ERA Project No. RES 0023163

Performance validation of RFI selected cattle under extensive cow/calf production systems

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Project End Date: August 31, 2017

Total Funds Received: $168,000 (Holdback: 20%)

Report Submission Date: October 5, 2017

TABLE of CONTENTS

LIST of ABBREVIATIONS

50K – 50,000 SNP panel
°C – Degrees celsius
AAFC – Agriculture and Agri-Food Canada
ADF – Acid detergent fiber
ADG – Average daily gain
ANOVA – Analysis of variance
BW – Body weight
C_3 – Cool season vegetation
C_4 – Warm season vegetation
CH_4 - Methane
CO_2 – Carbon dioxide
CP – Crude protein
d – Day
DM – Dry matter
DMI – Dry matter intake
DE – Digestible energy
EPD – Expected progeny difference
FCR – Feed conversion ratio
g – Gram
GEMS – GreenFeed emission monitoring system
GIS – Geographic information system
GPS – Global positioning system
H' – Shannon's diversity
ha - Hectare
hr – Hour
HSD – Honest significant difference test
ISA – Indicator species analysis
kg – Kilogram
LT – Lying time
m – Meter
mm - Millimeters
M - Million
MANOVA – Multiple analysis of variance
MBV – Molecular breeding value
ME – Metabolizable energy
MJ – Mega-joules
N – Nitrogen
NMDS – Non-metric multidimensional scaling
NMR – Nuclear magnetic resonance
OP–FTIR – Open path fourier transform infrared laser
P – Significance value
PerMANOVA – Permutational analysis of variance
pRFI – Predicted residual feed intake
RFI – Residual feed intake
RFI_{FAT} – Residual feed intake adjusted for backfat thickness

r – Correlation coefficient
R^2 – Coefficient of variation
SD – Standard deviation
SE – Standard error
SF_6 – Sulphur hexafluoride tracer technique
SNP – Single nucleotide polymorphism
sqrt – Square root transform
RFI – Residual feed intake
RFID – Radio frequency identification
TDN – Total digestible nutrients
rpm – Revolutions per minute
yr – Year

EXECUTIVE SUMMARY

Current efforts to increase profitability of the beef industry have targeted production efficiency and cost reductions. Residual feed intake (RFI) of beef cattle, the difference between actual and expected feed requirements for a given body size and production level, has been identified as an important attribute of efficiency. Low RFI animals require less feed to reach marketable weight and breeding animals require less feed to produce a weaned calf, and this in turn, could reduce environmental impacts of beef production, including greenhouse gas emissions. While improvements to RFI are a key component of industry competitiveness, most previous research on RFI has been done in drylots where dietary intake and animal behavior can be controlled. However, ranking of animals for RFI may vary depending on maturity (experience), environment (landscape and vegetation conditions), genetic makeup (i.e. RFI), animal behaviour, and ultimately dietary composition, and these factors have the potential to differ markedly on open rangeland. We used a combination of field studies and drylot trials to evaluate these factors, first for cow/calf pairs, and later for a subset of replacement heifers with divergent maternal predicted RFI (pRFI). Cows with higher maternal pRFI were found to produce calves with greater growth, ADG, and eventually weaning weights, suggesting cow/calf production on open range may not be independent of markers for RFI. Cow production metrics (weight and backfat gain) also declined more in relation to increasing pRFI for cows older than 5 yr of age. Cow diets varied temporally, with more warm-season vegetation consumed in summer, and dietary diversity expanding in fall. Cows with low pRFI generally had a narrower diet, limiting their diet to fewer species (and reducing use of introduced plant species). Cows selecting areas of high biomass were likely to wean larger calves, and warrant further study. While cow activity budgets (movement & resting patterns) varied markedly with time of year, pasture size and type, they were typically unrelated to pRFI. Replacement heifers from cows with greater pRFI had 14% greater feed intake in drylot, a pattern further supported by heifers with lower actual RFI_{FAT} (backfat adjusted) demonstrating reduced feed intake. While low RFI_{FAT} heifers had greater CH_4 and CO_2 yield (i.e., intake adjusted), lower feed intake in these same animals led to similar total CH_4 production, while CO_2 production remained overall lower. These findings indicate that selection for low RFI may reduce the footprint of CO_2, but not CH_4 production, in beef cattle, and warrants further investigation. Subsequent tests of replacement heifers on pasture failed to demonstrate any significant differences in feed intake or greenhouse gas emissions, despite a trend for low RFI_{FAT} animals to have lower feed intake, (4%) lower CH_4 yield, as well as reduced backfat, possibly due to low sample sizes. Overall, results of this research increase our understanding of the relationship between the existing selection criteria for feed efficiency in beef cattle. In combination, the information provided here on cow/calf production metrics, grazing behaviour, dietary selection, and subsequent replacement heifer evaluation for feed intake, RFI, and greenhouse gas emissions (both in drylot and pasture), have implications for improving beef production efficiency in Alberta, potentially refining the development of selection criteria for cow/calf systems, and highlighting several areas for additional research.

1. PROJECT DESCRIPTION

1.1. Background

Efforts to increase profitability of the beef industry have targeted increased production efficiency and cost reductions. Progress on the former has involved improvements to the quantity and quality of fodder (via better forage varieties and associated agronomics), and efforts to address cattle feed efficiency. Significant differences in residual feed intake (RFI) have been identified through numerous feed intake trials, and rapid advances are being made in the use of genetic markers (genomics) to identify efficient cattle. Selection for low RFI can result in substantial improvements in the feed conversion ratio (FCR) of animals (ranging from 9 to 15%) (Basarab et al. 2003), and has potential to increase profitability of the beef industry (Exton et al. 2000). Residual feed intake (RFI) is the difference between actual intake and expected feed requirements for maintenance and growth. Low or negative RFI animals are more efficient and require less feed to reach marketable weight, or in the case of cows and replacement heifers, produce a weaned calf. Measures of RFI are independent of growth and body weight, and instead represent differences among animals in efficiency of feed utilization (Moore et al. 2009).

Improvements to RFI in beef cattle, especially the cow herd, represent a key component of future industry competitiveness. Previous research has found improvements in RFI are possible in a feedlot context (Basarab et al. 2003; Nkrumah et al. 2006; Carstens and Tedeschi 2006), with major implications for reducing feed costs where young animals are fed a finishing diet high in grain and energy. However, research at the Kinsella Ranch has shown that the ranking of animals for RFI may vary depending on maturity, environment, compensatory gain, and diet (Durunna et al. 2011). Therefore, it is unclear if animals with low RFI under these conditions would be efficient in an extensive cow-calf system, where production efficiency may be influenced by attributes such as mobility, habitat and forage preferences, feed conversion efficiency under free-choice conditions, and maternal characteristics. Given the distinctly different foraging and environmental conditions found in pastures compared to drylots, and the known complexity of animal behavior that results under open-range foraging (Senft et al. 1987; Bailey et al. 1996), more research is needed to test cow/calf production attributes of low and high RFI maternal lines under open range grazing. Recent results from tame pastures and swath grazing are positive (Basarab unpublished) but data on the extent to which efficiency may be maintained in different environments (landscape conditions, forage availability and quality) are scarce, including native grasslands.

This project will test whether beef cattle efficiencies, as identified by RFI and marker assisted genetic selection, are associated with cow/calf performance when assessed under open range (cow/calf) production systems. This project will use the resources (RFI-tested cattle but also measurement tools) developed in other projects to investigate efficiency of different forage-based systems at the University of Alberta Mattheis Research Ranch.

1.2. Project Objectives

<u>Short-term objectives:</u>

- Determine whether cattle previously identified as low RFI exhibit favorable performance when tested in a cow/calf production system (extensive open rangeland) with free choice selective foraging, and whether cattle with high RFI are less efficient under the same conditions. To do so, we will quantify changes in body weight and composition, rebreeding ability and offspring pre-weaning growth, of cows having varying molecular breeding values for RFI, and grazing on open range.

- Test the performance of offspring from bulls previously identified as low or high RFI in an extensive cow/calf production system. Quantify forage intake of heifers with known differences in performance (efficiency or RFI) and behavior in free-choice grazing.
- Utilize the open range environment of the Mattheis Research Ranch to identify and test behavioral mechanisms responsible for influencing RFI in cow/calf pairs, including habitat type and availability, habitat selection, biomass availability, forage quality, and animal movement.
- Evaluate different methods for assessing efficiency in extensive cattle production.

Long-term objectives:

- Explore the performance of current selection methods and the need for alternative approaches to optimize feed efficiency and RFI for extensively managed cow/calf producers grazing rangelands in Alberta.

1.3. Project Modifications

We had one setback in this study, which was in the genotyping of bulls associated with the commercial cattle herd being investigated. Genotypes of the bulls was desired to track parentage of calves, and evaluate the contribution of bulls to calf performance on open range, as well as the following year in the heifer replacement study. However, high turnover in bulls, and logistical issues with tracking of bull DNA tissue samples, combined with the high genetic relatedness of bulls, led to a decision that this information could not be used in the final analysis. Two significant additions were made to this project, in that we evaluated methane and carbon dioxide emissions from replacement heifers in drylot with contrasting maternal genotypes for molecular breeding values for RFI using a GreenFeed system. Thereafter, a subset of these heifers was evaluated for feed intake and methane emissions using open-path laser technology while grazing on pasture. Additionally, we collected rumen fluid samples from replacement heifers in both drylot (n=60) and on pasture (n=16) for the assessment of rumen microflora composition using DNA markers. Those samples are being processed and analyzed in conjunction with Dr. Leluo Guan at the University of Alberta, and have the potential to provide a further mechanistic understanding for why/how heifers differ in both performance, but also methane production (i.e. by quantifying the type and amount of methanogens present in the rumen).

2. OUTCOMES AND LEARNINGS

2.1. Experimental Design, Data Collection and Analysis

2.1.1. Cow/calf production evaluation relative to RFI breeding values

We examined the performance of a commercial cow/calf herd grazing on Mixedgrass prairie at the Mattheis Research Ranch in SE Alberta during 2015. Tissue samples were obtained from all herd cows in the fall/winter of 2013-14, and 50K panels evaluated by Delta Genomics, in associated with the Canadian Hereford Association, to develop molecular breeding values for predicted residual feed intake (pRFI). Estimates of PRFI were made by comparing single nucleotide polyphisms (SNPs) known to reflect RFI, and were done with reference to the genomic library for purebred Herefords (i.e. animals with known RFI). Herefords were used as the base for assessment because the dominant genetics within the commercial herd investigated was comprised of this breed.

Estimates of PRFI were initially obtained for 400 cows. Cows ranged from 3 to 13 years in age. This list was then used to identify 3 herds with contrasting PRFI [high/inefficient, PRFI≥0.04, x=-0.074(SD=0.03); low/efficient, PRFI<-0.07, x=-0.108(SD=0.04); and moderate, those with PRFI in-between the above intervals, x=-0.018(SD=0.03)]. Herds with high, moderate and low pRFI initially had 80, 240, and 80 cows, respectively, though subsequent heavy culling in fall 2014 led to the loss of some study animals, leading to a sample size of 352 (74, 219 and 59 head for the high, moderate and low pRFI groups) the next spring. Mean cow ages among groups remained similar (high pRFI=4.1±2.3; mod pRFI=3.7±1.1; low pRFI=3.9±1.3). During the 2014 breeding season, cows in each grouping were grazed separately and exposed to bulls with known differences in RFI based on previous drylot tests. Cows with low pRFI were bred to (similarly) low RFI bulls (n=2), while high pRFI cows were bred to high RFI bulls (n=2); another 13 bulls of variable pRFI were exposed to the cow herd with medium pRFI. This process was intended to produce a calf crop in 2015 that contained divergent progeny for pRFI. While we initially were going to use progeny testing to determine the exact identity of each calf born in 2015, we discovered strong similarities among bull lineage complicated this process, and together with inconsistent records of sire placement during the breeding season, prevented this from occurring with certainty. Additionally, culling of several bulls after the 2014 season prevented us from genotyping every bull, rendering it impossible to retrospectively test the progeny of all calves.

During the 2015 calving season (April 16-June 8), most calves were weighed at birth using a cradle scale and all calves were sexed, tagged, and also estimated for birth weight. For those calves that could not be weighed (due to safety concerns; 43%), regressions of actual vs estimated birth weights were used to correct actual weight estimates ($R^2 \geq 0.51$). Birth dates were recorded to ensure known age at weaning in late October 2015. At the start of the grazing season on June 10, all cows were weighed and body condition scored (mm of backfat using ultrasound), with the same done at weaning on October 26, 2015. All cows were preg checked in the fall to determine their reproductive status (trimester of gestation). Calves were weighed shortly after weaning, then placed in drylot and fed a barley silage ration.

To evaluate whether cows having differing pRFI (and their calves) differed in metabolomics profile, we collected 10ml of blood from cows (and as many of their calves as possible) within the low and high pRFI herds on June 10, 2015, and again on October 26, 2015.

2.1.2. Evaluation of cattle grazing behaviour

To test whether cattle with contrasting pRFI differ in their grazing behaviour, we installed Lotek 3000 GPS collars on 27 cows (12=high pRFI, range=0.007 to 0.364, x=0.088; 15=low pRFI, range=-0.149 to -0.081, x=-0.102), which then grazed a large portion of the 2750 ha Mattheis Research Ranch. The grazed area included a complex of 16 native dry mixedgrass upland pastures (largely western wheatgrass, sandgrass, junegrass, needle&thread, and blue grama) and wetland pastures with abundant subirrigated areas (having bluegrass, sedges and rushes), ranging in size from 32 to 381 ha. Grazing periods ranged from 5 to 12 days. Cattle grazed all pastures together during the 2015 grazing season to ensure that cattle from all pRFI groupings had equal access to the same pasture conditions throughout the year. Collars were programmed to record the location of each animal from June 10 through October 26, 2015, with sampling intensity set to 15 minutes during peak foraging times (from 4 to 10 am, and 5 to 10 pm). These data were downloaded at the end of the summer, and positions subsequently overlaid on maps of the Mattheis Ranch; in combination with pasture boundaries, a soil layer provided spatial information on dominant vegetation types (lowland, midland, upland), a terrain index, and a map of available woody cover (to be evaluated for its ability to provide shelter). Collars also provided information on the ambient temperature. Finally, within each pasture and in the middle of each grazing period, forage samples were collected from 30, randomly located 0.25 m2 quadrats, stratified in proportion to predominant soil type, to quantify the quantity and quality of forage available to cattle. Samples were separated into grasses and forbs, dried and weighed, then ground to 0.1 mm size, and analyzed for acid detergent fiber (ADF) and nitrogen (N) concentration. Concentrations of N were multiplied by 6.25 to derive % crude protein. As many forage metrics were correlated with one another, we emphasized total herbage mass levels and grass crude protein to represent forage quantity and quality, respectively.

We evaluated cattle activity budgets during the summer of 2015. AfiActII pedometers were installed on the 27 cows with GPS collars. A series of mobile recording stations were used to download information on cow activity (movement/step rates, the number of lying bouts, and length of lying time). In large pastures, cows occasionally travelled out of the Wi-Fi range of readers, leading to data loss. However, we were able to summarize these 3 metrics for each cow within different season-pasture type combinations (early season in native grassland, mid-season in wetland pastures, and late/dormant season in native grassland) for analysis.

Last, to assess differences in dietary preferences of cattle with contrasting mbvRFI, we collected fresh fecal samples from 10 cows with low pRFI, and 10 cows with high pRFI. This was done in mid-July (main growing season) while cattle were on native grassland, and again in late September (dormant season) on native grassland. All 40 samples were dried, and a subsample sent to the Wildlife Habitat and Nutrition Lab at Washington State University for fecal histological analysis. The latter involved the preparation of 150 slides of fecal material for each of the 40 samples, which were then assessed under a microscope to determine the composition (based on frequency) of forage items, including all dominant grass species, sedges, rushes, horsetail, forbs, shrubs, lichen and funghi. A preliminary list of plant species was provided to the lab to familiarize technicians with the vegetation likely to be in the diet.

2.2.3. RFI assessment and methane emissions of replacement heifers in drylot

During December of 2015, a subset of 60 heifers with contrasting maternal pRFI were selected for the evaluation of actual RFI using GrowSafe technologies at the Lacombe Research Station. After arriving in Lacombe and following a 2 week acclimation period on their new diet

(Tables 12, 13), heifers were 276 (±16) days old at the start of the trial, and begun the intake trial on Feb. 19, which ran through April 26. Heifers were weighed on back to back days at the start of the trial, at the midpoint, and again at the end. Weights were averaged within each time, and the difference in weight used to calculate total gain per heifer over the trial period. GrowSafe bunks use RFID eartags to track the identity of each animal entering a bunk, and quantify feed intake for each animal during each feeding bout throughout the feeding period, with total feed intake and weight gain subsequently used to calculate actual RFI (Basarab et al. 2003; Wang et al. 2006).

From Feb. 19 to March 8, 2016, heifers also had access to a GreenFeed system within the drylot pen, which in addition to assessing feed intake (of pellets), also is able to assess methane emissions for each animal within a hooded chamber (Manafiazar et al. 2015). As heifers voluntarily utilized this system, data on methane emissions were not obtained for all animals (n=47 head had suitable data). Trace gas data were also binned in 3 hr intervals throughout the day for analysis to look at daily patterns of emissions.

2.1.4. Heifer intake and methane emissions on pasture

After the RFI drylot trial, heifers were returned to Mattheis, with 16 heifers subsequently evaluated for intake and methane emissions on pasture. Heifers selected for the trial differed in mean RFI (high=0.61; low=-0.56), with 8 animals per group. Heifers were conditioned on a tame forage oat field for 8 days in mid-June, then brought in twice a day (morning and evening) and fed 500 g of pelleted feed containing an alkane marker (Table 18) for 9 days. After each event, refusals were collected, dried and weighed. Thereafter, heifers were grazed as high and low RFI groups in 2 separate paddocks (~5x100 m in size), with one pen for each of the high and low RFI heifers. Fecal samples were collected daily from each animal, from which alkanes were quantified using extractions and gas chromatography. Combined with alkane analysis of in-situ forage, these data were used to derive dry matter intake (DMI) per heifer (Manafiazar et al. 2015). The layout of pens (Figs. 25-29; after Hu et al. 2016) also facilitated sampling 24 hr a day with open-path fourier transform laser to assess cattle-associated contributions to gaseous methane emissions (Flesch et al. 2004, Griffith et al. 2012; Harper et al. 1999) from each group of heifers for another 6 days. Heifers were moved to a new pen daily to ensure consistent access to high quality forage, and only periods of appropriate cross-winds were used to determine the group emissions rate of trace gases (Harper et al. 1999). Forage samples were clipped from 0.25 m2 quadrats within each pasture, and assessed for forage quality (Table 19). Heifers were weighed and backfat quantified at the start and end during the trial.

