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Effect of incorporating forage pea (Pisum sativum L.) hay into cereal hay on ruminal fermentation and apparent digestibility when fed to beef heifers

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Abstract: The objective of this study was to evaluate the inclusion rate of pea hay 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. Pea hay 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 hay linearly increased mean ruminal pH (\( P = 0.039 \)), the concentration of butyrate in ruminal fluid (\( P = 0.013 \)), plasma urea-N concentration (\( P = 0.001 \)), and quadratically increased ruminal ammonia concentration (\( P < 0.001 \)). 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. Overall, pea hay inclusion increased DMI, increased ruminal butyrate concentration, but reduced CP digestibility without affecting N balance.

Key words: diet selection, digestion, forages, palatability
INTRODUCTION

Cereal hay is a commonly utilized winter feed source for gestating beef cows (Voilesky et al. 2002). Incorporating legumes, such as pea (*Pisum sativum* L.), with cereals increases forage DM yield (Berkenkamp and Meeres 1987; Carr et al. 2004; McCartney and Fraser 2010), N yield (Carr et al. 2004; McCartney and Fraser 2010), and the CP concentration of the hay at harvest relative to a monoculture cereal crop (Aasen et al. 2004; Strydhorst et al. 2008). However, blends of cereals and legumes as annual hay are not commonly used (McCartney and Fraser 2010) and there is debate over appropriate seeding rates for the legume and cereal component (Gungaabayar et al. 2018). The consideration over the relative seeding rates are important as the legume and cereal seeding rates affect the relative proportions of cereal and pea in the final forage mix and ultimately the CP content of the final forage (McCartney and Fraser 2010; Gungaabayar et al. 2018).

While there are potential benefits of growing pea with 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 CDC 40-10, allowing for greater quality retention during harvest by reducing fragility-related losses from pod and leaf shatter (Warkentin et al. 2012).
There are very few studies that have evaluated the use of pea hay in diets for cattle. In fact, to the authors' knowledge, only one recent study has evaluated cattle responses to field pea (c.v. CDC Horizon), and in that study, the pea hay was grown and fed as a monoculture (Pursley et al. 2019). The use of a monoculture does not fit with most common practices where pea is included with cereals when used for silage or hay (Anderson et al. 2014). That said, previous research evaluating pea silage has shown that relative to barley silage, use of pea silage has been reported to increase DMI and plasma urea nitrogen, likely due to the greater CP concentration (Mustafa et al. 2000). Thus, information is needed to determine the effect of increasing pea hay inclusion in cereal hay-based diets for beef cattle.

We hypothesized that increasing pea inclusion in cereal hay would increase DMI and total tract digestibility, with similar effects occurring whether included with barley or oat hay. The objectives of this study were to evaluate DMI, 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.

MATERIALS AND METHODS

Forage Production

Monocultures of barley (Hordeum vulgare L.; c.v. CDC Maverick seeded at 319 kg/ha), oat (Avena sativa; c.v. CDC Haymaker seeded at 240 kg/ha), and pea (Pisum sativum L.; c.v. CDC Horizon seeded at 247 kg/ha) 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 with 50% of the monoculture seeding rate for each crop. For cereal-pea blends, the pea was seeded using a second pass. All plots received 35 kg/ha of urea 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 routinely monitored for stage of maturity and were 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 calendar 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 swather (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 fed.

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 1). The mean ambient temperature during the growing season was 17.5 and 17.6°C for barley and oat, respectively and precipitation during crop growth ranged from 57 to 87 mm for barley and oat, respectively as date of swathing differed. Barley, barley-pea, and pea required 9 d in the swath for curing prior to baling, while oat and oat-pea required 11 d.

Prior to cutting, 0.5-m² quadrat clippings (10-cm stubble height) were collected from 5 random locations in each plot (Table 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 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 the time of baling, a
representative sample of the forage was collected, dried, and ground for chemical analysis (Table 2). Subsamples of the cereal-pea blends were weighted, sorted by hand to determine the relative weights of barley or oat and pea. While previous studies have shown successful inclusion of pea within cereal crops (Gungaabayar et al. 2018), the pea hay only represented 1.62% and 1.65% (DM basis) for the barley- and oat-blends, respectively. Given the low pea hay abundance in the cereal-pea hay blends and the limited data available evaluating pea-hay inclusion rates into cereal-hay based diets, the study design was altered to allow for graded increases in pea hay inclusion in oat or barley hay (described below).

