	0.89
Isovalerate	1.77	1.85	1.45	0.236	0.42
Valerate	1.50	1.30	1.70	0.690	0.53
Caproate	0.23^b	0.15^b	0.27^a	0.127	<0.001

[a,b,c] Means within a row with uncommon superscripts are different ($P < 0.05$).

[1] Harvest maturities consisted of EARLY (plants with flat pods at one or more nodes), MID (filled pods at one or more nodes and leaves that were turning from green to gold), and LATE (yellow dry seeds filled pods on most nodes, and the leaves and pods were yellow).

Table 4.6. Effect of harvesting pea hay (*Pisum sativum* L.; c.v. CDC Horizon) at EARLY, MID, and LATE maturities on ruminal pool sizes of DM, $aNDF_{OM}$, and $uNDF_{OM}$, and the passage and reticulo-ruminal degradation rates of $aNDF_{OM}$ for yearling beef heifers.

Variable	EARLY[1]	MID	LATE	SEM	*P*-value
Reticulo-ruminal pool, kg					
Total	49.1	47.5	47.9	2.06	0.78
DM	9.2	10.2	9.0	3.29	0.55
$aNDF_{OM}$	6.4	7.0	6.1	2.20	0.57
$uNDF_{OM}$	4.8	5.0	4.4	1.55	0.61
Potentially degradable $aNDF_{OM}$[2]	1.7	2.0	1.8	0.66	0.32
$aNDF_{OM}$ k_p, %/h	2.10^{ab}	2.24^{a}	1.89^{b}	0.459	0.022
$aNDF_{OM}$ k_d, %/h	2.55	1.83	2.10	0.514	0.15

[1] Harvest maturities consisted of EARLY (plants with flat pods at one or more nodes), MID (filled pods at one or more nodes and leaves that were turning from green to gold), and LATE (yellow dry seeds filled pods on most nodes, and the leaves and pods were yellow).

[2] Potentially degradable NDF was calculated as ($aNDF_{OM}$ – $uNDF_{OM}$).

[a,b,c] Means within a row with uncommon superscripts are different ($P < 0.05$).

Table 4.7. Effect of harvesting pea hay (*Pisum sativum* L.; c.v. CDC Horizon) at EARLY, MID, and LATE maturities on apparent total tract digestibility when fed to beef heifers.

Digestibility, %	EARLY[1]	MID	LATE	SEM	*P*-value
OM	49.56	46.74	52.53	1.706	0.051
CP	63.50	60.06	62.72	4.213	0.58
aNDFom	15.45	18.58	14.89	2.237	0.41
ADF	21.19	19.98	17.14	3.185	0.63
Starch	96.10	92.23	93.08	1.286	0.071
Ether extract	71.09	60.70	66.01	7.460	0.36

[a,b,c] Means within a row with uncommon superscripts are different ($P < 0.05$).

[1] Harvest maturities consisted of EARLY (plants with flat pods at one or more nodes), MID (filled pods at one or more nodes and leaves that were turning from green to gold), and LATE (yellow dry seeds filled pods on most nodes, and the leaves and pods were yellow).

4.6 Discussion

It is important to note that in this study, pea hay treatment consisted of 40% of the dietary DM due to limited forage availability. In an applied beef cow production setting, forage would ideally consist of the majority of the diet, offered ad libitum with minimal supplementation to meet vitamin and mineral requirements (McCartney et al., 2004). However, Beck et al. (2009) were able to detect differences in DM and NDF total tract digestibility between wheat forage harvested at the boot and hard dough stages with only 40% dietary DM deriving from forage. Moreover, the supplemented pellet comprised of mostly oat hulls, a high fiber feed source which may be used as a supplemental roughage source in low-forage settings for ruminants (NDSU, 2015). Therefore, while this experimental model used included an atypically high inclusion of supplement, it is presumed that supplement level did not affect the observed differences in response to pea maturity.