2.1.5. Data analysis

Calf weaning weights were adjusted to 205-d (Gould 2015), and also converted to % of mature cow weights. Calf data (birth weight, ADG, growth and 205-d weight) were boxcox transformed. An ANOVA was used to compare all metrics between the cow groups of contrasting pRFI. Groups were fixed, while animals were random. Post-hoc comparisons used a Tukey's HSD ($P<0.05$). A similar procedure (ANOVA) was done on cow backfat and summer weight gain, with the addition of cow age as a covariate, with the model run using initial and final metrics and also the change in backfat and weight gain. Linear regressions were used to relate cow weight gain and the change in cow backfat to pRFI ($P<0.05$). Finally, a contingency test was used to evaluate the proportion of high, medium and low pRFI cows that conceived in the first and second breeding cycles, as well as cows that were open.

Cattle GPS locations for 27 head from June 10 – Oct. 24 were available for assessment. These were overlaid in a GIS to determine environmental conditions (available forage quantity and quality by soil polygon, terrain index, temperature, and distance from water) for each location for each cow throughout the summer, and MANOVAs and regression used to evaluate how environmental conditions varied in relation to the fixed effect of pRFI. Cow production metrics (change in cow weight and backfat, and adjusted 200-d and % weaning weights of calves) were also regressed against the aforementioned 'environmental conditions' cows were exposed to in order to evaluate whether and how they altered cow/calf production.

Cattle activity budgets were assessed by consolidating activity on lying bout frequency (# hr^{-1}), lying time (%), and movement rates (steps hr^{-1}) for each cow. Times associated with animal handling or pasture moves were removed. Data were assessed for the early (June 12-20), middle (July 23- Aug. 14), and dormant season on native pastures (Aug. 31-Oct. 25). Data were additionally partitioned for seeded pastures (early season: June 26-July 14; middle season: Aug. 15-31) and wetland pastures (early season: June 20-26; middle season: July 14-23). Final compiled data were transformed [sqrt or log10(x+1)], run in an ANOVA with pRFI as a fixed factor, with either seasonal times as a fixed effect within native pastures only (with pasture and animal random), or with pasture type (native vs wetland vs tame forage) as an additional fixed effect; pasture size was included as a covariate. Linear regressions were done between cattle activity metrics and pRFI, as well as pasture size, for the native pastures.

Histological information on cow diets was analyzed by examining the frequency of plant functional types (e.g. grasses, forbs, native, introduced) within the diet in ANOVA, with pRFI and season (summer and fall) as fixed factors, and cow as random. To parse out detailed differences, a PerMANOVA was done on the full dietary composition using PC Ord software, with an indicator species analysis (ISA) conducted to identify species with affinity to either high or low pRFI cow groupings.

DMI data of heifers in drylot and on pasture were assessed using ANOVA with RFI group as a fixed effect, with added regressions between DMI and each of pRFI (drylot) and actual RFI (pasture). Methane emissions (per day or 3 hr period, per animal, and standardized for body weight) and yields (corrected for feed intake) were compared between animals and RFI groups, with either animals as the replicate (drylot), or day of sampling as the replicate (for herds on pasture), and time of day (in 3 hr binned segments) as an additional fixed effect.

Blood samples collected from different sets of cattle (cows and calves) over the course of the trial have added new phenotypes to the dataset. All samples were in serum vacutainer tubes, kept on ice, and prepared within 72 hr of collection by centrifugation (10,000 rpm for 30min at 4^{o}C), then stored at -80^{o}C prior to metabolomics analysis. Blood samples from replacement heifers in drylot were collected in EDTA vacutainer tubes that were stored at -20^{o}C before preparation of plasma, which was then stored at -80^{o}C. A total of 406 samples were collected for analysis (see Table 24). Samples were analyzed using nuclear magnetic resonance (NMR) spectroscopy (700 MHZ Bruker instrument) at the Metabolomics Innovation Centre at the University of Alberta. A total of 46 metabolites per sample were identified and used in preliminary analysis. The sample spectra was profiled using Bayesil (http://tmic.bayesil.ca/users/login) and statistically analyzed using MetaboAnalyst (http://www.metaboanalyst.ca/).

2.2. Study Results & Discussion

2.2.1. Cow/calf production metrics relative to pRFI

Calves did not differ in birth weights among pRFI groups (Tables 1, 2). The mean age of calves from high, medium and low pRFI cows at weaning was 174 days, 172 days and 167 days, with calves from medium pRFI cows older than low pRFI calves ($P<0.05$). Calf weaning weights and 205-day weights were greater in calves from high pRFI cows compared to the other groups (Table 2). A similar pattern was evident for calf growth and average daily gain, with greater performance in calves from high pRFI cows. Actual weaning weights calculated as a % of mature cow weight remained similar among calves from the high (33.8%), medium (33.4%) and low (33.8%) pRFI cows ($P>0.05$). Values of relativized 205-day weaning weights were also similar ($P>0.05$), ranging from 40.5-41.8% of mature cow weight. Regression of weaning weights (actual and 200-day adjusted) against phenotypic RFI (for replacement heifers) showed little relationship, even when calf age was incorporated ($R^2 \leq 0.027$), with none of the relationships significant ($P \geq 0.57$).

High (n=70), medium (n=207) and low (n=58) pRFI cows had similar ages ($P>0.05$), with an average age of 4.12, 3.70, and 3.95 years, respectively. Cow age, as well as pRFI, had a significant effect on spring and fall cow weights (Table 1). Cows with high pRFI were heavier than medium and low pRFI cows in spring and fall (Table 3). Average spring cow backfat measures were 1.27 mm, 1.25 mm, and 1.27 mm, for high, medium and low pRFI cows, respectively, and did not differ ($P>0.05$). All pRFI cow groupings tended to increase in backfat over the grazing season, but remained low by the end of the year (<2.5 mm). Fall weights and fall backfat thickness, were both effected by the interaction of cow age and pRFI (Table 1). Regressions of cow weight gain and change in backfat over the summer against pRFI, conducted separately for older (> 5 yrs) and younger cows, revealed more negative relationships for older cows (Figs. 1 & 2), although R^2 values remained low (R^2=0.055 to 0.06). Cow pregnancy rates did not differ between high, medium and low pRFI cows (Fig. 3), with most cows (50%) conceiving during the first breeding cycle, with up to 18% of cows open after two cycles.

These results generally support the notion that cow weight gain, backfat increments, and growth are not affected by selection for RFI, even though cows with high pRFI were larger in size. In general, these results support other studies showing no difference in growth of lactating cows relative to pRFI, both in growth (Black et al. 2013; Arthur et al. 2005) and backfat (Castro Bulle et al. 2007; Fitzsimmons et al. 2013; Black et al. 2013). However, some evidence existed supporting the notion that the relationship of weight and backfat gain may be contingent on animal age, with more favorable cow weight gain and backfat improvement evident in cows with low pRFI, but only in older animals. The overall young age of breeding cattle studied here (mostly <5 yr) may therefore have limited our ability to find stronger results for older beef cows. Several previous studies have identified positive (rather than negative) relationships between RFI and backfat thickness (Arthur et al. 2001; Basarab et al. 2003; Robinson and Oddy 2004), and thus warrant further testing of the role of animal age in regulating relationships between pRFI and cow production.

Our results are also consistent with previous studies suggesting cow pregnancy rates do not vary with pRFI (Arthur et al. 2005), although low pRFI cows had significantly less backfat in the latter study, which tended to delay calving. While we did not separately test heifers, many of our study cows were relatively young in age (<5 years). A study by Shaffer et al. (2011) found that low RFI beef heifers reached puberty later. Reproductive performance is known to be directly related to backfat measures (Drennan and Berry 2006), in which reduced fat can negatively impact conception rates, as well as delay puberty (Basarab et al. 2007). As backfat measures did not differ among cows in the current pRFI groupings, neither the timing of conception nor their ability to conceive appear to have been altered.

Weaning weights and growth were generally greater in calves originating from cows with high pRFI, although cow age, calf age and calf sex accounted for a significant amount of variation in calf performance. However, weaning weights as a % of cow weight remained similar, suggesting low pRFI cows were smaller than high pRFI cows. More specifically, calves from low pRFI cows were lighter at weaning (166 kg) than high pRFI calves (191 kg) leading to similar % weaning weights (33.8%). The smaller size of low pRFI cows and associated offspring may reflect ongoing selection by producers in this commercial herd for smaller framed animals to produce more beef per hectare by enabling more cattle to be supported (personal communication), while also actively selecting for RFI, thereby explaining why low pRFI cows were smaller in size.

Our finding of greater growth in calves from high pRFI cows contrasts previous studies identifying RFI as being independent of body size and growth (Castro Bullet et al. 2007, Fitzsimmons et al. 2013; Koch et al. 1963, Kennedy et al. 1993, Crews 2005). Castro Bulle et al. (2007) examined the performance of high and low RFI steers, with no differences in initial body weight, final body weight or ADG. Although steer growth was not different, low RFI animals had lower DMI (Castro Bulle et al. 2007). Similar results were noted by Fitzsimmons et al. (2013) with no differences in initial weight, final weight and ADG between high and low RFI heifers, despite a 15% difference in DMI. As our study was done while grazing open grassland, the reason for the improved calf growth from high pRFI cows remains unknown, but could reflect differences in foraging conditions and cow/calf grazing behavior. Sires in the current study could also have contributed to observed differences in calf performance. Weaning weight EPDs generated by the Canadian Hereford Association of the two high RFI bulls were +26.3 (accuracy=0.42) and +35.0 (0.34), while the two low RFI bulls had weaning weight EPDs of +39.0 (0.46) and +34.1 (0.34). Notably, all bulls had weaning weight EPDs lower than the Hereford breed average of +48.9, suggesting differences in sire performance and growth potential were unlikely to contribute significantly to differences in calf weaning weight and growth.

MBVs are often used to measure the value of an animal for breeding purposes (Dekkers and Hospital 2002), such as offspring performance potential. In this study, MBVs of cows were used to predict progeny production metrics, as well as determine groupings of high, medium and low pRFI cows in an attempt to create efficient and inefficient cow-calf pairs. It is possible that data in the reference population used to assign MBVs may not have accurately accounted for phenotypes in mature, pregnant or lactating cows foraging on open pasture, especially considering that phenotypic RFI values (i.e. those used in the reference population) were collected from growing cattle, and often under drylot conditions (Basarab et al. 2003, 2011), rather than from gestating or lactating mature cows on open range. Indeed, RFI observations of growing cattle may not correspond to the RFI of the same animals in later life stages, and this could account for the difference in age-dependent cow traits relative to pRFI. Older cows that have fully completed their primary growth may be more likely to partition energy to lactation and weight/backfat gain in a manner that is relevant to cow/calf production. Ongoing energy expenditure and deposits influence differences in RFI, something that is not considered when evaluating RFI in the reference population of yearling (i.e. growing) cattle, and hence, RFI models should be modified to better account for the energy sinks of productive, lactating females (Black et al. 2013). Morgan et al. (2010) reported a moderate correlation between RFI of growing heifers and these same animals as gestating cows ($r=0.51$, $P<0.01$). This suggests RFI values may re-rank in different phases of the production cycle, with similar results found by Durunna et al. (2011), particularly when diets changed. Differing diets may have contributed to the lack of accuracy in the current study as cows were on low-energy, forage-based diets, while cattle in the reference population were fed energy dense diets in drylot. Free range cattle in this study would also be more susceptible to energy expenditure during travel and search for forage.

Prediction accuracy may also have been compromised as cattle in the current study were cross-breds (primarily Hereford, but variably combined with Angus), susceptible to hybrid vigor, and breed composition of each cow was not fully known. Cundiff et al. (1992) reported maternal heterosis increased weaning weights of progeny over all ages, including when comparing Hereford-Angus, relative to purebreds from each breed. Although not tested here, it is possible that cows from the high pRFI group may have had greater heterosis, increasing growth and calf weights. As explained by Kizilkaya et al. (2010), training in purebred cattle may not affect the accuracy of predictions made in crossbred cattle, suggesting breed composition, and therefore hybrid vigor, effected calves instead; this could warrant further testing using the project genotypes obtained in this study. While other dam characteristics (e.g. milk production) were not measured here, they are unlikely to reflect pRFI, because while milk production alters calf growth (Meyer et al. 1994), milk production is not related to RFI (Arthur et al.

2005; Crowley et al. 2011; Black et al. 2013), with similar results for milk quality (Black et al. 2013). This suggests that all calves (i.e. high, medium and low pRFI calves) should have received a similar plane of nutrition prior to weaning.

Finally, differences in weaning weight could have resulted as a by-product of the process of extensively selecting for RFI within cow-calf herds on pasture. Bailey et al. (2015) studied cattle grazing distributions and their relationship with genetic markers, reporting a significant proportion of grazing behavior (i.e. terrain use) phenotypes were associated with markers on 5 chromosomes across the genome. Differences in terrain can affect the type and quality of forages available (Holechek 1988), meaning that cattle genetically predisposed to selecting differences in terrain may experience differences in feed nutritional quality, and subsequent intake. In the current study, topography was much less pronounced than in the study by Bailey et al. (2015), and although terrain indices were included as a factor in the assessment of cow performance, terrain did not emerge as a significant response factor.

2.2.2. Cow activity on open range

Across all cattle examined, 95% of observations for cows within the various study paddocks were within 263 m of water, suggesting a tendency to largely utilize areas around available drinking water (Table 4), which is well below those guidelines often used to allocate forage in arid rangelands (i.e. up to 1.6 km). This short distance to water likely reflects the relatively high productivity of this sub-irrigated environment (Table 5). Cows occupied areas with mean temperatures of less than 22^{o}C during the summer/fall period. It was also noteworthy that herbage values from plant communities the cows occupied were typically above 9% protein and below 35% ADF.

In contrast to expectations, estimates of pRFI were found to be independent of the various environmental conditions (distance to water, temperature, forage availability and quality) cows were subject to while on pasture based on MANOVA (P=0.68), with univariate analyses showing similar indifferences. Values of pRFI were found to be positively related to the 205 weaning weight of calves (Fig. 4). Similarly, few measures of cow/calf productivity were ultimately found to be related to the environmental metrics individual cows were exposed to, suggesting productivity in this open-range environment was only weakly coupled to resource availability (water, forage quantity and quality) as well as associated conditions (topography, shrub cover, ambient temperature), or that the sample size of 27 cows was insufficient to parse out these effects. As previous studies with GPS collars have used far fewer animals than this (e.g. Kaufmann et al. 2013), it is more likely that as cattle were exposed to a variety of environments throughout the grazing season (i.e. dryland, wetland, and tame pastures of various sizes and states of vegetative development) that changing conditions allowed cows to optimize their productivity.

Among the few effects that were found, calf 205 day adjusted weaning weights increased with herb biomass selected by the dam (Fig. 5). Although the mechanism for this is unclear, the use of more productive areas may have increased forage intake, improved lactation, and hence led to greater calf growth. Increased occupation of areas far from water were also associated with increased backfat gain in cows (Fig. 6). While areas around water are generally productive, they also were often represented by an abundance of weedy vegetation, including halophytic plant species, and while convenient to achieve gut fill, this vegetation may have led to reduced production, and warrants further testing.

RFI group, both alone and in combination with season of grazing, did not contribute to cow movement rates on native pasture ($P \geq 0.21$, Table 6). Movement rates were effected by season of grazing ($P<0.0001$): movement rates were highest in the early season, decreased in mid-summer, and fell further in fall (Fig. 7). Movement rates in native pasture did not vary with pasture size (P=0.89). Season of grazing, both alone and in combination with RFI group, effected the frequency of lying bouts $P \leq 0.0003$). Cows had the greatest frequency of lying bouts prior to July 23 (Fig. 8). When the interaction of grazing season and RFI was explored, only high RFI animals had greater lying bouts in the early season compared to mid and late season (Fig. 9), with no differences between RFI groups within a season ($P \geq 0.08$), nor in the low RFI group between seasons ($P \geq 0.15$). Pasture size was a significant covariate on lying bout ($P<0.0001$), with lying bouts more abundant as pasture size increased (Fig. 10). Lying time was not altered by pRFI, alone or in combination with season of grazing, but was altered by season of grazing (P=0.004). Cattle spent more time in mid-summer lying down than early and later on (Fig. 11). Lying time again varied with pasture size (P<0.0001), accounting for 27% of variation in lying time, which declined with pasture size (Fig. 12), suggesting cattle spent more time searching for forage therein (and in the process, taking frequent breaks to rest).

When assessed across all pasture types, RFI group once again did not affect cow movement rate, nor any other behavioral response (Table 7). Pasture type and season of grazing, both individually and their two-way interaction, altered movement rates and lying bout frequency (P≤0.05; Fig. 13). In the early season, cattle had lower movement rates in wetlands than other pasture types, but this disappeared in mid-summer. Movement rates within wetland pastures did not vary with timing (P=0.99). Cattle had a greater frequency of lying bouts early in the year (P<0.0001), and within the early season, lay down more often in tame pastures (Fig. 14). Similarly, lying bout frequency was higher in wetlands than native pastures in mid-summer (Fig. 14), and could reflect high quality forage rapid passage rates in these favorable moisture environments, in turn necessitating more frequent changes between feeding and ruminating. Pasture size contributed to lying bout frequency in the ANOVA (P=0.007, Table 7), but regression showed pasture size explained only 1% of the variation in lying bout frequency. Although pasture type altered lying time, no post-hoc differences were evident (P≥0.13). Native pastures had greatest lying time, followed by tame and cultivated pastures (31, 29, and 26%); lower quality in more arid dryland pastures would be expected to slow passage rates and prolong rumination periods. Simple regressions of cow movement rate against the forage metrics revealed that forb ADF, forb protein, grass protein, and forb biomass, were all related to cow movement rate (min P<0.05), though these variables explained little (1-5%) of the variation in movement rate. Forb protein and biomass accounted for a cow lying time in regression models (both P<0.001), explaining 9 and 4%, respectively. Regression of lying bout was related to forb ADF, protein and biomass (min P<0.01), accounting for 2, 2, and 7% of the variation in lying bout frequency, respectively.