**Experimental Design**

Use of heifers in this study was approved by the University of Saskatchewan Animal Research Ethics Board in compliance with the Canadian Council on Animal Care (Ottawa, ON, Canada). Six ruminally-cannulated Hereford-cross heifers were used in a 6 × 6 Latin square design, balanced for carry-over effects, with 25-d periods. Heifers were housed in individual pens (3 × 3 m) with rubber mats on the floor and a suspended ball (Tug-N-Toss, Jolly Pets, Streetsboro, OH) for environmental enrichment. Heifers had unrestricted access to water throughout the study. With the exception of during total collection, heifers had access to an outdoor exercise pen daily (1 h) at which time pens were scraped and washed.

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 (Table 3). Diets were formulated using the Nutritional Dynamic System (Reggio Emilia, Italy) for cross-bred beef heifer with a BW of 450 kg and and ADG of 0.70 kg/d. The barley- and oat-based diets (0% pea inclusion) met the predicted metabolizable energy
and exceeded the metabolizable protein included 0, 15%, or 30% pea forage to represent a range that could be expected when cereals and pea are grown in mixtures (Gungaabayar et al. 2018). Thus, treatments consisted of 92% forage (DM basis) and 8% of a supplement providing minerals and vitamins. The forage 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 and the pea and cereal hays were mixed together by hand and offered as long-stem hay. Cattle were provided their pelleted mineral and vitamin supplement at 0730 h and the forage at 0800 h. Feed refusals were collected and weighed each day at 0700 h.

**Heifer BW, DMI, and Nutrient Sorting**

Heifers were weighed at 0700 h (immediately prior to feeding) 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 the complete feed refusals were collected daily during from d 22 to 25. The daily feed samples were composited to yield a single sample for each ingredient and the refusal samples were composited to yield a single sample for each heifer. Sample DM was determined by drying at 55°C in a force-air oven until achieving a constant weight. The composite samples of feed and refusals were sent to Cumberland Valley Analytical Services (Waynesboro, PA) for chemical analysis (described below).

Nutrient sorting was calculated as described by (Rosser et al. 2016) using a modification from the particle size sorting index originally described by (Leonardi and Armentano 2003). The

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nutrient sorting index was calculated using actual nutrient intake when divided by the theoretical nutrient intake if no sorting occurred. The resulting coefficient was multiplied by 100 and values less than 100% indicate selective refusal while values greater than 100% indicate selective consumption.

**Ruminal Fermentation, Microbial Protein Supply, Nitrogen Balance, and Apparent 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 resulting 750-mL sample was 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) to determine short-chain fatty acid (SCFA) concentrations using gas chromatography (Agilent 6890; Agilent Technologies Canada Inc., Mississauga, ON, Canada) according to Khorasani et al. (1996). A second 10-mL sample of ruminal fluid was preserved in 2 mL of 1% sulfuric acid to determine the ammonia-N concentration as described by Fawcett and Scott (1960).

Ruminal pH was recorded every 5 min for 96 h, beginning at 0800 h on d 22 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 using pH 7 and 4 buffer solutions held at 39°C prior to insertion and upon removal from the rumen. The loggers recorded data in mV. To convert mV to pH, beginning and ending regressions derived from the starting and ending standardization events, were used with the assumption of linear drift over time.

Urinary catheters (2-way Foley catheter, C. R. Bard, Inc., Murray Hill, NJ) were inserted into each heifer on d 21. Bladder catheters were filled with 70 mL of saline solution and allowed
1 day for adaptation with urine collection initiated on d 22. Heifers were tethered from d 22 to d 25 to avoid complications with the urinary collection and loss of feces. 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 to minimize volatilization losses. Each day, a 35-mL representative sample was collected from each heifer and stored at -20°C. The daily samples were then 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). Briefly, the microbial purine derivatives absorbed were calculated as: (total purine derivatives excreted [mmol/d] – 0.385 × BW0.75) / 0.85, assuming that 85% of the purine derivatives were absorbed (Chen and Gomes 1992). From this, microbial N flow was calculated by multiplying the absorbed microbial purine derivatives by 70 mg/mmol which was assumed to be the N content of purines. The result was then divided by the purine ratio of ruminal microbes:total N (0.116) and the assumed digestibility (83%). The value was then multiplied by 1000 as a unit correction to achieve values on a g/d basis (Chen and Gomes 1995).