When grown as a forage, pea is often included in a mixture with other crops such as oat

with other crops, harvest maturity is based upon the maturity of the cereal rather than the pea. This practice ignores any potential effects of pea maturity on yield, palatability, or animal performance during feeding. When grown as a monoculture, the recommendation is to harvest for hay when the bottom pods are filling. However, it was found DM yield increased with advancing maturity, supporting the work of Rosser et al. (2013) that evaluated harvest maturity in cereal crop yield. Moreover, in this study, starch and CP concentration increased, which in turn decreased relative fiber concentrations advancing stages of maturity. These changes in nutrient composition resulted in a greater yield of potentially digestible nutrients. Greater yield and starch concentrations are in concordance with previous work showing that delaying the stage of maturity at harvest for cereal hay can increase forage yields (Rosser et al., 2013) without affecting consumption or digestibility (Rosser et al., 2016).

Starch digestibility tended to decrease with advancing maturity, but remained above 90% in all stages of maturity. Pea starch is highly digestible even without processing (Anderson et al., 2007). In the present study, it was found that increasing harvest maturity of pea decreased ruminal pH. The decrease in pH is likely in response to greater quantities of starch consumed in the diet and the resulting acid production from starch fermentation (Ørskov, 1986), especially when considering the only minor reduction in starch digestibility with advancing pea hay maturity. It is important to note that while total SCFA was not different between treatments, SCFA concentration is not indicative of actual production (Dijkstra et al., 1993).

As noted above, ruminal pH decreased with advancing pea hay maturity. The response for reduced pH is likely a combination of increased starch intake, reduced rumination time, and less avoidance of small and medium size particles by heifers when fed pea hay with more advanced maturity. To further support this, rumination time decreased with advancing pea maturity. Rumination is associated with ruminal buffering due to its association to increase saliva production which contributes to the ruminal buffering capacity (Allen, 1997). It is important to note that while advancing maturity of pea hay may cumulate to a decreased ruminal pH, mean and minimum pH were well within normal ranges and the reduction does not imply greater risk for ruminal acidosis.

The reduction in rumination time may be a result of increased starch content and decreased NDF concentration observed with increasing maturity. However, ruminating time in min/kg NDF also decreased with advancing maturity, suggesting that the physical effectiveness of NDF decreases (Mertens, 1997). Decreased physically effective NDF, along with the decreased ruminal pH, can reduce ruminal motility (Allen, 1997) thereby affecting particulate passage out of the rumen. Okine et al. (1989) reported that k_p can be altered without differences in digestibility (Okine et al., 1989). Indeed, a reduction in rumination time and reduced NDF k_p with advancing pea maturity were observed, without differences in nutrient digestibility. The reduction in peNDF with advancing maturity is logical given that cattle fed EARLY selectively avoided short particles and cattle fed LATE tended to selectively avoid long particles. However, it is not clear why k_p for NDF decreased as the increased consumption of small and medium particles and reduction in consumption of large particles would be expected to increase k_p. It is plausible that the selective eating behavior may have caused decreased rumen motility thereby decreasing both rumination time and k_p.

As indicated above, EARLY fed cattle selectively avoided small and medium size particles and LATE cattle selectively avoided long particles. These data support previous work showing similar sorting trends based on the stage of maturity for cereal hay (Rosser et al., 2016;

Rosser et al., 2017) where harvesting at less mature state increases selective avoidance against fine particles. It is important to note that the selection index against small particles may be, in part, due to increased fragility for EARLY pea hay versus MID and LATE. Particle fragility can result in the production of fine particles from longer particles and would appear as selective consumption of the larger particles and selective avoidance of the smaller particles. However, forage fragility was not specifically evaluated, so whether differences in fragility with advancing maturity occurs remains speculative.

4.7 Conclusion

Overall, the stage of pea maturity at harvest when used for hay does not affect DMI for beef cattle but decreases rumination time, decreases the rate of ruminal NDF passage, decreases mean ruminal pH, and may reduce total tract starch digestibility without affecting the digestibility of other nutrients. These results suggest harvesting for field pea can be delayed to reduce curing time and maximize yield.