Overall, we found limited differences in cow activity in relation to pRFI. Although it is possible that animals with divergent MBVs for RFI do not express strong activity differences, the discontinuous data collected by the pedometers, particularly with the need to link to reader stations, may have caused some data loss. While the distance travelled and the destination for an animal cannot be quantified using pedometer data alone, we were nevertheless able to get a sense of cow activity on these pastures, including variation in activity among pastures types and grazing seasons.

We did not find differences among RFI groups in terms of the frequency or duration of time animals spent lying down. These findings indicate that either the MBVs for RFI do not reflect differences in cattle resting activity, or that resting among cattle does not differ in relation to genetic markers for this trait. Alternatively, our range of pRFI values in the cows studied may have been too low to effectively test for differences in resting activity. All animals had a similar frequency and duration of lying time early and late in the grazing season. Early season pastures were characterized by low to moderate grass biomass of excellent quality (high protein and low fibre) than subsequent seasons (Table 5), conditions that may lead to cattle spending longer times searching for abundant feed. Spring also coincides with the highest protein and energy demands of cattle when supporting lactation and post-winter recovery (National Research Council 1996). As forage quality and quantity reach optimum levels in mid-summer, animals may then need to travel less to find favorable feed. This period is essential for regaining fat stores for maintaining pregnancy and body condition through the ensuing winter, and lower movement rates would support more energy allocation to this goal.

Fall generally coincides with high grass biomass, but less favorable protein and fibre levels. Lower movement rates then could represent reductions in search time as animals instead strive to achieve gut fill (Bailey et al. 1996; Demment and Greenwood 1988). The consequence of this is longer rumination times to process forage, including that with lower digestibility. While lying time and rumination are correlated (Lofgreen et al. 1957), we did not see increased lying times compared to seasons of good forage quality. Heterogeneity in rangeland vegetation may create challenges for herbivores seeking to optimize nutrient intake, but also dampens the temporal changes in forage quantity and quality cattle are subject to, and extends the period over which quality feed is available (Rittenhouse and Bailey 1996). Bailey (2005) stated that cattle are better able to select high quality diets as the growing season progresses when there are a variety of forages in different phenological states. The ability to select for higher quality diets in larger pastures with increased vegetation diversity may also explain the findings of an increased frequency of lying bouts and decreased lying time with pasture size. The contrasting nature of these responses suggests animals may be getting up and down more often to explore more territory in search of ideal forage.

The pattern of increased cattle activity during the early grazing season held true particularly for tame pastures. Spring is a time of high energy demand so animals are likely spending time exploring pastures looking for high quality forage, resting for a short time to digest, and then searching again. As tame pastures in the mid-season grazing period were revisited from the early season, regrowth here was of good quality and animals may have had to move less to find high quality feed. There was no activity difference between seasonal sampling times for wetlands, and this could have been because water and quality feed were never lacking. Activity within the wetlands was lower than either the tame or native pastures - with the exception of mid-season movement - and this further supported the hypothesis that good quality forage was easily found. Bailey (1995) found that cattle in areas with heterogeneous patches of vegetation selected areas with better quality feed regardless of biomass available, and developed sufficient preference for these areas that they were willing to travel back to them repeatedly. In contrast, within homogeneous areas cows moved between patches more often and spent more time at the boundary of patches to minimize the distance travelled for variety. Kaufmann et al. (2013) found that at the patch level forage quantity (and to a lesser extent quality) determined cattle selection.

Native grasslands of the Mattheis Ranch do have subtle, but important variability in topography, which may be another reason for our results. Kaufmann et al. (2013) found that slope negatively affected cattle selection in montane habitats. Bailey et al. (2004) concluded that animals within the same herd utilized different portions of the landscape, with some animals choosing to spend more time climbing to higher elevations and others remaining on low-lying flatter areas. This vein of research has progressed most recently to finding specific markers within the bovine genome that together explain up to 47% of the phenotypic variation in terrain use indices (Bailey et al. 2015).

2.2.3. Cow diet and linkages to production metrics

Fecal histology revealed that grasses and sedges accounted for the majority of forage items in cow diets (>96%; Table 8), while forbs and shrubs accounted for less than 1% each. Forage items found in trace amounts included cattail, Flodmann's thistle, lichen and mushroom. These results are consistent with the notion that beef cattle are bulk feeders and prefer feeding on graminoid vegetation. Dominant plant species in the diet (those over 10% each) included upland sedges, followed by sand grass, western wheatgrass, blue grama grass, and needle & thread; combined, these 5 plant species/groups comprised 79% of average cow diets.

Season of sampling strongly affected the abundance of all main dietary components (Table 9), including grasses, sedges, forb+equisetum, and woody vegetation. Cows grazing on native mixedgrass prairie consumed a third less grasses in fall than summer, with a shift towards sedges instead (Table 10). Cattle also increased the abundance of broadleaf vegetation (forbs, equisetum, and woody species) within the diet, although these remained at 5% or less of the diet throughout the study (Table 10). Further examination of the data indicated that cattle preferred to utilize C_4 (warm-season) vegetation in summer compared to fall (falling to less than half in the latter), while increasing their use of introduced vegetation. The latter also coincided with a general increase in the number of forage items found in the diet of cattle during fall, with a parallel increase in dietary diversity (Table 10). These findings indicate that under favorable foraging conditions (i.e. abundant quantity and quality in July), cattle had a simple diet, preferring to feed on a select graminoids. However, when dry conditions prevailed in late summer, cattle diversified their diet to include more broadleaf plants and sedges.

Cattle diets differed between cows with contrasting pRFI, but only for select plant groupings (Table 9). Cows with low pRFI had a reduced abundance of introduced vegetation (4.4±0.6) in their diet (P=0.005) compared to high pRFI cows (7.2±0.6), and lower associated diversity as well (low pRFI=0.833±0.011 vs high pRFI=0.878±0.011; P=0.01). Dietary richness was impacted by a season*pRFI effect, whereby low pRFI cows tended to have lower richness in summer (low=11.5 vs high=12.2), but not fall (low=14.6 vs high=13.4). A similar interaction of season*pRFI was evident for grass, sedge and forb+equisetum in the diet (Table 9), whereby low pRFI cows demonstrated a greater shift away from grasses and towards alternative food items, specifically sedges and forbs (Fig. 15). This result suggests low RFI cattle may have greater dietary plasticity over time, particularly as foraging conditions change.

NMDS ordination of dietary data resulted in a 2-dimensional solution with final stress of 10.7 (Fig. 16). The first and second axes accounted for 78.1 and 15.8% of variance in dietary data. While RFI did not demonstrate any clear pattern in relation to either axes (Axis 1, r=-0.036; Axis 2, r=0.160), season of grazing demonstrated strong segregation on both axis 1 (r=-0.867) and axis 2 (r=0.592). Species overlay on the ordination indicated that a high diversity of species were associated with fall grazing (Fig. 16), which included Agrostis, Artemisia, sedges, Hordeum, Koeleria, Muhlenbergia, Juncas spp, and the introduced grass Poa pratensis (Table 11). In contrast, the warm season grasses Bouteloua gracilis and Calamovilfa longifolia, along with Distichlis, Eleocharis, and Pascopyrum, were associated with July grazing. Only a single species (Poa pratensis) was associated with pRFI, being preferred in the diets of less efficient (high pRFI) cows. These findings highlight the key role of dietary selection by cattle, particularly in relation to seasonal foraging conditions.

Despite limited differences at the species level, cows with greater pRFI were associated with greater dietary diversity, including the abundance of introduced plant species (Fig. 17). Conversely, cows hypothesized to have greater efficiency had reduced diversity (and reduced introduced vegetation), suggesting cattle that perform better may limit their diet (at least in theory) to forage items that optimize their performance. Finally, measures of animal production indicated that cow and calf weight gain demonstrated opposing relationships with the amount of C_4 (warm-season) vegetation in the maternal diet (Fig. 18); while cows gained more weight with greater C_4 in the diet, their calves had lower weaning weights. The opposite occurred for cows with low dietary C_4 vegetation. This trend is notable and suggests that cattle selecting more warm-season grass were better able to maintain themselves, but were less able to support their offspring. This pattern raises interesting questions as to what inherently regulates C_4 selection in the diet (as all cows were exposed to the same pastures in this study), and into the morpho-physiological mechanisms regulating the trade-off between cow and calf gain, and specifically whether cattle could be selected to favor C_3 over C_4 vegetation and thereby maintain greater calf growth. For example, as C_3 (cool-season) vegetation is typically higher in forage quality (protein and digestibility), this may explain the greater calf performance, although it does not explain why associated cow performance did not mirror its calf, and would require the assessment of genetic EPDs for growth from calf genotypes.

2.2.4. DMI and methane assessment of heifers in drylot

Heifers from cows with high pRFI (n=29) had an average RFI_{FAT} value in drylot of 0.37 (SD=0.44) and ranged from 0.032 to 1.95, while heifers from low pRFI cows (n=28) had an average RFI_{FAT} of -0.39 (SD=0.26) and ranged from -1.05 to -0.04. High RFI_{FAT} heifers consumed 14% more DM on a daily basis (Tables 14, 15). Despite this, heifer ADG, FCR, initial and final trial weights, and metabolic mid-feeding period weight, were similar (Table 15). The frequency of daily feeding events (events day^{-1}) was also greater in high RFI_{FAT} heifers (P=0.03), though total feeding duration (min day^{-1}) did not differ between groups. Daily feeding frequencies for the high and low RFI_{FAT} heifers were 127 (SE=5.45) and 101 (SE=5.56) events day^{-1}, respectively, while total daily feeding times were 132.8 (SE=4.41) and 135.5 (SE=4.41) min day^{-1} for high and low RFI_{FAT} heifers, respectively. Linear regression of average daily

DMI and phenotypic RFI demonstrated a positive relationship (R^2=0.41; P<0.0001), with heifers born from low pRFI cows consuming less silage than those from high pRFI cows (Fig. 19).

Low RFI_{FAT} heifers consumed less feed throughout the course of the 76-day intake trial (Table 15). Previous studies report low RFI cattle consume less than high RFI cattle without compromising growth (Herd et al. 2014), which is consistent with this study as DMI was reduced but did not alter heifer size and ADG. The significant relationship between RFI_{FAT} and daily DMI is also consistent with previous studies (Lancaster et al. 2009; Kelly et al. 2010; Lawrence et al. 2012; Fitzsimmons et al. 2013). Fitzsimmons et al. (2013) also tested replacement heifers on forage or grass silage based diets, but grouped DMI values by RFI rather than RFI_{FAT}. Fitzsimmons et al. (2013) reported a correlation of 0.63 (P<0.01), just below that of the current study (r=0.66, P<0.0001); the stronger relationship in the current study may be due to a larger sample size (n=57 vs 22 heifers). Lawrence et al. (2012) identified an even stronger relationship between RFI and DMI (R^2=0.66, P<0.001) of growing heifers consuming a grass silage diet.

Despite differences in DMI between groups of high and low RFI_{FAT} heifers, most performance metrics did not differ between the two groups: initial and mid-period weight, as well as metabolic mid-period weight, were similar between high and low RFI_{FAT} heifers (Table 15), with only final weights marginally greater (P=0.054) in high RFI_{FAT} animals. Additionally, ADG and end-of-trial backfat measures were similar between groups. Part of the variation in heifer weights could be attributed age, which had a moderate effect on initial weight, final weight, mid-period weight, and metabolic midweight (Table 14), and is consistent with previous studies (Basarab et al. 2003; Nkrumah et al. 2004; Kelly et al. 2011; Fitzsimmons et al. 2013). High and low RFI bulls tested for individual feed intake on a concentrate diet with access to grass hay, had similar initial and final body weights, along with similar ADG and metabolic body weight (Kelly et al. 2011). Bulls only differed in rib fat and muscle depth, wherein high RFI bulls had greater muscle depth and greater backfat (Kelly et al. 2011). However, the latter study did not adjust RFI for backfat, which may contribute to the inconsistent response with the current study. Our results are similar to Fitzsimmons et al. (2013) where backfat thickness, initial body weight, final body weight, and ADG of high and low RFI heifers on a grass silage diet did not differ relative to RFI.

Overall CH_4 production was similar between high and low RFI_{FAT} heifers (Tables 16, 17), but average CO_2 production was lower for low RFI_{FAT} heifers (Table 17); these results occurred despite low RFI heifers having greater CH_4 and CO_2 yield in drylot (Table 17). Although RFI_{FAT} group did not effect CH_4 emissions, day of sampling and time of day, together with the interaction between RFI_{FAT} group and time, altered CH_4 production, while CO_2 production was affected by the time heifers spent at the GEMS unit (Table 16). Both high and low RFI_{FAT} heifers produced the least CH_4 from 2100-2400 hr, with similar mean values of 128.7 g $head^{-1}$ (SD=2.5) and 129.6 g $head^{-1}$ (SD=2.5), respectively (P>0.05) (Fig. 20). Both groups produced the most CH_4 between 600-900 hr, with high RFI_{FAT} heifers producing 162.9 g $head^{-1}$ (SD=2.5) and low RFI_{FAT} heifers producing 164.9 g $head^{-1}$ (SD=2.5). Linear regression of heifer actual phenotypic RFI_{FAT} with CH_4 production showed no relationship (R^2=0.002, P=0.77; Fig. 21), although a positive relationship (R^2=0.27, P<0.001) was evident between daily DMI and daily CH_4 production (Fig. 22). Linear regressions of CH_4 yield showed a negative relationship (R^2=0.44, P<0.0001) between RFI_{FAT} and CH_4 yield (Fig. 23), as well as a negative relationship (R^2=0.28, P<0.001) between CH_4 yield and dry matter intake (Fig. 24).

Although high and low RFI_{FAT} heifers had similar CH_4 production, the interaction between RFI_{FAT} and day of sampling suggested that CH_4 differed between RFI_{FAT} groups only on certain days. Differences in drylot CH_4 production were inconsistent with previous studies where high RFI cattle had greater CH_4 production (Nkrumah et al. 2006; Hegarty et al. 2007; Jones et al. 2011; Fitzsimmons et al. 2013). Fitzsimmons et al. (2013) reported a difference in DMI and CH_4 between high and low cohorts using much smaller sample sizes (7-8 per group), and thus, sample size in the current study (n=42) should not have affected the current results. While the method used to measure CH_4 emissions in the current study has seldom been reported, it should be noted that it was different from the method used by Fitzsimmons et al. (2013) (i.e. GEMS rather than SF_6 tracer technique). Manafiazar et al. (2017) concluded that the GEMS unit was a credible and repeatable way in which emissions could be monitored, and as such it was unlikely that the method of measuring CH_4 emissions affected the results of the current study.

Results from the current study are more directly aligned with the results from Waghorn and Hegarty (2011) and McDonnell et al. (2016), in which absolute CH_4 production remained similar in high and low RFI animals. Waghorn and Hegarty (2011) analyzed CH_4 production from eight high and eight low RFI dairy cows on a forage based diet, while McDonnell et al. (2016) analyzed CH_4 emissions of 14 high and 14 low RFI cattle on various diets, including pasture, grass silage and a total mixed ration. McDonnell found CH_4 production was greatest when cattle consumed the total mixed ration and remained lowest when cattle were on pasture. Furthermore, CH_4 was only correlated with daily DMI when cattle were on pasture (r=0.42, P<0.05), and there was no correlation between RFI and CH_4 (McDonnell et al. 2016), as seen in the current study. McDonnell et al. (2016) reported that errors associated with the SF_6 tracer technique used to measure enteric CH_4 could have influenced the results. As reported by Waghorn and Hegarty (2011), no differences in CH_4 existed between high and low RFI cows (P=0.09), a result which was reportedly associated with the higher CH_4 yields of low RFI cows.

Low RFI_{FAT} heifers had greater CH_4 yields in drylot when compared to high RFI_{FAT} heifers. Previous research related to CH_4 yield is conflicting, as some studies report no differences in CH_4 yield between high and low RFI heifers on grass silage diets (Fitzsimmons et al. 2013), nor in steers fed concentrate diets (Hegarty et al. 2007). In contrast, McDonnell et al. (2016) and Waghorn and Hegarty (2011) reported low RFI cattle had greater CH_4 yields, though these differences were only greater in the study by McDonnell et al. (2016). Methane yields relative to RFI_{FAT} in the current study paralleled the latter investigations, as methane yield was negatively correlated with RFI_{FAT} (r=-0.66, P<0.0001), and also negatively correlated with DMI (r=-0.53, P<0.001).

Although not examined here, it is possible that low RFI_{FAT} heifers had greater CH_4 yield due to greater digestibility and greater rumen retention times, resulting in more CH_4 produced per unit feed consumed. McDonnell et al. (2016) examined apparent total tract digestibility of organic matter and gross energy, finding low RFI animals had greater organic matter digestibility (P=0.027), and slightly greater gross energy digestibility, which they concluded could increase methanogens (and thus CH_4 production). Along with differences in digestibility, differences in feed retention time could contribute to differences in CH_4 yield, especially considering that increases in digestibility are often directly associated with rumen retention time (Waghorn and Hegarty 2011). Greater dietary digestibility could also explain the similar CH_4 production between RFI treatments; although low RFI_{FAT} heifers had lower DMI, they produced more CH_4 per unit DMI.

Methane aside, our finding that high RFI heifers produced more CO_2 in drylot than low RFI heifers suggests selecting for low RFI cattle could result in reduced greenhouse gas emissions associated with CO_2, potentially offsetting a portion of the increased CH_4 yield. As identified in an earlier study, cattle that consume less feed (i.e. low RFI cattle) produce fewer greenhouse gases, with one of those gases being CO_2 (Beauchemin et al. 2010). Although CO_2 has 23 times less the global warming potential of CH_4, it still influences overall GHG emission levels due to its relative abundance in the environment (including ~35x the relative production emissions of CH_4 by heifers in this study).