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 time-point was stored (-20°C) in order to create a 4-d fecal composite sample for each heifer. The composite sample was thawed, dried at 55°C until achieving a constant weight, ground to pass through a 1-mm sieve, and sent to Cumberland Valley Analytical Services (Waynesboro, PA) for chemical
analysis 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.

**Plasma and Serum Metabolites**

Jugular catheters were inserted on d 21 to enable frequent blood collection as described by Joy et al. (2017). Blood samples were collected every 4 h over a 24-h duration starting at 0800 h on d 24. At each collection time-point, 10 mL of blood was collected into a tube 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 a tube 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 a 5-mL vial and stored at -20°C until being used to determine the concentration of β-hydroxybutyric acid (BHBA) according to Williamson et al. (1962).

**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 OM, CP, NDF, ash corrected NDF (aNDFOM), ADF, starch, ether extract, Ca, and P. DM content of feed ingredients were determined according to method 2.1.4 (National Forage Testing Association, 2006) and ash was determined according to AOAC
method 942.05 (AOAC 2000). Crude protein was analyzed using nitrogen combustion (Leco FP-528 Nitrogen Combustion Analyzer, LECO Corporation, St. Joseph, MI). Neutral detergent fiber (NDF) was determined according to Van Soest et al. (1991) utilizing α-amylase and sodium sulfite and the residue was ashed to determine aNDF<sub>om</sub>. ADF was determined according to AOAC method 973.18 (AOAC, 2000) and starch was determined according to Hall (2009). The ether extract concentration was determined according to AOAC (method 2003.05; AOAC, 2006). Calcium and P concentrations were determined after ashing the samples and digesting in 15% nitric acid (method 985.01; AOAC, 2000).

**Statistical Analysis**

Data were analyzed using the Mixed Model procedure of SAS (version 9.4; SAS Inst. Inc., Cary, NC) as a 6 × 6 Latin square design. The model included the fixed effects of cereal type, pea inclusion, cereal × pea inclusion with heifer and period included as random effects. The Kenward-Roger approximation was used for calculating degrees of freedom and the linear and quadratic effects of pea inclusion were assessed. All data and their residuals were confirmed to be normally and independently distributed. Rumen SCFA, rumen ammonia-N, and blood metabolites were analyzed with the fixed effects of cereal type, pea inclusion, time, cereal × pea inclusion, cereal × time, pea × time (hour of sampling), and the cereal × pea × time interactions. Time was included as a repeated measure and the covariance error structure that yielded the lowest Akaike’s and Bayesian Information Criterion values for each variable was used. Heifer and period were included as random effects. The linear and quadratic effects of pea inclusion of pea hay inclusion were also assessed. However, we did not detect 2- or 3-way interactions with time (data not shown), and hence, only main effects of cereal type, pea inclusion rate, and the
cereal × pea inclusion interaction are reported. For all analysis, significance was declared when $P < 0.05$ and the Tukey’s honestly significant difference test was used to separate means.

RESULTS

Forage Production and Treatments

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 2 and 3). Barley-based diets were numerically greater in starch concentration and oat diets were greater in aNDF$_{OM}$, NDF, and ether extract.

BW, DMI, and Ruminal Fermentation

BW and ADG were not affected by cereal hay type or pea hay inclusion ($P > 0.26$; Table 4). However, including pea hay increased DMI relative to cereal-only treatments without detectable linear or quadratic effects. There were no effects of cereal hay type or pea hay inclusion on minimum or maximum ruminal pH ($P \geq 0.14$), although mean ruminal pH increased linearly with pea hay inclusion ($P = 0.039$). There was no effect of cereal hay type or pea hay inclusion on total ruminal SCFA concentration; however, molar proportions were affected by both cereal hay type and inclusion rate of pea hay. For the molar proportion of acetate, there was an interaction among cereal 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 hay inclusion. Use of barley hay resulted in lesser concentrations of butyrate ($P < 0.001$) than oat hay, 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 with increasing pea hay inclusion ($P = 0.011$).

**Blood metabolites**

No interactions between cereal hay type (barley vs. oat) and pea hay inclusion rate (0, 15, and 30%) were detected for blood metabolite concentrations (Table 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 hay inclusion ($P = 0.028$). Plasma urea-N decreased and then increased in response to pea hay inclusion ($P = 0.001$).