5.0 GENERAL DISCUSSION

The overall objective of this research was to evaluate the effects of field pea hay used for beef cattle when fed to cattle in a mixture with cereal hay as well as to determine the optimal harvest maturity for field pea. It was hypothesized that increasing level of field pea inclusion in cereal hay would reduce NDF concentration and alter ruminal fermentation while increasing intake and digestibility, with no effect of cereal hay type (barley vs. oat). Furthermore, delaying harvest to more advanced stages of field pea maturity would decrease DMI, digestibility, and rate of passage within the GI tract. The data collected supports the hypothesis that increasing pea inclusion increases intake and modifies ruminal fermentation; however, pea inclusion did not affect overall digestibility. Advancing maturity of pea hay slowed ruminal NDF passage rate, but did not affect intake, ruminal fermentation, or digestibility.

5.1 Challenges and Opportunities with the Management of Cereal-Pea Hay Mixtures

One of the potential issues with feeding forage mixtures is the difference in palatability between the different components of the mixture. Palatability and selection preferences are determined by the combination of several factors, including colors and flavors of the feed (Van Soest, 1994). In previous research where field pea hay inclusion was increased at the expense of oat straw for sheep diets consisting of 70% forage, pea hay was reported to be more palatable than oat straw (Bastida-Garcia et al., 2011). In that study, as pea hay inclusion increased, total forage intake increased, supporting the increased intake results in Chapter 3. However, in Chapter 3, it was found that, based on the nutrient sorting index, cattle demonstrated a selective aversion to the pea component of a cereal-pea blended hay diet. For example, as pea hay inclusion increased in the diet, the concentration of CP was relatively constant while NDF and ADF decreased. However, cattle fed diets containing pea hay were shown to select against CP and for NDF and ADF, reflecting their selection for cereal hay components of the diet over the pea hay component. While this argument that cattle selected against pea hay is logical based on sorting data, this study did not separate the refusal into individual plant species and, as such, this observation remains speculative. It is possible that selection preferences are due to the novelty of pea forage diets to the cattle and the short duration of dietary periods due to the Latin square design preventing them from having to adapt to the diet.

Being a leguminous species, field pea contains a greater concentration of CP and lower than cereal species (Brundage et al., 1979). Therefore, increasing pea inclusion levels in forage DM may allow for increased dietary CP. It is important to note that the nutrient analysis results in Chapter 3 indicate an increase in CP with pea inclusion rate for barley treatments, but a decrease between 0% and 15% in oat treatments. This difference is attributed to different cereal forages being used between diets with pea and without pea. Though there were no nutrient analyses conducted on individual plant components of the mixed forages, it appears as though the oat in the mixed forage treatments (grown in mixture) is slightly lower in CP concentration than the oat used in the cereal-only treatment (grown in monoculture). The CDC Horizon pea cultivar produced for this study ranged from approximately 14 to 15% CP depending on maturity: a CP value slightly lower than those previously reported for other pea cultivars. Conversely, the CP concentration of the cereal hay the studies in this thesis were 10.25 and 11.22% for barley and oat, respectively. As such, increasing inclusion of pea hay in the diet increased the overall dietary CP concentration, though slightly, from 10.74% CP in 0% pea hay to 11.33% CP in 30% pea hay diets. Likewise, the concentration of NDF decreased from 49.76% to 44.83% between 0 and 30% pea hay, respectively. Similar trends in dietary composition have been reported in previous studies where cereals were mixed with pea forage (Walton, 1975; Berkenkamp and Meeres, 1987; Chapko et al., 1991; Anil et al., 1998). Thus, producers concerned about protein deficiency in diets for their cattle could include pea hay to improve the CP concentration of the forage.

Producing cereal-pea intercrops or cereal-pea mixtures requires a different agronomic management approach than producing cereal monocultures. Firstly, seeding rates and row arrangement must be considered. Legumes are unable to compete well against oat and barley when seeded at monoculture seeding rates (Strydhorst et al., 2008). As a strategy to increase pea abundance, the pea seeding rates can be increased to a rate greater than if the cereal hay was seeded alone (Strydhorst et al., 2008), or an intercropping system with alternating rows between pea and cereal (Chen et al., 2004). In the intercropped arrangement, the pea is grown in between but separately from the cereal plants, reducing the competitive nature of the mixture and allowing for greater pea presence in the overall forage DM yield.