2.2.5. DMI and methane assessment of heifers on pasture

High and low RFI_{FAT} heifers had an average RFI_{FAT} value of 0.52 (SD=0.49) and -0.59 (SD=0.30), respectively (P<0.0001). High and low RFI_{FAT} heifers were 427 (SD=20.9) and 442 (SD=6.7) days of age, respectively (P=0.053). High RFI_{FAT} heifers consumed 8.13 kg DM day^{-1} (SD=1.71) while low RFI_{FAT} heifers consumed 7.88 kg DM day^{-1} (SD=1.30), but did not differ significantly, along with most measures of performance (Tables 20, 21). The lone difference was in final backfat thickness, with high RFI_{FAT} heifers having more backfat. Regression of phenotypic RFI_{FAT} values and individual DMI revealed a significant relationship (R^2=0.13, P=0.006), though regression of DMI and RFI_{FAT} plotted for each day showed marked differences among heifers, as well as differences from day to day (Fig. 30).

Time of day altered CH_4 production on a g day^{-1} basis, as well as standardized CH_4 production (Tables 22, 23). Sampling day also altered CH_4 yield (g kg^{-1} DMI). Although high RFI_{FAT} heifers produced more CH_4 (203.3±27.5SD g $head^{-1}$ day^{-1}), it was not significantly greater than the low RFI_{FAT} heifers (195.6±27.5SD g $head^{-1}$ day^{-1}). Standardized CH_4 production and CH_4 yield were also similar between high and low RFI_{FAT} heifers. Diurnal patterns of CH_4 production (Fig. 31) revealed that CH_4 production was greatest for all heifers between 9 am and noon, right after heifers were given access to fresh forage, and then declined to a minimum the next day between 6 and 9 am; however, CH_4 production differed between high and low RFI_{FAT} heifers only between midnight and 3 am (Fig. 31).

Our results showed DMI on pasture did not differ between high and low RFI_{FAT} heifers, in contrast to results in drylot. In general, research on DMI on pasture is limited, though Manafiazar et al. (2015) found lower DMI in low RFI_{FAT} heifers compared to high RFI_{FAT} heifers using alkane tracers. The latter study found a difference of 0.46 kg DM day^{-1} as opposed to a difference of 0.25 kg DM day^{-1} in the current study, and could reflect a larger number of heifers tested (>100 per group, vs 8 here). Daily DMI relative to RFI may also have been more detectable if observations were collected over a longer time (vs 6 days), with daily fluctuations affecting the accuracy of DMI estimates. Drylot DMI trials run for 35+ days to ensure accuracy (Wang et al. 2006), and reduces variation within and between animals.

The use of n-alkanes to predict DMI could have affected DMI accuracy. Several studies (Dove and Mayes 1991; Mayes et al. 1986; Moshtaghi-Nia and Wittenberg 2002) use dosed and natural alkanes to report DMI estimates of beef cattle on pasture; however, estimations were only accurate when cattle consumed the same forage. The accuracy of DMI values could have been affected by consumption of plants other than oats with differing alkane profiles, such as weeds (Dove and Mayes 1991). Although the forage oats had been sprayed to eliminate broadleaf weeds and help ensure a monoculture, some weeds were still present, and could ultimately have affected DMI, including in relation to RFI_{FAT}.

CH_4 production did not differ between RFI_{FAT} groups. Few studies have used the OP-FTIR method to monitor CH_4 emissions of cattle with differing RFI values (Jones et al. 2011); instead, many have used the SF_6 tracer method on pasture. Jones et al. (2011) monitored CH_4 emissions of high and low RFI beef cows feeding on high and low quality annual Mediterranean pastures in Australia, also reporting no difference in CH_4 emissions between RFI groups when consuming low quality forage, a result that was likely driven by low crude protein, which were too low to meet nitrogen requirements of rumen microbes (Kerley and Lardy 2007). However, when cows were grazing high quality pastures, there was a difference in CH_4 emissions between high and low RFI groups (Jones et al. 2011). As forage quality was high in the current study, the lack of a difference in methane production likely reflects similar DMI, as these are inter-dependent (Blaxter and Clapperton 1965; Johnson and Johnson 1995; Grainger et al. 2007). Low observation numbers may also have limited the detection of methane differences. A total of 101, 15-min observation periods over a six day period, were available, were considered to be quality observations (i.e. not affected by weather, turbulence or winds moving parallel to the grazing strips). A minimum of 100 quality observations are typically needed. Due to wind and lightning storms affecting most of the six days of the observation period, the OP-FTIR unit was shut down several times throughout the trial. System shut-down reduced the number of 15-min observations, limiting the overall number of quality observations collected. Although additional grazing strips were fenced off, CH_4 observations could not be extended due to time constraints on equipment use. While an increased number of CH_4 observations over a longer period could have increased the likelihood for more significant results, Jones et al. (2011) also collected CH_4 observations for six consecutive days, 24 hr each day, and led to significant effects.

Our diurnal patterns of CH_4 production were similar to Jones et al. (2011), who found patterns of CH_4 emissions were highly variable for high and low RFI_{FAT} cattle on high and low quality forages, with peak standardized CH_4 production (g kg BW^{-1} day^{-1}) occurring just before 12 pm on most days. In the current study, CH_4 production (g $head^{-1}$ $hour^{-1}$) for both high and low RFI_{FAT} heifers was greatest between 9 am and 12 pm, shortly after entry to fresh pasture, suggesting abundant methanogenesis with access to high quality forage. In contrast, CH_4 production was lower in low RFI_{FAT} compared to their high RFI_{FAT} counterparts 15 hr later, and well after satiation with fresh forage. This pattern may reflect a difference in longer-term post-ingestive fermentation of fresh forage consumed in the middle of the previous day right after pasture entry. For example, this may reflect differences in the efficiency of feed breakdown by microbes in the rumen of animals with differing RFI as long as 15-18 hr after consumption, and warrants further investigation.

Previous studies on CH_4 emissions using the SF_6 tracer method are limited to cattle in a drylot environment (Hegarty et al. 2007; Fitzsimmons et al. 2013), and are therefore not representative of the current study. Fitzsimmons et al. (2013) monitored CH_4 emissions of heifers selected for divergent RFI while on a grass silage diet, which may be more representative of the current study than results from Hegarty et al. (2007) as they were collected from steers on concentrate-based diets. Fitzsimmons et al. (2013) reported different results than those of the current study as there was a significant difference in both CH_4 production and DMI, results of which were not significantly different in the current study. It is likely that the environment, and method of CH_4 measurement, resulted in inconsistent results, signifying the need for further research of DMI and associated CH_4 emissions by beef cattle grazing on pasture.

2.2.6. Metabolomics

Preliminary statistical analyses of the profiles showed some association of metabolites with pRFI in serum from cows and calves on pasture, and this correlation was more apparent in the case of cows. However, there was relatively small overlap between the metabolites in each case. Further analysis is required to determine if these results provide any utility in terms of predicting RFI, and to compare these results with those from heifers in feedlot. L-glutamine was identified as the most important metabolite differentiating the two groups in the case of the cows. This metabolite is the most prevalent amino acid in the bloodstream and considered an important component for nitrogen transfer between tissues, development of intestines, and the immune system, especially at times of inflammation (Ribeiro et al. 2015). Thirteen other metabolites differed between the high and low pRFI groups. Additional literature mining is required to discover the biological networks and identify the potential biochemical pathways associated with the metabolites associated with the trait and their relevance to feed efficiency. Further work is required in terms of comparison between the different samples collected, including between the cow/calf pairs and whether there is any impact of transport on the blood metabolome, which may relate to differences in stress response.

2.3. Tables and Figures

2.3.1. Cow/calf production metrics while grazing on open pasture

Table 1. Summary ANOVA results on the cow and calf production metrics for each of the high, medium and low RFI cows examined during the 2015 grazing season.

Calf Production Metrics

Factor	Birth Weight F-Value	Birth Weight P-Value	Average Daily Gain F-Value	Average Daily Gain P-Value
Cow Age (cov I)	0.09	0.77	11.6	0.0008
Calf Sex (cov II)	18.6	< 0.0001	8.64	0.004
RFI Category	1.71	0.18	8.40	0.0003

Factor	Weaning Weight F-Value	Weaning Weight P-Value	205-Day Weaning Weight F-Value	205-Day Weaning Weight P-Value	Growth F-Value	Growth P-Value
Cow Age (cov I)	12.4	0.0005	0.56	0.45	0.62	0.43
Calf Age (cov II)	93.4	< 0.0001	3.80	0.05	4.98	0.03
RFI Category	5.70	0.0038	7.37	0.0008	8.91	0.0002

Cow Production Metrics

Factor	Change in Weight F-Value	Change in Weight P-Value	Spring Weight F-Value	Spring Weight P-Value	Fall Weight F-Value	Fall Weight P-Value
Cow Age	6.92	0.078	29.4	< 0.0001	8.66	0.004
RFI Category	1.17	0.23	5.13	0.006	12.2	< 0.0001
Age* RFI	1.96	0.14	1.21	0.301	6.59	0.002

Factor	Change in Backfat F-Value	Change in Backfat P-Value	Spring Backfat F-Value	Spring Backfat P-Value	Fall Backfat F-Value	Fall Backfat P-Value
Cow Age	0.61	0.44	1.65	0.199	1.35	0.247
RFI Category	1.22	0.30	0.80	0.449	2.25	0.107
Age*RFI	1.22	0.30	0.79	0.453	2.33	0.099

Table 2. Calf production metrics for each of the high, medium and low pRFI cow groups assessed during the 2015 grazing season.

	Least Square Means	SE
Birth Weights (kg)		
High pRFI	37.9[a]	0.8
Medium pRFI	38.8[a]	0.4
Low pRFI	40.3[a]	1.0
Weaning Weights (kg)		
High pRFI	188.4[a]	3.4
Medium pRFI	177.7[b]	1.5
Low pRFI	170.5[b]	4.1
205-day Adjusted Weaning Weights (kg)		
High pRFI	229.7[a]	4.2
Medium pRFI	214.8[b]	1.9
Low pRFI	204.5[b]	4.9
Growth (kg)		
High pRFI	191.4[a]	4.2
Medium pRFI	176.1[b]	1.9
Low pRFI	164.5[b]	4.9
Average Daily Gain (kg)		
High pRFI	0.87[a]	0.02
Medium pRFI	0.80[b]	0.01
Low pRFI	0.75[b]	0.02

Means within a response variable with different letters differ ($P<0.05$).

Table 3. Production metrics for each of the high, medium and low pRFI cow groups assessed during the 2015 grazing season.

	Least Square Means	SE
Spring Weight (kg)		
High pRFI	518.0[a]	6.3
Medium pRFI	487.0[b]	3.8
Low pRFI	495.0[b]	7.4
Fall Weight (kg)		
High pRFI	566.4[a]	7.2
Medium pRFI	537.6[b]	4.3
Low pRFI	522.8[b]	8.4
Change in Cow Weight (kg)		
High pRFI	45.4[a]	4.2
Medium pRFI	51.8[a]	2.4
Low pRFI	44.7[a]	4.6
Spring Backfat (mm)		
High pRFI	1.21[a]	0.10
Medium pRFI	1.24[a]	0.06
Low pRFI	1.26[a]	0.11
Fall Backfat (mm)		
High pRFI	2.28[a]	0.17
Medium pRFI	2.14[a]	0.10
Low pRFI	2.11[a]	0.20
Change in Cow Backfat (mm)		
High pRFI	0.90[a]	0.10
Medium pRFI	0.83[a]	0.06
Low pRFI	0.91[a]	0.10

Means within a response variable with different superscripts differ ($P<0.05$).

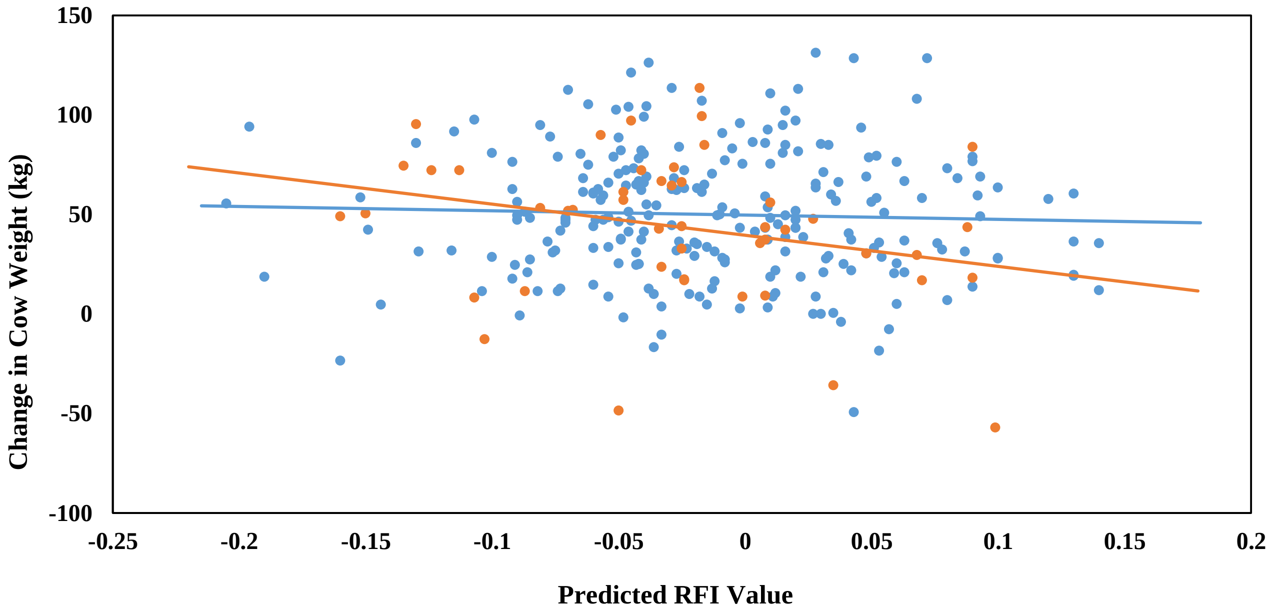


Fig. 1. Regression of the change in cow weight (kg) against pRFI, with cows grouped by age. Blue points represent cows younger than 5 years of age, and orange points represent cows that were 5 years of age and older. Corresponding lines represent the linear relationships of the different age groups. Younger cows: y = 49.64 – 21.55x, R^2=0.002, Adj. R^2=-0.0023, P=0.51. Older cows: y = 39.56–156.49x, R^2=0.071, Adj. R^2=0.055, P=0.061

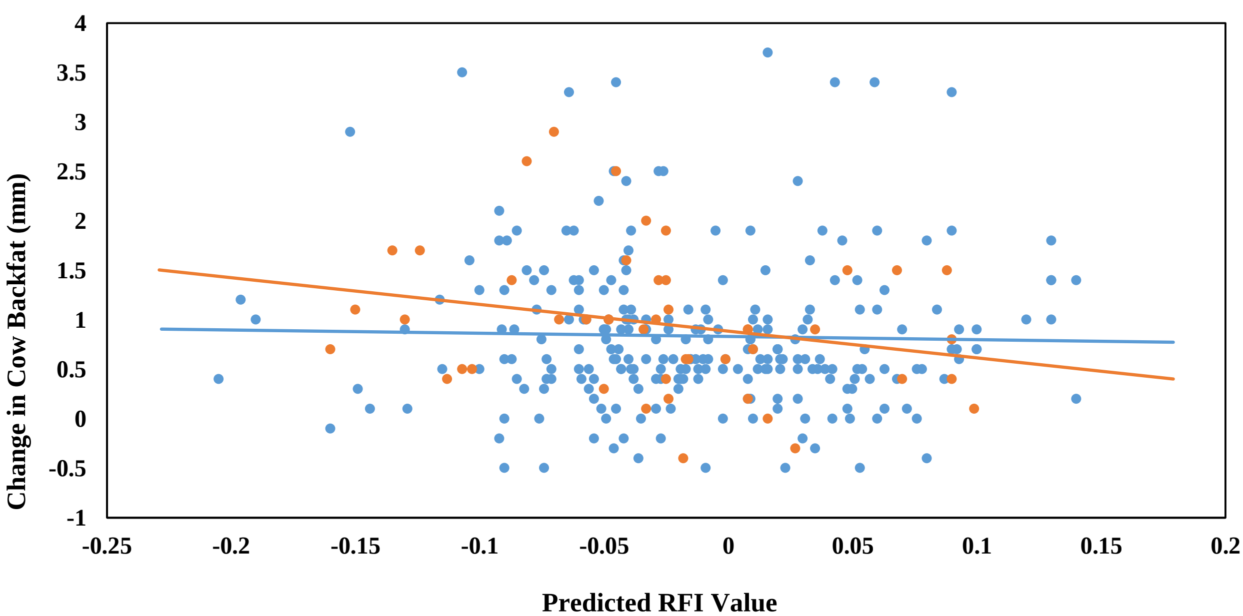


Fig. 2. Regression of the change in cow backfat (mm) against pRFI, with cows grouped by age. Blue points represent cows <5 years of age, and orange points represent cows that were >5 years of age. Corresponding lines represent the linear relationships of different age groups. Younger cows: y = 0.83 – 0.33x, R^2=0.0007, Adj. R^2=-0.0034, P=0.67. Older cows: y = 0.89 – 2.70x, R^2=0.060, Adj. R^2=0.039, P=0.101.