**Eating behavior**

Heifers fed oat hay selectively sorted for CP ($P = 0.022$; Table 5) and against aNDFOM 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 hay linearly decreased selection for CP ($P < 0.001$), linearly decreased the selection against aNDFOM and ADF, and linearly increased selection for ether extract ($P \leq 0.006$) with increasing pea hay inclusion.

**Apparent Total Tract Digestibility and Nitrogen Balance**

Dry matter, OM, and CP digestibility were greater for heifers fed oat hay than barley hay (Table 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 hay type, pea hay inclusion, or their interaction on fiber digestibility (aNDFOM and ADF; $P \geq 0.17$). An interaction between cereal hay type and pea hay inclusion was detected for starch digestibility, with starch digestibility numerically greater when pea hay was included at 30% than 0% ($P = 0.053$; data not shown) for the barley hay treatments while starch digestibility was
numerically lesser ($P = 0.080$; data not shown) when pea hay was included at 30% 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 7) without affecting total purine derivative excretion. As such, there no differences in the predicted daily microbial nitrogen supply ($P = 0.24$) were observed.

**DISCUSSION**

While we intended to evaluate the effect of pea hay 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 we cannot confirm, the low inclusion rate may have been affected by factors such as seeding depth and drier than normal growing 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. These inclusion rates represent a broad range of pea hay inclusion with the 30% inclusion representing the upper pea hay inclusion expected based on recommended seeding rates (Gungaabayar et al. 2018). This
treatment structure is novel and addresses a critical gap in the literature: namely, how pea hay inclusion affects feed intake and nutrient utilization for beef cattle. This is important as pea hay inclusion influences the cost, relative proportions of cereal and pea in the final forage mix, and ultimately the CP content of the final forage (McCartney and Fraser 2010).

There were limited interactions between the cereal hay source and pea hay inclusion rate with the exception that starch digestibility and the molar proportions of acetate and valerate were affected by the interaction. For starch, digestibility decreased with increasing inclusion of pea hay when combined with oat hay, but starch digestibility increased with advancing inclusion of pea hay when included with barley hay. The interactive effect is likely explained by the relative starch digestibility of pea grain in whole-plant pea hay when compared to barley or oat grain in whole-plant cereal hay. For example, whole oat has greater starch digestibility than barley; the latter requiring more extensive processing to improve digestibility (Campling 1991).

Furthermore, oat grain has been reported to be more degradable than barley grain when ground for in situ degradation experiments (Herrera-Saldana et al. 1990). Use of whole pea grain, relative to rolled or ground pea grain has been reported to improve DMI and ADG for growing steers further supporting adequate digestibility of whole pea (Soto-Navarro et al. 2012). In addition, (Pursley et al. 2019) reported total tract starch digestibility of pea hay ranged from 92 to 96% depending on stage of maturity at harvest. However, for pea silage, the in situ effective degradability of starch was less than for barley silage (86.3 vs. 97.4 % DM; Mustafa et al. 2000). While we cannot confirm ruminal digestibility, it is likely that the pea grain in the whole-plant pea hay had an intermediate digestibility relative to the cereal grain component in barley and oat hay thereby increasing starch digestibility for barley hay but decreasing it for oat hay treatments.
Future research is required to evaluate ruminal starch digestibility in whole-crop forages including pea hay.

**Effect of Pea Inclusion in Cereal Hay**

Previous research has reported that feeding pea grain as a protein source to cattle increased DMI relative to cereal-only diets (Soto-Navarro et al. 2012) and increased DMI for lactating Holstein cows when fed pea silage compared to barley silage (Mustafa et al. 2000). However, Jaster et al. (1985) did not observe any differences for DMI of growing Holstein heifers when fed barley or oat silage compared to barley-pea or oat-pea silage. That said, we are not aware of research evaluating pea hay inclusion in diets for beef cattle. We observed that inclusion of pea at either 15 or 30% increased DMI relative to no pea hay inclusion, regardless of whether it was incorporated with barley or oat hay. The improvement in DMI may be attributed to the lower NDF concentration in pea hay compared to the cereal hays in the present study. DMI for low-energy dense diets is negatively impacted by NDF intake due to ruminal distension and the slower passage rate associated with high NDF diets (Dado and Allen 1995; Oba and Allen 1999; 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 (35.65%) 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, we observed that cattle selected against fibrous components in cereal-only 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.
In the present study, heifers sorted for CP and against NDF and ADF in the cereal-hay only treatments while sorting against CP and selecting less against fiber in cereal-pea hay 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 hay was included in a cereal hay-based diet, cattle may select for the cereal hay component over the pea hay. Furthermore, we observed that despite greater CP concentration and increased DMI, pea hay inclusion did not increase CP intake, microbial protein supply. The lack of a positive effect on CP intake is supported by previous studies (Khorasani et al. 2001; Vander Pol et al. 2008, 2009) using pea silage. 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 hay inclusion rate increased.