In this research conducted within this thesis, there was very low pea hay abundance when included with barley or oat. Pea production was likely limited due to shallow seeding depth and abnormally dry growth conditions. This study utilized CDC Horizon as the pea cultivar such that a new semi-leafless forage-type pea could be evaluated (Warkentin et al., 2012). However, it is possible that this cultivar selection further exaggerated the difference in competitiveness between pea and cereal, as it has been reported that the semi-leafless type peas are less competitive than the leafed varieties (Asci et al., 2015).

Furthermore, producing an intercrop of pea and cereal or a pea-cereal forage mixture requires the consideration of harvest maturity of both species when used for greenfeed. Rosser et al. (2013; 2016) recommended harvesting oat and barley hay at the hard dough stage as a strategy to maximize the yield of digestible energy. Currently, the harvest maturity of cereal-pea forage mixtures is based upon the maturity of the cereal species, which generally comprise the majority of the blends (Uzun and Asik, 2012). While this approach overlooks the maturity of the pea forage, support for the practice is provided in Chapter 4 where it was observed that advancing maturity of pea hay at harvest numerically increased forage yield without affecting DMI or digestibility. However, the risk of harvesting for cereal maturity and not pea maturity is potential pea field losses due to the pea maturing more quickly than the cereal. As such, if the pea reaches senescence before the cereal forage is at the desired harvest maturity, there is greater risk of pod shelling, seed loss, and leaf shatter of the ripened pea crop. Cultivar breeding and selection for mixed forages should allow for a pea and cereal crop which matures at similar rates to allow for optimizing growing potential without risking field losses from an overly matured crop.

5.2 Effect of Pea Hay Inclusion on Ruminal Fermentation

In this project, increasing the inclusion rate of field pea hay diets for cattle altered the molar proportions of individual SCFA. Of importance, increasing pea hay inclusion increased the proportions of acetate and butyrate at the expense of propionate, but did not affect total SCFA concentrations. The latter result is supported by those of Bastida-Garcia et al. (2011) where total concentration of SCFA was not affected by increasing field pea hay inclusion from 0 to 75% of the diet for sheep. Similarly, Vander Pol et al. (2009) and Froidmont and Bartiaux-Thill (2004) both reported no difference in total production of SCFA in response to increasing pea inclusion into dairy cow diets. In contrast, Reed et al. (2004) included pea as a grain source into feedlot steer diets and observed an increase in total SCFA concentration. While total SCFA concentration did not differ between treatment diets in the present studies, it is important to note that fermentation was still altered, as evidenced by the changes in relative molar concentrations in response to increasing pea hay inclusion. In Chapter 3, the molar proportion of propionate decreased as acetate and butyrate increased. Similarly, an increase in butyrate concentration was observed in dairy cows (Khorasani et al., 2001) and finishing beef steers (Reed et al., 2004), both of which were fed field pea grain at 0, 33, 67, and 100% of the concentrate in the diet. The reduction in propionate and corresponding increases in butyrate and acetate production indicate that pea shifts fermentation to a less energetically efficient process.

In Bastida-Garcia et al. (2011) there was no difference reported for the concentration of ruminal NH_3-N among diets ranging from 0% to 75% pea hay inclusion within the forage DM. Conversely, other studies have reported an increase in ruminal NH_3-N in response to pea inclusion (Khorasani et al., 2001; Reed et al., 2004; Vander Pol et al., 2009). The research in this thesis supports these latter findings, reporting a strongly significant quadratic increase in ruminal NH_3-N with increasing pea hay inclusion. Increasing ruminal ammonia concentration is indicative of an increase in proteolysis and protein degradation in the rumen (Vander Pol et al., 2009), which is a response to be expected with increasing dietary CP concentration via pea inclusion. However, ruminal ammonia-N concentrations in Chapter 3 were not increasing to levels where toxicity would be a concern. Furthermore, an increase in N excretion, particularly urinary excretions, could be indicative of an excessive supply of dietary CP or an inefficiently metabolized N source, both of which are costly to production. In Chapter 3 there was no effect of pea hay inclusion rate on N excretion or overall N retention, as supported by previous research (Khorasani et al., 2001; Vander Pol et al., 2008; Vander Pol et al., 2009).