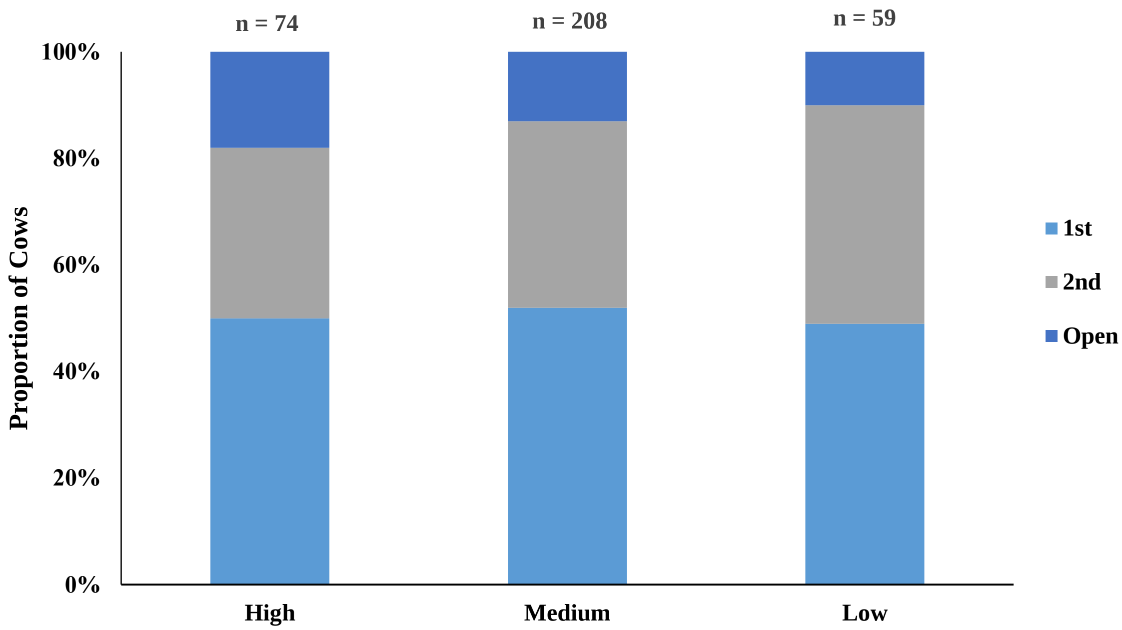


Fig. 3. Proportion of high, medium and low pRFI cows that became pregnant during the first and second breeding cycles, as well as the proportion of cows that remained open following the 2015 breeding season.

2.3.2. Cattle habitat selection and activity budgets on pasture

Table 4. Summary of environmental conditions at various cow locations observed through the GPS collars. Data are based on all cow observational locations across all study pastures. Quantiles represent cut-offs for respective intervals of data.

	Quantile						
Response	10%	25%	50%	75%	90%	95%	Mean
Distance from water (m)	199	209	225	234	256	263	226
Proportion of observations within 200 m of water (%)	46.7	50.2	53.3	55.7	59.3	61.7	53.1
Temp (^{o}C)	18.1	18.8	19.2	19.8	22.2	22.4	19.6
Herbage mass (kg ha^{-1})	1139	1170	1193	2207	1322	1500	1196
Herbage ADF (%)	30.5	31.9	32.3	32.6	35.9	37.6	32.6
Herbage protein (%)	9.0	9.9	10.0	10.1	11.8	12.2	10.2

Table 5. Variation in mean forage quality (fiber and crude protein concentration), as well as grass and forb biomass, within native pastures across the study area, in relation to topographic position and season of grazing.

Response	Level	Acid detergent fibre (%)		Crude Protein (%)		Biomass (kg ha^{-1})	
		Forb	Grass	Forb	Grass	Forb	Grass
Topographic Position	Upland	39.5	42.5	12.3	8.1	372	1295
	Midland	40.4	45.4	12.9	8.5	639	1630
	Lowland	41.1	41.9	10.7	8.8	514	1633
Timing of Grazing	Early	53.1	41.8	13.3	9.2	608	1218
	Mid	30.3	42.9	12.2	8.9	736	1665
	Late	37.2	45.3	10.4	7.2	180	1675

Table 6. Results of the ANOVA evaluating variation in lying bout frequency, proportion of time spent lying down, and movement rates by cattle, in relation to pRFI grouping, season of grazing, and their interaction, while grazing on native pastures. Pasture size was included as a covariate in the model.

	Lying Time (%)		Lying Bout (# hr^{-1})[1]		Movement Rate (steps hr^{-1})[2]	
Model Factor	F-Stat	P-Value	F-Stat	P-Value	F-Stat	P-Value
Pasture Size	28.0	**<0.0001**	39.7	**<0.0001**	0.02	0.89
pRFI Group	0.09	0.77	0.07	0.79	1.58	0.21
Time of Grazing (early, mid, late season)	5.83	**0.004**	20.5	**<0.0001**	46.9	**<0.0001**
Time of Grazing*pRFI Group	0.12	0.89	8.17	**0.0003**	0.90	0.41

[1] Lying bout analysis was based on log transformed data.

[2] Movement rate analysis was based on square root transformed data.

Table 7. Results of the ANOVA evaluating variation in the number of lying bouts, proportion of time spent lying down, and movement rates by cattle, in relation to pRFI group, pasture type, season of grazing (early and mid-growing season only), and all interactions thereof. Pasture size was included as a covariate in the model.

Response	Lying Time (%)		Lying Bout (# hr^{-1}, log transformed)		Movement Rate (steps hr^{-1}, square root transformed)	
	F-Stat	P-Value	F-Stat	P-Value	F-Stat	P-Value
Pasture Size	2.58	0.11	7.55	**0.007**	0.87	0.35
pRFI Group	0.20	0.66	0.13	0.72	1.13	0.29
Pasture Type (Native/Tame/Cultivated)	3.23	**0.04**	3.11	**0.047**	6.10	**0.003**
Pasture Type*pRFI Group	0.16	0.85	0.04	0.96	1.37	0.26
Time of Grazing (early, mid, late)	2.28	0.13	24.2	**<0.0001**	63.4	**<0.0001**
Time of Grazing*pRFI Group	0.02	0.87	2.72	0.10	1.03	0.31
Pasture Type*Time of Grazing	2.02	0.13	3.29	**0.04**	9.68	**<0.0001**
Pasture Type*pRFI Group*Time	1.60	0.20	2.15	0.12	0.24	0.79

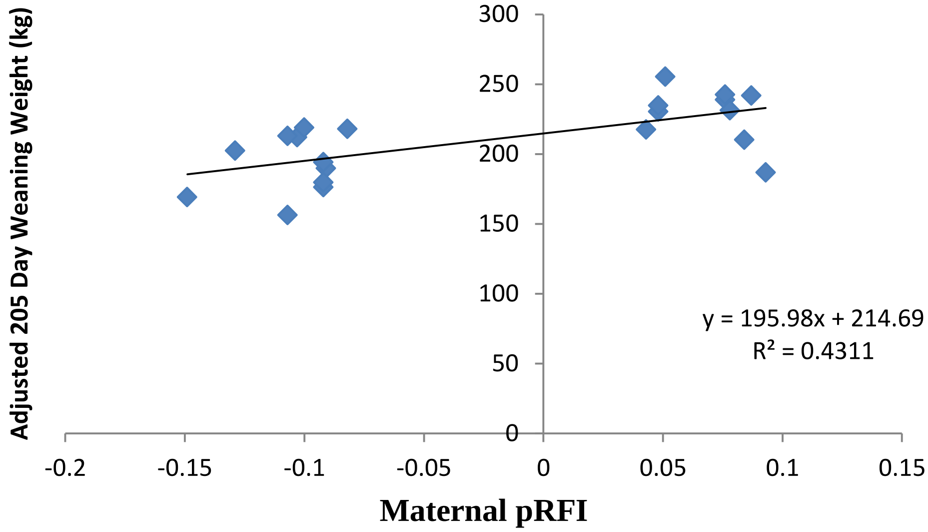


Fig. 4. Relationship between maternal pRFI and 205 adjusted calf weaning weight during the grazing season (P=0.001).

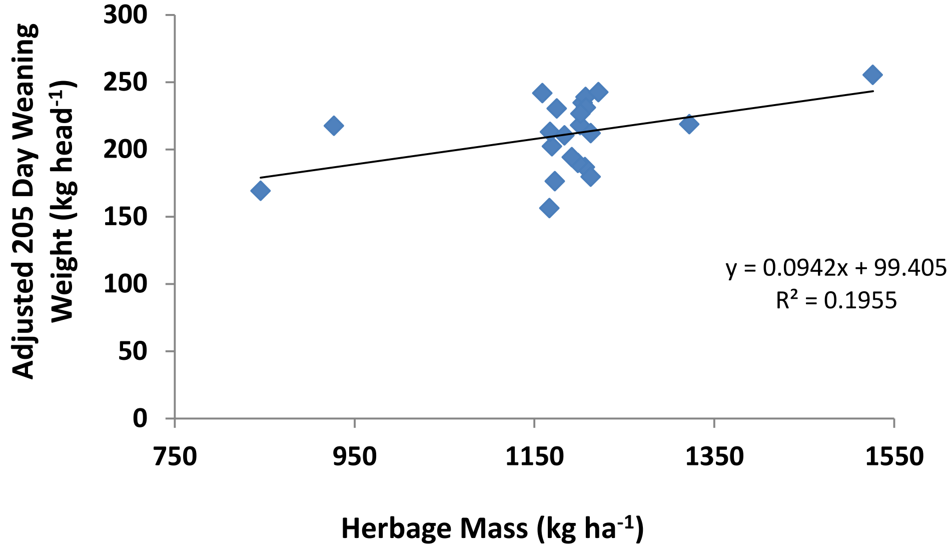


Fig. 5. Relationship between 205 day weaning weight and the average herbage mass of locational data for cows during the grazing season (P=0.045).

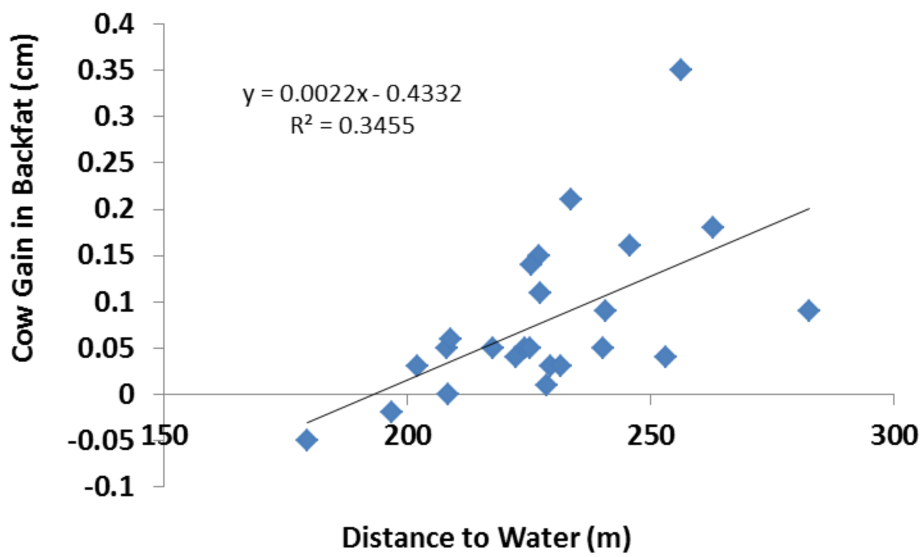


Fig. 6. Relationship between cow gain in backfat and average locational distance from water during the grazing season (P=0.003).

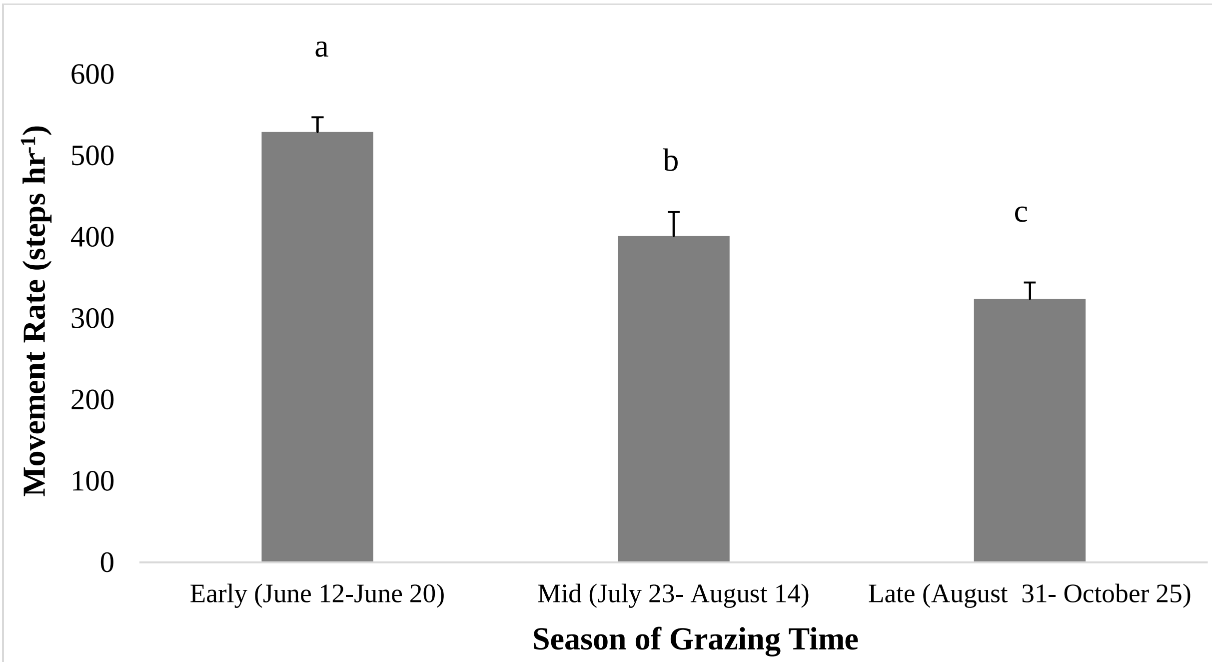


Fig. 7. Mean cow movement rate (steps hr^{-1}) of 27 cattle grazing in three different seasons of native pasture use (early, mid, and late season). Means with different letters differ, P<0.05.

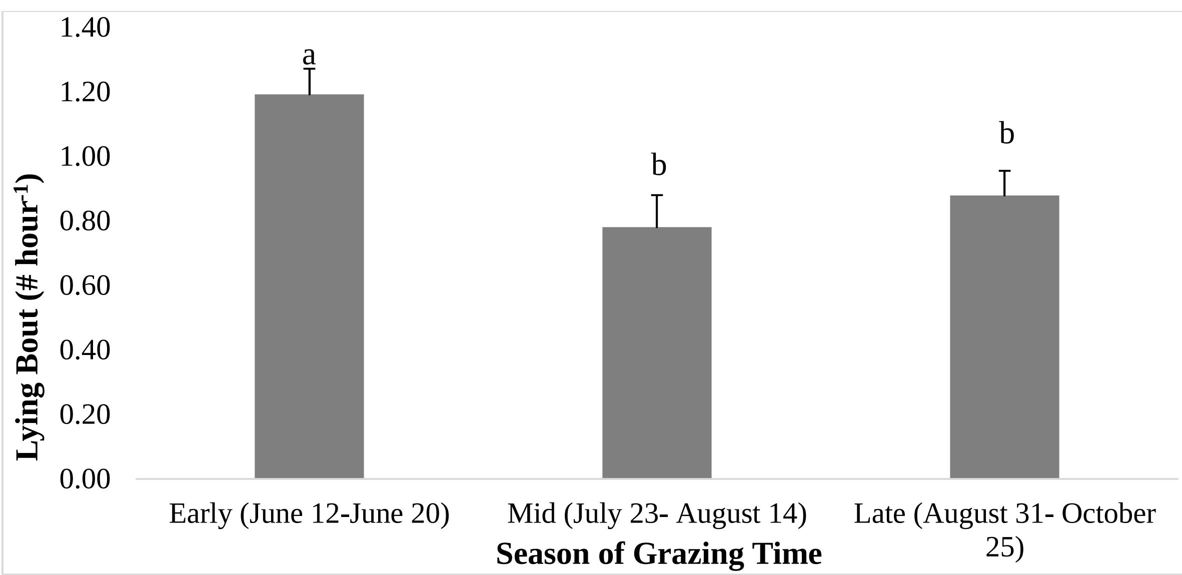


Fig. 8. Mean frequency of lying bouts (# hour^{-1}) by 27 cattle during each of three different seasons of native pasture use (early, mid and late season) during the summer of 2015. Means (±1SE) are untransformed. Means with different letters differ, P<0.05.

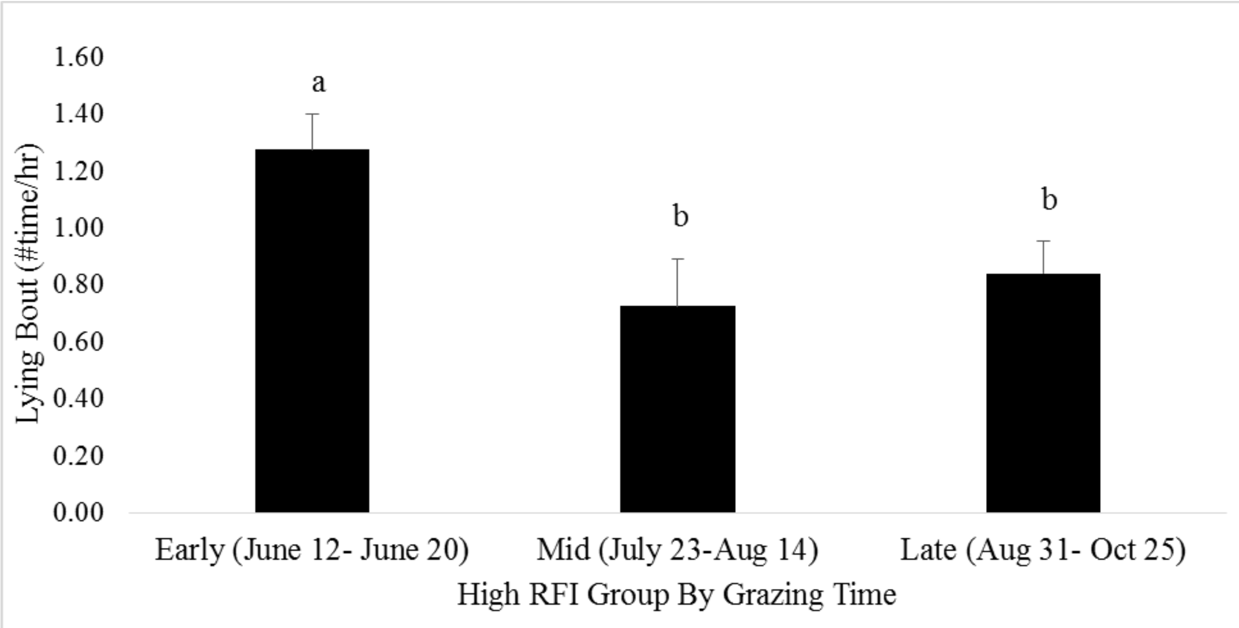


Fig. 9. Mean (±SE) lying bout frequency (# hour^{-1}) by 12 cattle from the high pRFI grouping, while grazing on native pastures at three different times of the year (early, mid, late growing season). No differences occurred for the low pRFI groups (P>0.05). Means with different letters differ (P<0.01).