As expected based on findings by Reed et al. (2004), increasing pea hay concentration in the diet increased mean ruminal pH, potentially due to the high ruminal buffering effect of legumes compared to cereals through cation exchange capacity (Jasaitis et al. 1987; Van Soest 1994). However, while we did detect a linear increase in ruminal pH with increasing pea hay inclusion, the magnitude of the response is small and the biological implications may be limited. 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).

In the present study, ruminal ammonia concentration increased quadratically with increasing pea hay inclusion despite pea hay quadratically reducing CP digestibility and that heifers decreased their sorting for CP with increasing pea hay inclusion. Increased ruminal ammonia concentration could be expected given the numerically greater CP for pea hay than oat or barley hay. While previous studies evaluating pea hay inclusion have not evaluated ruminal degradability of the CP fraction (Pursley et al. 2019), a study evaluating pea silage relative to barley and alfalfa silage reported that pea had greater effective degradability of CP measured in situ relative to barley silage (Mustafa et al. 2000). When grown in combination, barley-pea silage had greater CP digestibility than barley silage alone, but oat silage and oat-pea silage did not differ in CP digestibility (Jaster et al. 1985). Thus, the results of the present study are partially supported by previous research and the quadratic increase in ruminal ammonia likely was the causative factor for the linear increase in plasma urea nitrogen and tendency for increased urinary urea excretion.

**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 stimulated DMI to a greater extent than oat in dairy cattle (Khorasani et al. 1996) and sheep (McCartney and Vaage 1994), with no intake differences observed in beef heifers (McCartney and Vaage 1994). In accordance with the results of McCartney and Vaage (1994), we found that when fed as hay, there were no difference in DMI between barley and oat hay treatments for 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 as previously described. 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 the cattle in the present study given the measured ADG. For example, given that 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. In addition, metabolism studies with relatively short periods are also not well suited for accurate determination of ADG thereby partly explaining the discrepancy between the actual ADG and N-retention predicted ADG.

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 >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. Our results also 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 among cultivar types within a species.

CONCLUSION

In the present study, binary mixtures of pea and cereal did not result in the successful establishment of a pea-cereal mixture. Use of hand-mixing to incorporate long-stem pea hay into cereal hay may improve DMI, modify ruminal fermentation, but may decrease CP digestibility and reduce N-balance when included with oat hay. When comparing cereal hay sources, oat hay induced less sorting behavior by cattle and had greater total tract digestibility than barley hay. These results are interpreted to suggest that pea hay inclusion up to 30% of the forage DM is suitable for growing beef cattle, regardless of whether included with oat or barley hay; however, inclusion of pea hay with oat may decrease starch and CP digestibility, and reduce N-balance.

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### Table 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 and oat-pea mixtures.

| Agronomic management | Crop type | Barley | Barley-Pea | Oat | Oat-Pea | Pea |
|----------------------|-----------|--------|------------|-----|---------|-----|
| Pre-swathing         |           |        |            |     |         |     |
| Days from seeding    |           | 71     | 71         | 77  | 77      | 71  |
| Growing degree days  |           | 934    | 934        | 1033| 1033    | 934 |
| Mean ambient temperature, °C |   | 17.5   | 17.5       | 17.6| 17.6    | 17.5|
| Precipitation, mm    |           | 57     | 57         | 86.9| 86.9    | 57  |
| Date of swathing, 2017 |         | 04-Aug | 04-Aug    | 11-Aug| 11-Aug | 04-Aug |
| Predicted yield, t/ha (DM) |   | 9.6    | 10.7       | 9.8 | 13.8    | 12.8|
| DM at swathing, %    |           | 46     | 47.5       | 46.5| 43.5    | 32.1|
| Post-swathing        |           |        |            |     |         |     |
| 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|