Mean ruminal pH was also shown to increase with pea inclusion levels, supporting the results of Reed et al. (2004). When comparing barley and oat with pea grain, where the majority of the starch content in the harvest crop is located, both the extent of ruminal starch degradability and the rate of starch degradation is lower in pea than either of the cereals (Cerneau and Michalet-Doreau, 1991). Therefore, replacing cereal feed sources with pea exchanged a highly and rapidly degradable starch source with a slower, less degradable source, reducing the change in pH in response to starch fermentation. Furthermore, it is believe that pea forage increased mean ruminal pH due to the cation exchange capacity giving a high ruminal buffering effect to legumes forages (Jasaitis et al., 1987; Van Soest, 1994). While the results demonstrate that ruminal fermentation is significantly altered with increasing levels of pea hay inclusion, these changes are small and likely not of biological significance (Khorasani et al., 2001).

5.3 Limitations of the Experimental Models

This research, though designed to be thorough and extensive, does come with its limitations. For both studies, there were no replicated field plots, as forage was only produced in a single plot for each forage treatment/yr. Being that each crop was produced only in one location, one plot, and one growing season, it is not possible to conduct statistical analysis on the crop data, such as yield or nutrient composition. However, this project was part of a joint study between plant and animal scientists (Gungaabayar et al., 2018). This portion of the research was focused on the animal effects of the forages, therefore this research only needed crop production for nutrient analysis and the feeding trials. Further plot, location, and year replications were evaluated in the plant science projects associated with this research. Seeding methods further limited the ability to produce a more ideal representation of forage component presence in the cereal-pea blended plots. During seeding, large differences in size and weight between cereal and pea seeds prevented true mixture seeding. Instead, cereals were seeding in one row, and a second pass with the seeder was required to seed pea. This method likely disrupted the seeding depth of cereals and peas, preventing peas from being able to fully compete with the cereals. Legumes are often not as competitive as cereal species and can produce low yields without considering planting density or row spacing (Strydhorst et al., 2008). It is recommended that in order to increase pea presence in cereal-pea forage intercrops, the crops should be planted in separate rows to allow for pea to grow without the competition of barley (Chen et al., 2004). Because of the lack of pea presence in the cereal-pea blends, the treatments needed to be re-designed. Diets were hand mixed to produce pea hay blends of 0, 15, or 30% of hay DM. Therefore, the treatment diets were not true forage mixtures from production. In mixed forage where pea was grown within a cereal crop, the pea plant would tangle itself within the cereal with its tendrils, making the individual plant components more difficult to separate than in this hand-mixing scenario. It is possible that sorting behaviors may be exaggerated in this study, where individual plant components were more easily separated.

That said, the focus of this research was on the effects of feeding pea hay to beef cattle. These cattle experiments were specifically designed for multiple replications with strong experimental power. The cattle were housed in individual metabolism stalls which allowed for a much more in-depth scientific study of biological processes. In Study 2 (Chapter 4), cattle were only offered a 40% hay DM treatment diet due to hay production limitations. This level of forage in the diet is much lower than a typical winter grazing production scenario would provide. Some eating behaviors, such as rumination time and eating time, will differ as forage to concentrate ratio increases due to the increased volume and NDF concentration associated with high forage diets. While this is a low forage inclusion rate, it is important to note that changes in response to dietary forage treatments have been observed at 40% forage inclusion (Beck et al., 2009; Rosser et al., 2016).

Going forward, further research is needed to evaluate the effects of cereal-pea blends and pea harvest maturity on forage loss and nutrient retention in winter swath-grazing and bale-grazing systems. Moreover, research should continue with grazing studies evaluating animal intake, ADG, BCS, reproductive efficiency, and a comparative cost analysis of the forage mixture systems when used throughout a winter-feeding season.

6.0 CONCLUSIONS

Field pea forage offers potential to slightly increase dietary protein supply for beef cattle diets, though there is little benefit associated with fermentation, nitrogen metabolism, and overall digestibility. Cereal-pea mixtures pose issues with sorting as a result of differences in palatability between forage species, though these issues may vary when the forage is grown in mixture rather than hand-blended, as in this research. When field pea is produced as a hay forage source, the harvest maturity of pea has little impact on cattle intake, eating behavior, performance, or digestibility. Therefore, producers may make harvest decisions based on agronomic factors without concern of affecting their cattle.

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