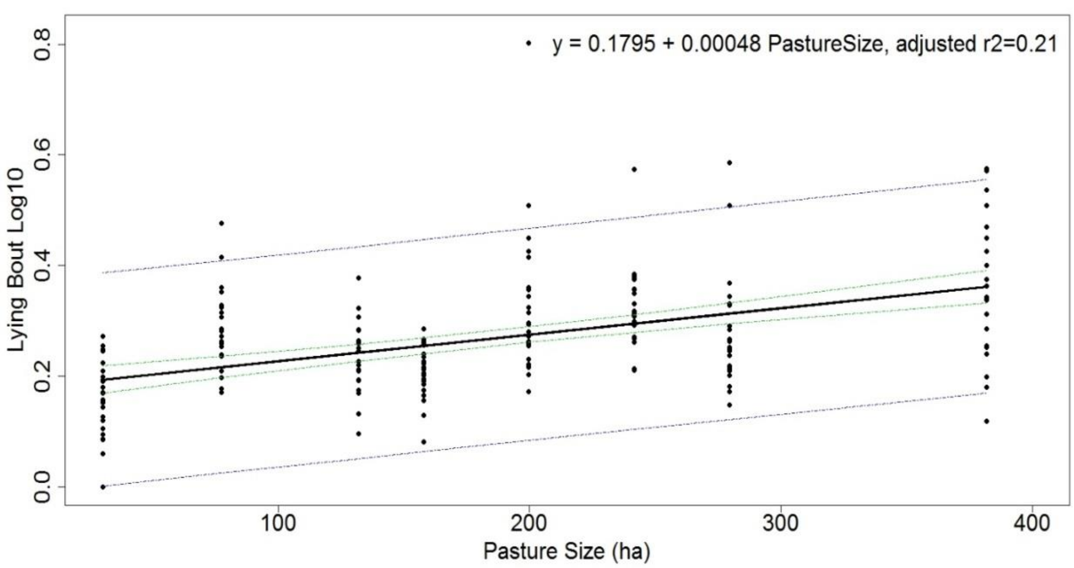


Fig. 10. Linear regression of log10 transformed lying bout against pasture size for 27 cattle grazing within 8 native pastures. Data are averaged across all grazing times (early, mid, and late season). Pasture size contributed significantly (P<0.0001) to the transformed lying bout model.

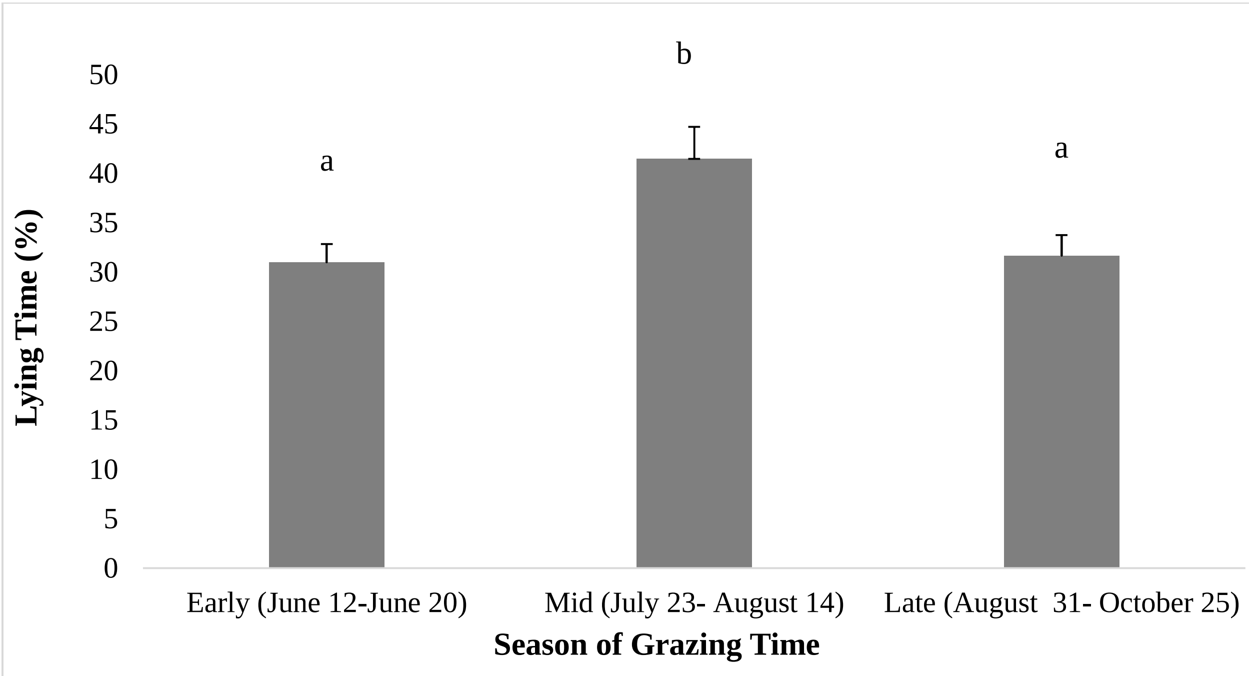


Fig. 11. Comparison of mean lying time (%) of 27 cattle during each of three different seasons of grazing on native pasture (early, mid and late season). Means with different letters differ, P<0.05.

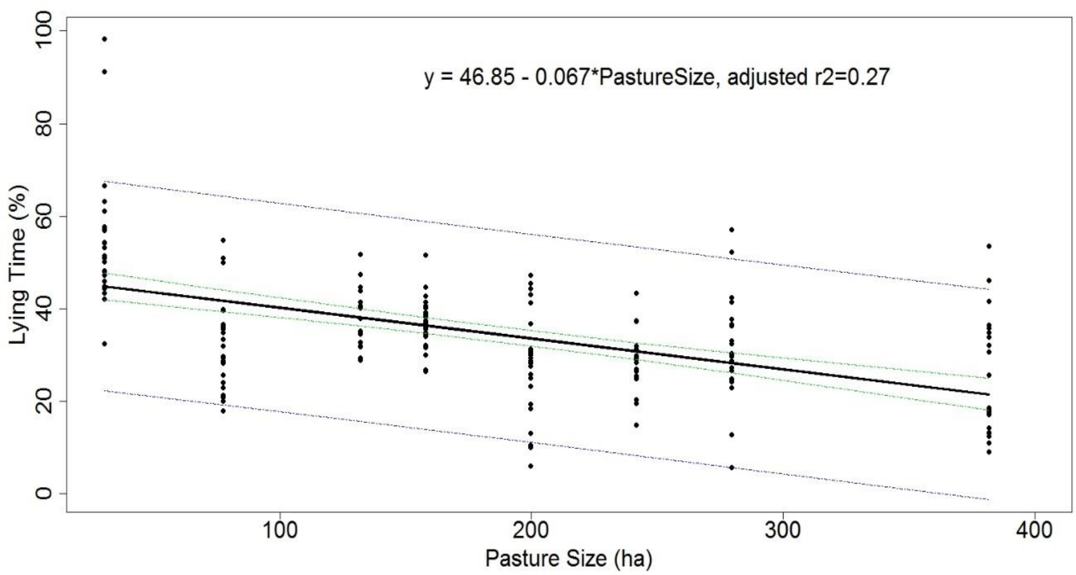


Fig. 12. Relationship between cattle lying time (%) and the size of 8 native Dry Mixedgrass pastures for 27 cattle grazing during 2015. Data were averaged across all seasons of grazing (early, mid, and late season). Lying time declined with increasing pasture size (LT=46.9–0.07PS; Adj. R^2=0.27; P<0.001).

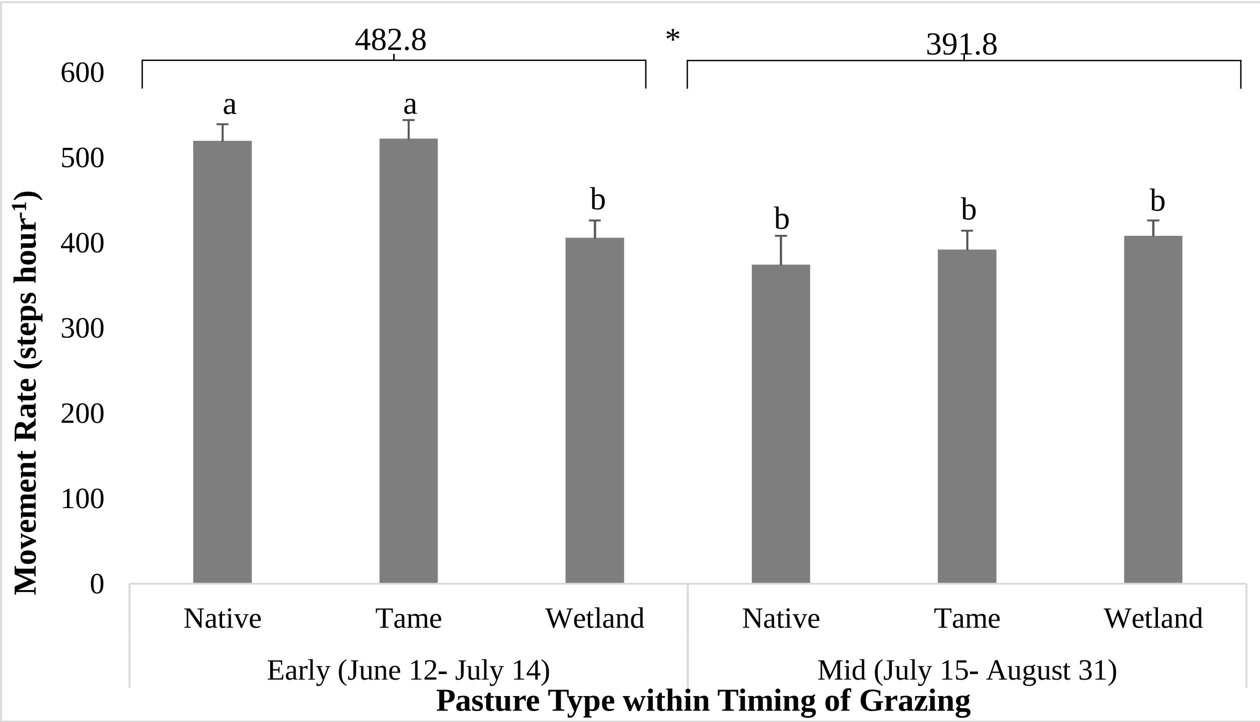


Fig. 13. Mean (±SE) movement rate (steps hour^{-1}) of 27 cattle grazing within three different pasture types (native, tame, and wetland) and during each of two grazing seasons (early and mid summer). Data presented are untransformed. Within a time, pasture type means with different letters differ, P<0.05. Asterisk indicates a different between primary times of grazing (P<0.05).

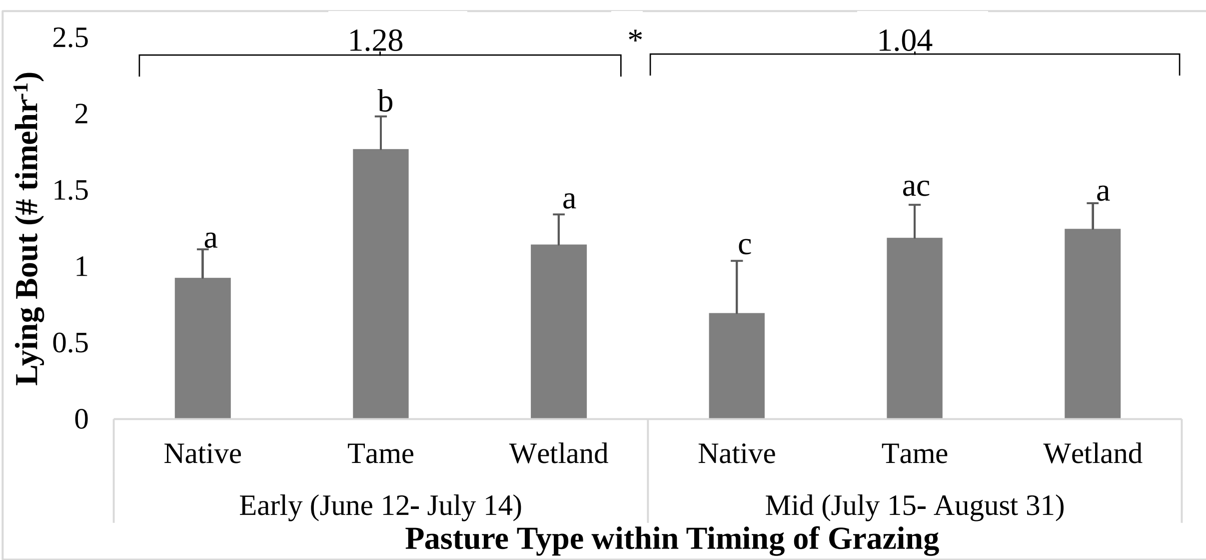


Fig. 14. Mean (±SE) frequency of lying bouts (# hour^{-1}) of 27 cattle grazing within each of three different pasture types (native, tame and wetland) and during each of two seasons (early and mid-summer). Within a time, lying bout means with different letters differ, P<0.05. Asterisk indicates a difference in lying bout frequency between seasons of grazing (P<0.05).

2.3.3. Dietary composition of cows on pasture

Table 8. Complete listing of the frequency of all dietary items found in cows grazing mixedgrass prairie on the Mattheis Ranch during 2015. Data are averaged among seasons and cows with different pRFI.

Plant Species/Component	Common Name	Mean	SD
Elymus lanceolatus	Northern wheatgrass	1.77	1.72
Pascopyrum smithii	Western wheatgrass	15.55	7.14
Agropyron spp.	Crested wheatgrass	0.24	0.86
Agrostis scabra	Ticklegrass	0.44	0.88
Bouteloua gracilis	Blue grama grass	12.97	6.21
Calamovilfa longifolia	Sand grass	16.03	10.96
Distichlis spicata	Salt grass	0.23	0.53
Hordeum jubatum	Foxtail barley	1.53	1.80
Koeleria macrantha	June grass	1.14	1.42
Muhlenbergia spp.	Muhli grass	0.33	0.49
Poa pratensis	Kentucky bluegrass	5.49	3.24
Hesperostipa comata	Needle & thread	10.61	5.18
Unknown Grasses	N/A	0.61	0.62
Total Grasses		***66.93***	***15.69***
Carex spp.	Dryland sedges	23.64	11.70
Juncus balticus	Wire rush	4.94	3.63
Scirpus / Eleocharis	Spike & bull rush	0.77	1.29
Total Sedges/Rushes		***29.34***	***14.27***
Astragalus cicer	Cicer milkvetch	0.01	0.08
Cirsium flodmanii	Flodmann's thistle	0.01	0.05
Erigeron spp.	Fleabane	0.01	0.05
Oenothera gaura	Primrose	0.15	0.34
Lactuca pulchella	Lettuce	0.02	0.09
Lithospermum incisum	Stoneseed	0.04	0.11
Melilotus officinalis	Sweet clover	0.03	0.16
Polygonum spp.	Smartweed	0.03	0.14
Typha latifolia	Cattail	0.06	0.20
Unknown Forbs	N/A	0.46	0.62
Total Forbs		***0.81***	***0.91***
Equisetum	Horsetail	2.06	2.17
Artemisia frigida leaf	Fringed sage	0.60	1.04
Shepherdia leaf	Thorny buffaloberry	0.22	0.39
Symphoricarpos occidentalis leaf	Thorny buffaloberry	0.03	0.16
Total Shrubs		***0.84***	***1.10***
Lichen/Mushroom		0.03	0.16
Total		**100.00**	

Table 9. Summary of significance for the ANOVA test results evaluating variation in histological dietary composition (frequency data) of 20 beef cows in response to different seasons (summer vs fall) and pRFI grouping (high vs low), as well as their interaction, while grazing native mixedgrass prairie at Mattheis ranch during 2015.

Dietary Component	Season	pRFI	Season*pRFI
------------------------- Main Dietary Components ----------------------------			
Grasses	P<0.0001	P=0.96	P=0.02
Sedges	P<0.0001	P=0.73	P=0.057
(Grass+Sedge)	P=0.048	P=0.37	P=0.046
Forb+Equisetum	P=0.0003	P=0.65	P=0.49
Woody	P=0.002	P=0.23	P=0.14
-------------------------- Secondary Plant Groupings ----------------------------			
C4 (warm season)	P<0.0001	P=0.43	P=0.66
Introduced Veg'n	P=0.01	P=0.005	P=0.87
Dietary Richness	P=0.0002	P=0.58	P=0.049
Dietary Diversity	P<0.0001	P=0.01	P=0.18

Table 10. Comparison of mean (±SD) summer and fall dietary composition (% frequency) for 20 beef cows while grazing native mixedgrass prairie at Mattheis ranch during 2015.

Response	Summer	Fall	P-value
	------------------------- Main Dietary Components	----------------------------	
Grasses	79.7 (9.2)	54.1 (8.7)	<0.0001
Sedges	17.8 (8.3)	40.9 (8.2)	<0.0001
(Grass+Sedge)	97.5 (2.4)	95.0 (2.4)	0.048
Forb+Equisetum	2.2 (2.3)	3.5 (2.0)	0.003
Woody	0.2 (0.3)	1.5 (1.2)	0.002
	------------------------- Secondary Plant Groupings	----------------------------	
C_4 (warm-season)	40.2 (13.6)	18.4 (6.2)	<0.0001
Introduced Veg'n	4.6 (2.4)	7.0 (3.5)	0.013
Dietary Richness	11.9 (1.6)	14.0 (1.4)	0.0002
Dietary Diversity	0.812 (0.067)	0.899 (0.046)	<0.0001

Table 11. Results of the indicator species analysis (ISA) relating pRFI and season of grazing with the diets of beef cows while grazing native mixedgrass prairie at Mattheis ranch during 2015.