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- **a** Data derived from SRC Climate Research Station 4057180 (Saskatoon, SK).
- **b** The pea hay represented 1.62% and 1.65% (DM basis) for the barley-pea and oat-pea hay, respectively.
- **c** Data is calculated from seeding date until date of swathing.
- **d** Daily growing degree days were calculated as: (maximum temperature + minimum temperature)/2 − 5°C.
- **e** Data were calculated from date of swathing until date of baling.
Table 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 | Barley | Barley-Pea<sup>a</sup> | Oat | Oat-Pea<sup>a</sup> | Pea | Supplement<sup>b</sup> |
|------------|--------|------------------------|-----|---------------------|-----|------------------------|
| DM (%)     | 88.83 ± 2.24<sup>c</sup> | 89.37 ± 2.19           | 87.99 ± 2.56 | 85.90 ± 7.42        | 88.26 ± 2.21 | 94.01 ± 0.42          |
| 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<sub>OM</sub> | 50.95 ± 2.11         | 48.68 ± 1.72           | 52.82 ± 3.31 | 51.38 ± 1.83        | 35.65 ± 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          |
| Ether extract | 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           |

<sup>a</sup>The pea hay represented 1.62% and 1.65% (DM basis) for the barley-pea and oat-pea hay, respectively.

<sup>b</sup>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).

<sup>c</sup>Values are listed as mean ± SD.
Table 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.

| Variable | Barley\(^a\) | Oat\(^a\) |
|----------|---------------|------------|
|          | 0 | 15 | 30 | 0 | 15 | 30 |
| Ingredient inclusion rate (% DM) | | | | | | |
| Barley | 92.00 | - | - | - | - | - |
| Barley-Pea\(^b\) | - | 79.69 | 65.87 | - | - | - |
| Oat | - | - | - | 92.00 | - | - |
| Oat-Pea\(^b\) | - | - | - | - | 79.72 | 65.92 |
| Pea | - | 12.31 | 26.13 | - | - | - |
| Supplement\(^c\) | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 |
| DM, % | 90.69 | 89.73 | 89.7 | 90.28 | 90.83 | 90.61 |
| Nutrient composition\(^d\) (% DM) | | | | | | |
| OM | 91.65 ± 0.310 | 91.44 ± 1.585 | 91.47 ± 1.341 | 91.77 ± 0.636 | 92.00 ± 0.607 | 91.94 ± 0.518 |
| CP | 10.29 ± 0.955 | 10.59 ± 0.682 | 11.37 ± 0.844 | 11.18 ± 0.677 | 10.50 ± 1.325 | 11.29 ± 0.995 |
| aNDF\(_{OM}\) | 48.9 ± 1.914 | 45.45 ± 1.442 | 43.93 ± 1.358 | 50.62 ± 3.012 | 47.61 ± 1.573 | 45.72 ± 1.544 |
| ADF | 29.69 ± 2.282 | 28.39 ± 2.483 | 28.2 ± 2.424 | 28.8 ± 1.686 | 28.29 ± 2.285 | 28.11 ± 1.765 |
| Starch | 14.4 ± 1.847 | 16.6 ± 2.418 | 17.05 ± 2.318 | 13.51 ± 3.475 | 14.33 ± 5.078 | 15.17 ± 4.346 |
| Ether extract | 2.81 ± 1.393 | 2.51 ± 0.352 | 2.42 ± 0.285 | 3.38 ± 1.644 | 3.33 ± 1.509 | 3.1 ± 1.243 |
| Ca | 0.96 ± 0.031 | 1.03 ± 0.057 | 1.17 ± 0.051 | 0.91 ± 0.044 | 1.00 ± 0.029 | 1.14 ± 0.040 |
| P | 0.47 ± 0.029 | 0.44 ± 0.025 | 0.45 ± 0.025 | 0.44 ± 0.026 | 0.46 ± 0.018 | 0.46 ± 0.017 |

\(^a\)Within each cereal grain type (barley and oat), pea hay was included to account for 0, 15, or 30% of the DM.

\(^b\)Barley-Pea hay consisted of 98.38% barley DM and 1.62% pea DM. Oat-Pea hay consisted of 98.35% oat DM and 1.65% pea DM.

\(^c\)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).