Treatment	Species	Preferred Class	ISA Value	Random Group	P-Value
pRFI					
	Poa pratensis	High pRFI	64.8	53.8	0.0008
Season					
	Agrostis scabra	Fall	70.0	25.3	0.0002
	Artemisia frigida	Fall	77.7	30.7	0.0002
	Bouteloua gracilis	Summer	63.8	53.0	0.0002
	Calamovilfa longifolia	Summer	73.9	54.3	0.0002
	Carex spp.	Fall	69.7	53.1	0.0002
	Distichlis spicata	Summer	45.0	18.0	0.002
	Eleocharis spp.	Summer	59.0	32.0	0.001
	Hordeum jubatum	Fall	68.1	46.4	0.005
	Juncus spp.	Fall	78.1	53.6	0.0002
	Koeleria macrantha	Fall	100	32.4	0.0002
	Lithospermum incisum	Summer	25.0	11.8	0.05
	Muhlenbergia spp.	Fall	80.0	27.3	0.0002
	Oenothera gaura	Summer	45.0	17.9	0.0008
	Pascopyrum smithii	Summer	63.1	53.0	0.0004
	Poa pratensis	Fall	59.4	53.8	0.04

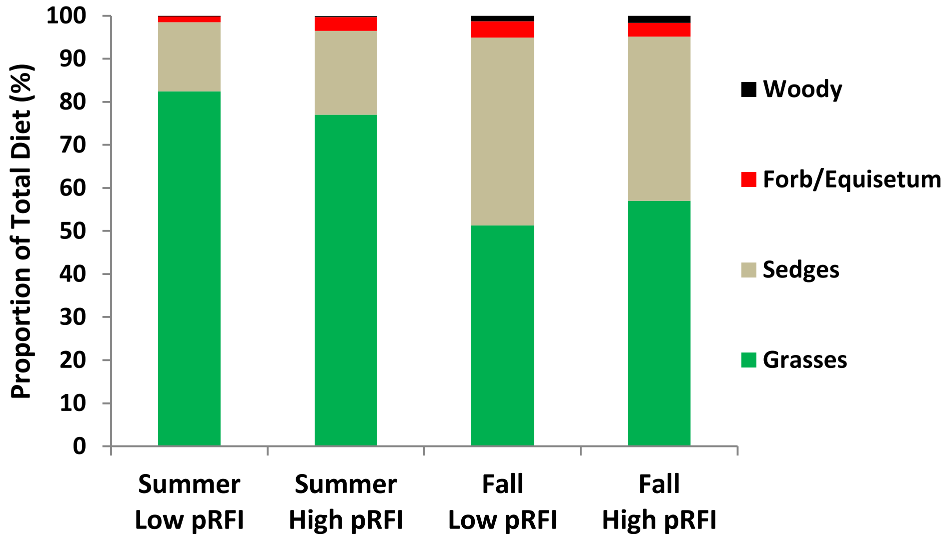


Fig. 15. Changes in the relative composition of major dietary items in cows with low and high pRFI when grazing during the summer and fall on native mixedgrass prairie during 2015. All vegetation groups were impacted by a season*pRFI interaction (P≤0.05) except woody species.

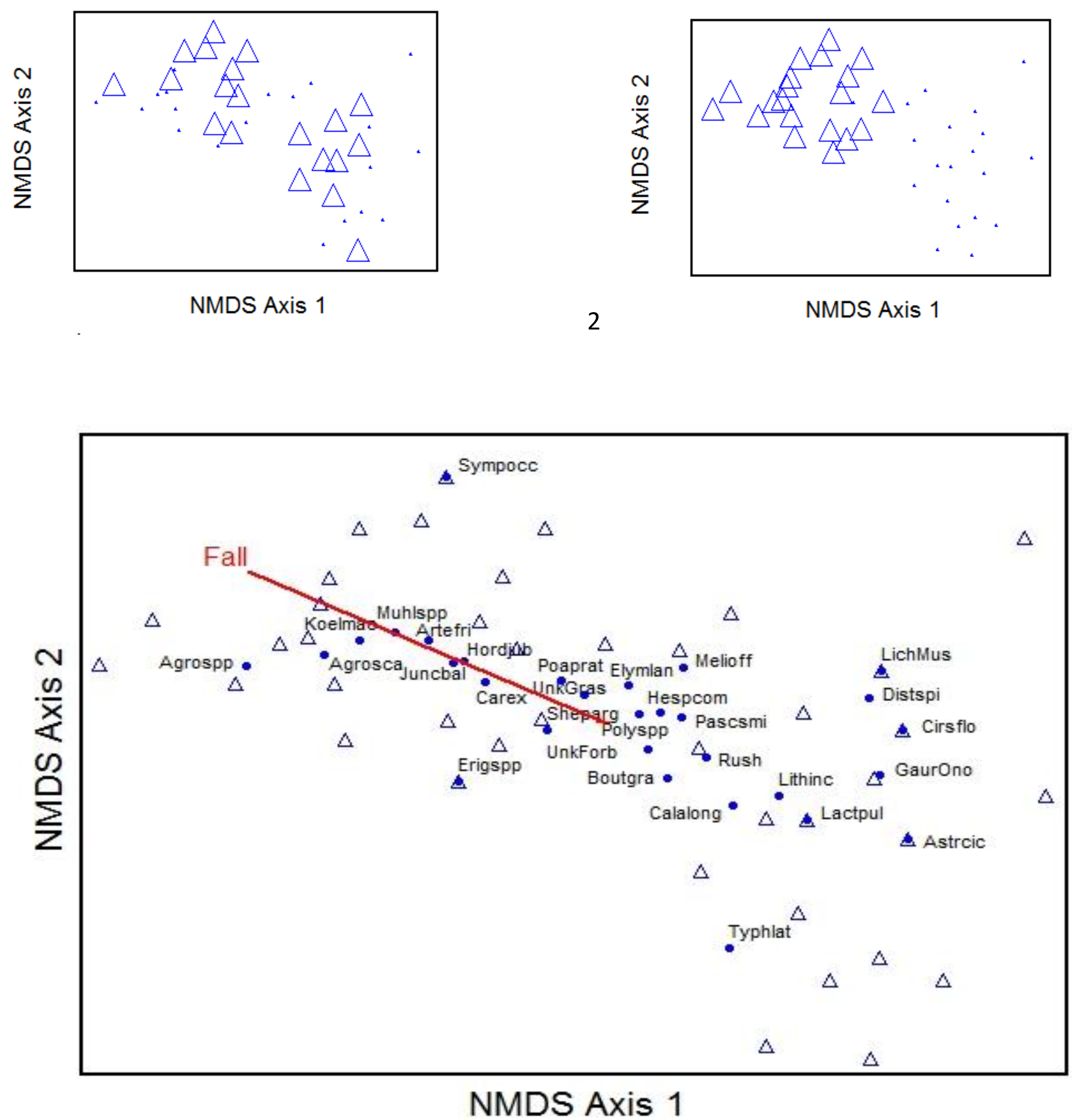
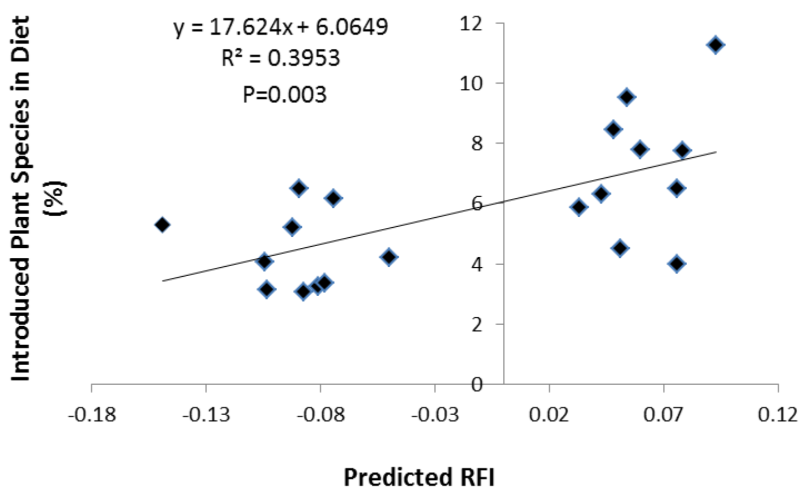


Fig. 16. Results of the NMDS ordination of fecal histological composition, with a 2-dimensional solution with final stress of 10.7. The upper left and right graphs show the distribution of diets in relation to different pRFI scores (larger symbols=greater pRFI) and seasons (larger symbols=fall grazed), respectively. The bottom graph depicts the overlay of diet components with |r|>0.3, with the fall seasonal vector.



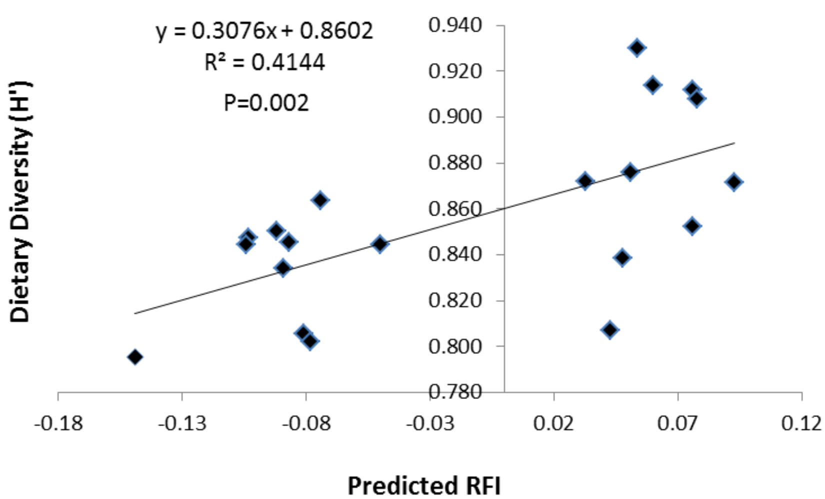


Fig. 17. Changes in the total abundance of introduced vegetation (top) and dietary (Shannon's) diversity (bottom) in relation to pRFI within cows grazing at the Mattheis Ranch in mixedgrass prairie during the 2015.

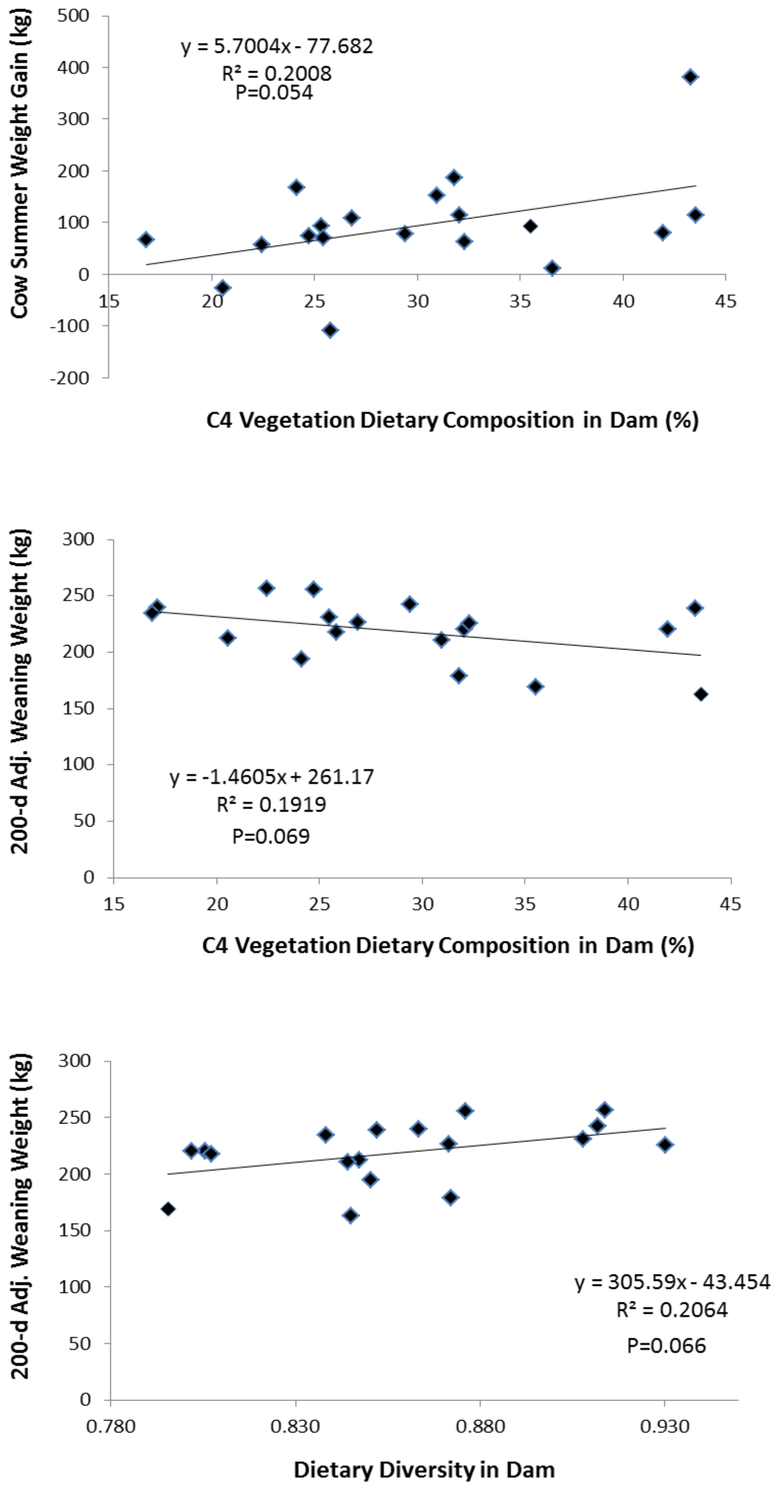


Fig. 18. Changes in cow weight gain (top) and 200-day calf adjusted weaning weight (middle) in relation to the proportion (%) of C4 vegetation in the cow diet. The bottom graph depicts the relationship between calf weaning weight and dietary diversity (Shannon's index). All data are from 20 cattle grazing mixedgrass prairie at the Mattheis Ranch during 2015.

2.3.4. Drylot intake/RFI test and greenhouse gas evaluation

Table 12. Composition of barley silage fed to replacement heifers on dry matter basis.

Dry matter (%)	36.72
Metabolizable energy (MJ kg $^{-1}$)^{X}	9.51
Crude protein (%)	10.93
Acid detergent fibre (%)	31.37
Neutral detergent fibre (%)	47.43
Total digestible nutrients (%)	63.03
Calcium (%)	0.39
Phosphorus (%)	0.26

^{x}Metabolizable energy (ME), MJ kg^{-1} DM = ((TDN, %/100) x 4.4 Mcal kg^{-1} TDN) x 4.184 MJ DE Mcal^{-1} x 0.82 MJ ME MJ^{-1} DE (NRC 1996).

Table 13. Composition of Diet 1 and Diet 2 pellets used in the GEMS, all percentages on DM basis.

	Diet 1	Diet 2
Dry Matter (%)	96.2	97.6
Crude Protein (%)	15.9	17.3
Acid Detergent Fibre (%)	9.55	7.8
Neutral Detergent Fibre (%)	23.2	18.6
Calcium (%)	1.8	1.28
Phosphorus (%)	0.61	0.33
Magnesium (%)	0.28	0.14
Potassium (%)	0.73	0.48
Sodium (%)	0.38	0.33

Table 14. Summary ANOVA results for various production metrics, including DMI, FCR, initial, mid and final calf weight, as well as metabolic midweight. Also shown are results for RFI unadjusted and adjusted for backfat, ADG and backfat.

	Dry Matter Intake		**Feed Conversion Ratio**	
	F-Value	P-Value	F-Value	P-Value
RFI Group	$17.57_{(1, 54)}$	0.0001	$2.32_{(1, 54)}$	0.13
Calf Age	$0.51_{(1, 54)}$	0.48	$0.081_{(1, 54)}$	0.78
	Initial Calf Weight		**Final Calf Weight**	
	F-Value	P-Value	F-Value	P-Value
RFI Group	$0.11_{(1, 54)}$	0.74	$0.42_{(1, 54)}$	0.056
Calf Age	$5.78_{(1, 54)}$	0.02	$3.56_{(1, 54)}$	0.065
	Midweight		**Metabolic Midweight**	
	F-Value	P-Value	F-Value	P-Value
RFI Group	$0.27_{(1, 54)}$	0.60	$0.005_{(1, 54)}$	0.94
Calf Age	$3.81_{(1, 54)}$	0.056	$3.81_{(1, 54)}$	0.056
	Residual Feed Intake		**Residual Feed Intake – Fat Adj.**	
	F-Value	P-Value	F-Value	P-Value
RFI Group	$53.97_{(1, 54)}$	< 0.0001	$53.98_{(1, 54)}$	< 0.0001
Calf Age	$1.90_{(1, 54)}$	0.17	$1.91_{(1, 54)}$	0.17
	Average Daily Gain		**Backfat**	
	F-Value	P-Value	F-Value	P-Value
RFI Group	$0.22_{(1, 54)}$	0.64	$0.10_{(1, 54)}$	0.75
Calf Age	$0.039_{(1, 54)}$	0.84	$0.52_{(1, 54)}$	0.47

Table 15. Dry matter intake and performance of heifers fed barley silage for 65 days in drylot at the Lacombe Research Station.