*The mean ± SD of 6 samples are reported.*
Table 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.

| Variable                        | Barley<sup>a</sup> | Oat<sup>a</sup> | P-value<sup>b</sup> |
|--------------------------------|-------------------|-----------------|---------------------|
|                                | 0%    | 15% | 30% | 0%    | 15% | 30% | SEM<sup>c</sup> | C  | I  | C×I  | L  | Q  |
| Initial BW, kg                 | 450.0 | 448.0 | 426.0 | 426.0 | 449.0 | 427.0 | 15.8 | 0.57 | 0.35 | 0.65 | 0.90 | 0.94 |
| Final BW, kg                   | 465.0 | 460.0 | 436.0 | 433.0 | 459.0 | 438.0 | 15.6 | 0.37 | 0.32 | 0.44 | 0.76 | 0.92 |
| ADG, kg/d                      | 0.2   | 0.4  | 0.5  | 0.6   | 0.4   | 0.6  | 1.82 | 0.26 | 0.63 | 0.44 | 0.46 | 0.55 |
| DMI, kg/d                      | 7.2   | 8.0  | 7.7  | 7.2   | 7.8   | 7.9  | 0.36 | 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                        | 6.5   | 6.5  | 6.6  | 6.4   | 6.6  | 6.6  | 0.06 | 0.89 | 0.14 | 0.35 | 0.091 | 0.93 |
| Maximum                        | 7.0   | 7.0  | 6.9  | 6.9   | 7.0  | 7.0  | 0.06 | 0.99 | 0.59 | 0.62 | 0.67 | 0.58 |
| Mean                           | 6.7   | 6.7  | 6.8  | 6.7   | 6.7  | 6.8  | 0.04 | 0.60 | 0.039 | 0.57 | 0.024 | 0.96 |
| Ruminal fermentation           |       |      |      |       |      |      |      |      |      |      |      |      |
| Ammonia, mg/dL                 | 3.0   | 2.9  | 4.1  | 1.5   | 2.0  | 3.1  | 0.32 | <0.001 | <0.001 | 0.20 | <0.001 | 0.011 |
| SCFA, mM                       | 88.1  | 84.2 | 83.9 | 89.3  | 84.5 | 87.8 | 3.71 | 0.55 | 0.59 | 0.88 | 0.31 | 0.42 |
| SCFA, mol/100 mol              |       |      |      |       |      |      |      |      |      |      |      |      |
| Acetate                        | 68.69 | 68.14 | 68.65 | 68.13 | 69.62 | 70.20 | 0.533 | 0.005 | 0.074 | 0.024 | <0.001 | 0.67 |
| Propionate                     | 17.8  | 16.7 | 15.8 | 18.7  | 16.6 | 15.8 | 0.39 | 0.96 | <0.001 | 0.61 | <0.001 | 0.40 |
| Isobutyrate                    | 0.8   | 0.8  | 0.9  | 0.8   | 0.9  | 0.9  | 0.025 | 0.44 | 0.19 | 0.79 | 0.009 | 0.70 |
| Butyrate                       | 10.7  | 11.3 | 11.5 | 8.7   | 9.9  | 10.6 | 0.374 | <0.001 | 0.013 | 0.34 | <0.001 | 0.55 |
| Isovalerate                    | 1.1   | 1.1  | 1.2  | 1.0   | 1.1  | 1.2  | 0.037 | 0.95 | 0.073 | 0.64 | 0.001 | 0.38 |
| Valerate                       | 1.38  | 1.23 | 1.27 | 0.91  | 1.05 | 1.19 | 0.177 | <0.001 | 0.014 | 0.023 | 0.52 | 0.79 |
| Caproate                       | 0.4   | 0.4  | 0.5  | 0.3   | 0.4  | 0.5  | 0.014 | 0.06 | <0.001 | 0.97 | <0.001 | 0.037 |
| 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 |

**Note:** Means within a column not sharing a common lowercased italic letter differ significantly at the $P < 0.05$ level for the interaction between whole-crop cereal type and pea hay inclusion.

aWithin each cereal grain type (barley and oat), pea hay was included to account for 0, 15, or 30% of the DM.

b$P$-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.

cSEM of the cereal-inclusion (C × I) interaction.
Table 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.

| Sorting index | Barley | Oat | P-value |
|---------------|--------|-----|---------|
|               | 0% | 15% | 30% | 0% | 15% | 30% | SEM | C | I | C×I | L | Q |
| OM            | 100.15 | 100.32z | 100.13 | 100.17 | 100.15 | 100.16 | 0.073 | 0.55 | 0.49 | 0.37 | 0.91 | 0.30 |
| CP            | 102.91 | 97.9 | 98.3 | 105.46z | 100.31 | 99.8 | 0.963 | 0.022 | <0.001 | 0.87 | <0.001 | 0.028 |
| aNDF<sub>OM</sub> | 98.87 | 101.98z | 101.55 | 97.81z | 99.51 | 99.9 | 0.726 | 0.01 | 0.006 | 0.64 | 0.017 | 0.14 |
| ADF           | 94.85 | 100.18 | 99.48 | 96.29z | 98.00 | 97.61 | 1.008 | 0.25 | 0.002 | 0.11 | 0.024 | 0.066 |
| Starch        | 97.1 | 95.01z | 96.55 | 103.69 | 100.77 | 99.12 | 1.807 | 0.002 | 0.25 | 0.42 | 0.38 | 0.83 |
| Ether extract | 73.37 | 103.72z | 103.68z | 98.06 | 95.23 | 98.7 | 8.054 | 0.67 | 0.29 | 0.24 | 0.025 | 0.073 |

**Note:** Means with the lowercase letter z differ significantly from 100.00 at the *P* < 0.05 based on a 2-tailed t-test.

*Within each cereal grain type (barley and oat), pea hay was included to account for 0, 15, or 30% of the DM.*

*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.

*Sorting index was calculated as *(actual nutrient consumed)/(theoretical nutrient consumed) × 100%*, as described in in Rosser et al. (2016) based off that presented by Leonardi and Armentano (2006).

*SEM of the cereal-inclusion (C × I) interaction.*
Table 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.

| Digestibility (% DM) | Barley<sup>a</sup> | Oat<sup>a</sup> | P-value<sup>b</sup> |
|----------------------|---------------------|-----------------|--------------------|
|                      | 0% 15% 30%          | 0% 15% 30%      | SEM<sup>c</sup>   |
| 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                   | 64.02 65.88 68.09   | 69.46 69.85 69.74 | 1.345 0.002 0.24 0.32 0.09 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<sub>OM</sub>    | 61.63 63.73 63.3    | 64.90 61.92 62.07 | 1.950 0.95 0.94 0.28 0.79 0.93 |
| ADF                  | 54.69 56.99 57.29   | 61.09 56.24 57.74 | 2.169 0.19 0.79 0.17 0.85 0.50 |
| Starch               | 70.40<sup>b</sup> 72.73<sup>b</sup> 79.06<sup>b</sup> | 97.13<sup>a</sup> 94.59<sup>a</sup> 89.11<sup>a</sup> | 2.197 <0.001 0.97 0.001 0.84 0.90 |
| Ether extract        | 68.73 64.02 64.87   | 67.56 76.46 71.14 | 4.357 0.028 0.61 0.14 0.88 0.49 |

**Note:** Means within a column not sharing a common lowercased italic letter differ significantly at the *P* < 0.05 level for the interaction between whole-crop cereal type and pea hay inclusion.

<sup>a</sup>Within each cereal grain type (barley and oat), pea hay was included to account for 0, 15, or 30% of the DM.

<sup>b</sup>*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.

<sup>c</sup>SEM of the cereal-inclusion (C × I) interaction.
Table 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.

| Variable                      | Barleya | Oata | P-value2 | SEMc | C | I | C×I | L | Q |
|-------------------------------|---------|------|----------|------|---|---|-----|---|---|
| Intake N (g d⁻¹)              | 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 d⁻¹)         | 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⁻¹)        | 48.5    | 46.8 | 42.9     | 29.3 | 35.7 | 39.0 | 8.93| 0.001| 0.79| 0.11| 0.95| 0.94|
| Urinary output (kg d⁻¹)       | 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⁻¹)      | 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 PDd                   |         |      |          |      |      |      |     |      |      |     |      |      |
| Allantoin (mmol d⁻¹)          | 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 (mmol d⁻¹)          | 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 (mmol d⁻¹)              | 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 N² (g d⁻¹)          | 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⁻¹)            | 20.0    | 32.4 | 38.7     | 48.9 | 36.9 | 39.8 | 9.20| 0.033| 0.77| 0.071| 0.65| 0.97|

aWithin each cereal grain type (barley and oat), pea hay was included to account for 0, 15, or 30% of the DM.

bP-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.

cSEM of the cereal–inclusion (C × I) interaction.

dPD = purine derivatives

ePredicted according to Chen and Gomes (1992).