	High RFI_{FAT}		Low RFI_{FAT}	
Response	**LSM**	**SE**	**LSM**	**SE**
Daily Dry Matter Intake (kg DM day^{-1})	6.21[a]	0.13	5.43[b]	0.13
RFI	0.36[a]	0.07	-0.37[b]	0.07
RFI_{FAT}	0.36[a]	0.07	-0.37[b]	0.07
Initial Weight (kg)	269.1[a]	4.27	267.1[a]	4.35
Final Weight (kg)	314.1[a]	5.82	308.6[a]	5.92
Mid Weight (kg)	288.2[a]	5.91	284.4[a]	5.02
Metabolic Mid Weight (kg)	69.9[a]	0.91	69.2[a]	0.93
Backfat (mm)	4.09[a]	0.3	3.96[a]	0.30
Average Daily Gain (kg d^{-1})	0.58[a]	0.03	0.56[a]	0.03
Feed Conversion Ratio	12.22[a]	0.64	10.81[a]	0.65

Table 16. Summary ANOVA results for CH_4 and CO_2 production (g head^{-1} day^{-1}) and yield (g kg^{-1} DMI) for replacement heifers fed in drylot.

	CH_4 Production		**CO_2 Production**	
Response	F-Value	P-Value	F-Value	P-Value
RFI_{FAT} Group	$0.04_{(1, 3644)}$	0.84	$30.83_{(1, 3644)}$	< 0.0001
Day	$6.73_{(28, 3644)}$	< 0.0001	$7.17_{(28, 3644)}$	< 0.0001
RFI_{FAT} Group: Day	$1.46_{(28, 3644)}$	0.056	$1.26_{(28, 3644)}$	0.17
Effective Time*	$0.93_{(1, 3644)}$	0.33	$7.14_{(1, 3644)}$	0.0076
Time Bin	$44.91_{(7, 3644)}$	< 0.0001	$23.65_{(7, 3644)}$	< 0.0001
RFI_{FAT} Group: Time Bin	$2.28_{(7, 3644)}$	0.026	$4.07_{(7, 3644)}$	0.0002
	CH_4 Yield		**CO_2 Yield**	
	F-Value	P-Value	F-Value	P-Value
RFI_{FAT} Group	$11.78_{(1, 41)}$	0.001	$10.10_{(1, 41)}$	0.003
Day	$0.00_{(1, 41)}$	0.98	$0.13_{(1, 41)}$	0.72

Table 17. Means and standard deviations of CH_4 and CO_2 production and yield from high and low RFI_{FAT} replacement heifers while in drylot. Means with different letter within a row differ, P<0.05.

	High RFI_{FAT}		**Low RFI_{FAT}**	
	Mean	SD	Mean	SD
Methane Production (g head^{-1} day^{-1})	149.0[a]	36.0	148.7[a]	36.1
Methane Yield (g kg^{-1} DMI)	23.6[a]	2.6	26.4[b]	2.6
Carbon Dioxide Production (g head^{-1} day^{-1})	5414.0[a]	734.3	5264.3[b]	696.1
Carbon Dioxide Yield (g kg^{-1} DMI)	870.8[a]	79.3	947.0[b]	73.4

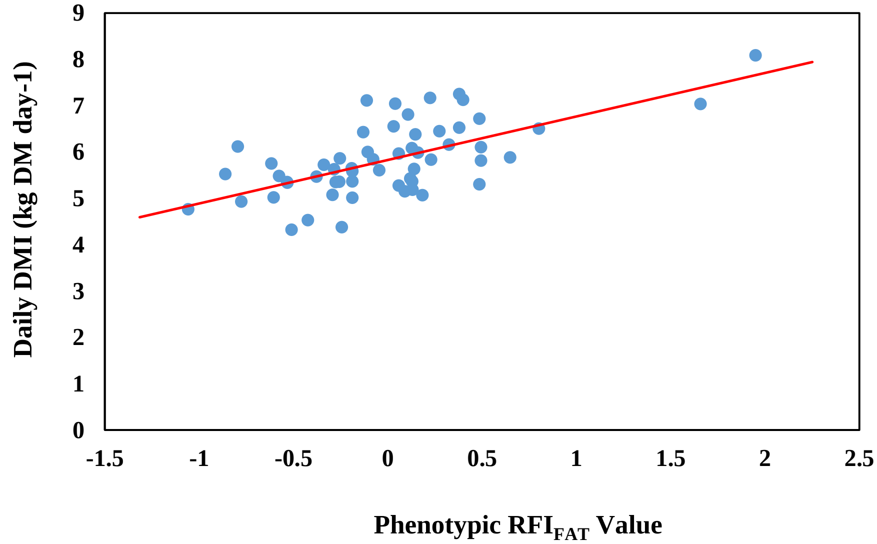


Fig. 19. Linear regression of replacement heifer DMI with respect to phenotypic RFI$_{FAT}$ value. $y = 5.83 + 0.094x$, R^2=0.41, Adjusted R^2=0.39, P<0.0001.

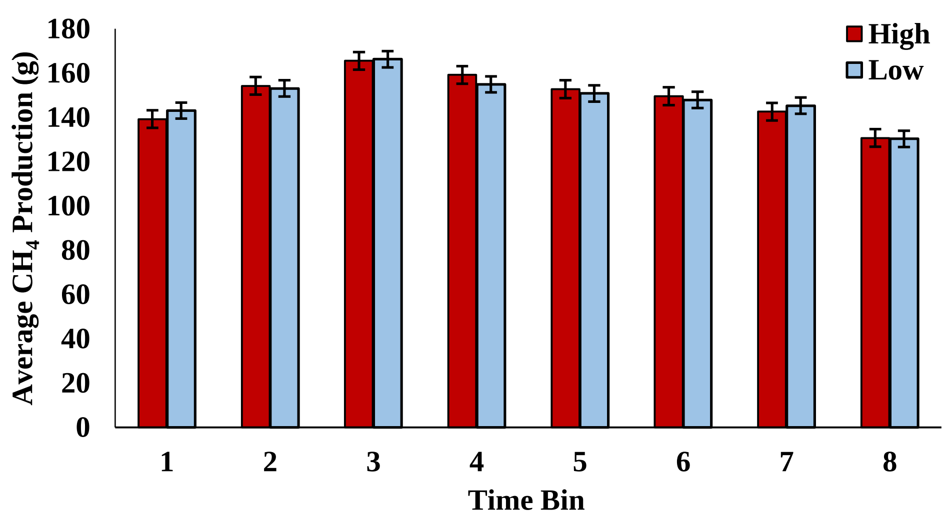


Fig. 20. Average CH_4 production of high and low RFI$_{FAT}$ heifers in drylot (g head^{-1}) over a 24-hour time period, separated into eight successive three-hour time periods, starting at midnight.

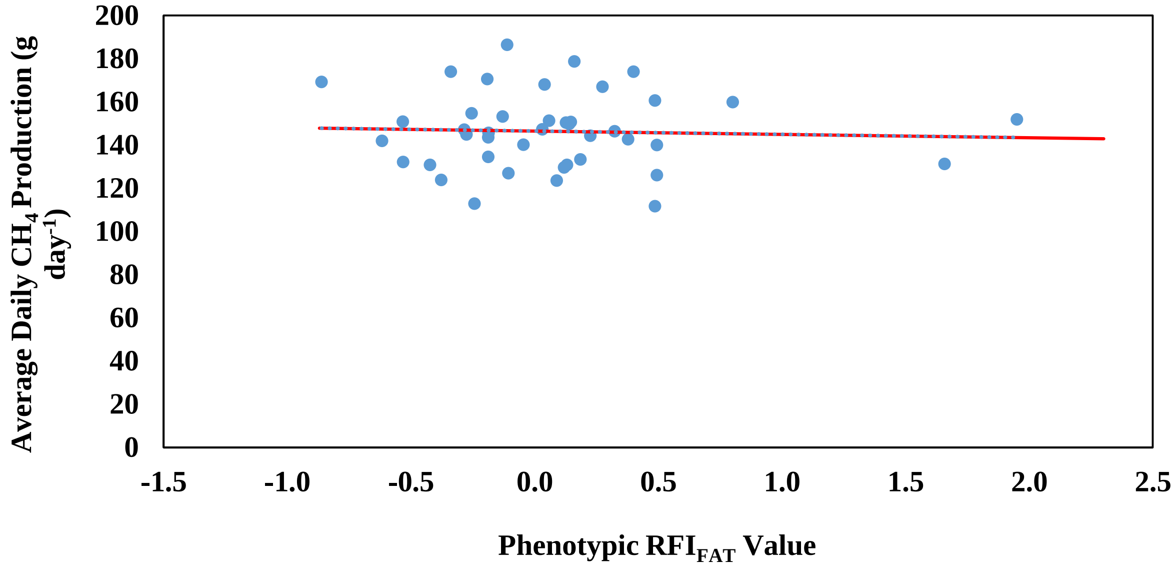


Fig. 21. Linear regression of daily CH_4 production (g day^{-1}) and phenotypic RFI_{FAT} value of heifers in drylot. y = 146.53 – 1.56x, R^2=0.002, Adjusted R^2=- 0.023, P=0.77.

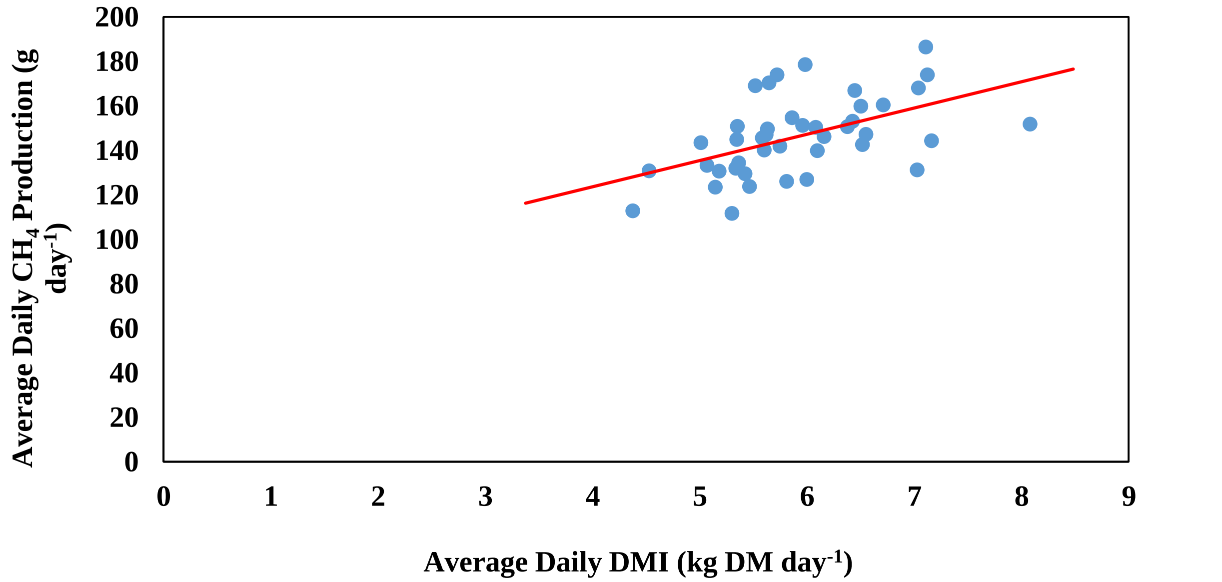


Fig. 22. Linear regression of average daily CH_4 production (g day^{-1}) and average daily DMI (kg DM day^{-1}) of heifers in drylot. y = 76.40 + 11.81x, R2=0.27, Adjusted R^2=0.25, P<0.001.

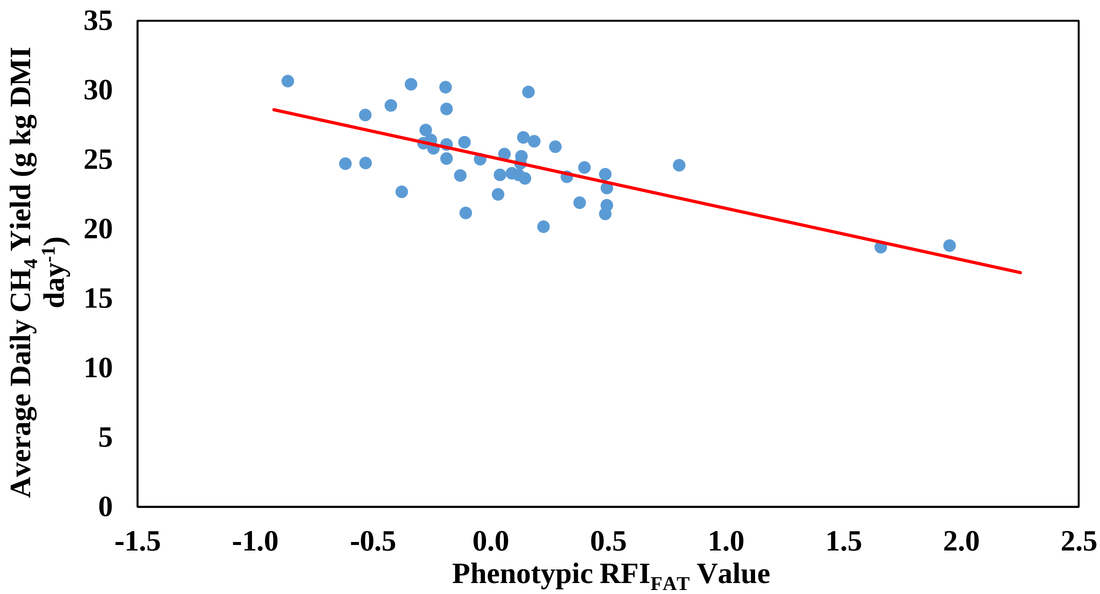


Fig. 23. Linear regression of phenotypic RFI_{FAT} value and average daily CH_4 yield (g kg DMI day^{-1}). y = 25.18 – 3.70x, R2=0.44, Adjusted R^2=0.43, P<0.0001.

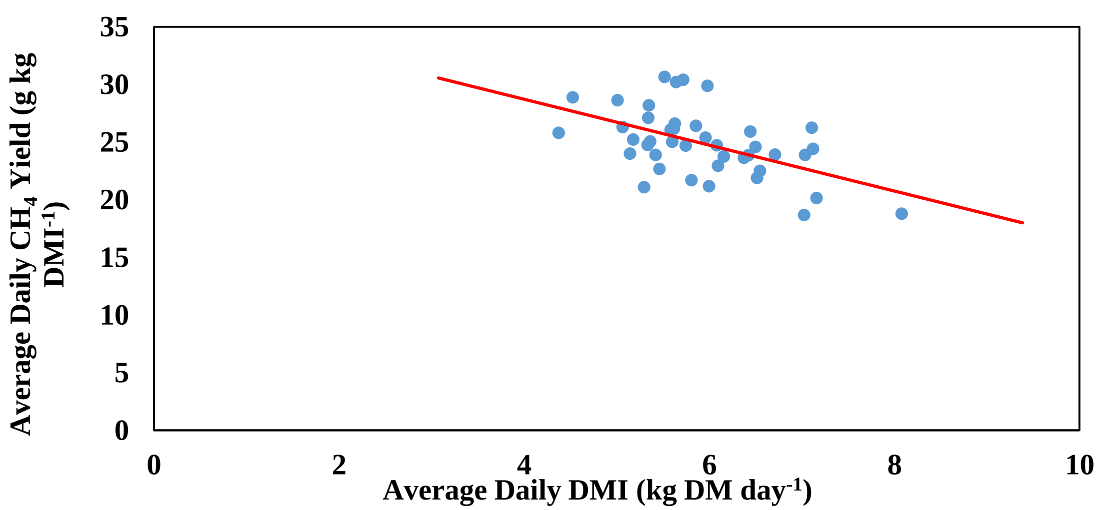


Fig. 24. Linear regression of average daily CH_4 yield (g kg DMI day^{-1}) and average daily dry matter intake (kg DM day^{-1}). y = 36.68 – 1.98x, R2=0.28, Adjusted R2=0.26, P<0.001.

2.3.5. Pasture intake and greenhouse gas trial

Table 18. Summary of mean (SD) n-alkane pellet nutritional composition during the dosing period. All nutritional values are on a dry matter basis.

Dry Matter (%)	89.3 (1.8)
Crude Protein (%)	17.5 (0.6)
Acid Detergent Fiber (%)	11.6 (0.9)
Neutral Detergent Fibre (%)	19.0 (0.3)
Total Digestible Nutrients (%)	82.7 (0.5)
Calcium (%)	0.19 (0.01)
Phosphorus (%)	0.54 (0.005)
Magnesium (%)	0.22 (0.004)
Potassium (%)	0.56 (0.01)

Table 19. Summary of the mean (SD) nutritional composition of pasture forage oats during the warm-up and sampling periods. All values are on a dry matter basis.

	Warm-Up Period (day -8 to -1)	Sampling Period (day 9-14)
Dry Matter (%)	20.9 (3.0)	19.5 (2.7)
Crude Protein (%)	30.0 (2.2)	23.5 (0.9)
Acid Detergent Fiber (%)	21.7 (1.7)	24.5 (0.7)
Neutral Detergent Fiber (%)	45.3 (1.8)	48.6 (1.7)
Total Digestible Nutrients (%)	66.9 (1.1)	65.4 (0.9)
Calcium (%)	0.26 (0.2)	0.25 (0.07)
Phosphorus (%)	0.41 (0.03)	0.35 (0.03)
Magnesium (%)	0.24 (0.04)	0.24 (0.02)
Potassium (%)	3.57 (0.2)	4 (0.4)

Table 20. Summary ANOVA table for DMI and animal size and condition metrics for each of the high and low RFI_{FAT} heifers while grazing on pasture.

	DMI (kg day^{-1})			
	F-Value	P-Value		
RFI Group	0.41 (1, 14)	0.533		
Sampling Day	31.89 (1, 79)	< 0.0001		
	Initial BW (kg)		**Final BW (kg)**	
	F-Value	**P-Value**	**F-Value**	**P-Value**
RFI Group	0.12 (1, 13)	0.76	0.002 (1, 13)	0.96
Age	0.37 (1, 13)	0.56	19.70 (1, 13)	< 0.001
	Initial Backfat (mm)		**Final Backfat (mm)**	
	F-Value	**P-Value**	**F-Value**	**P-Value**
RFI Group	0.17 (1, 13)	0.68	5.41 (1, 13)	0.04
Age	42.93 (1, 13)	< 0.0001	19.04 (1, 13)	< 0.001

Table 21. Summary least square means for DMI and associated animal production metrics of high and low RFI_{FAT} heifers (n=16) while grazing on pasture. Within a row, means with different letters differ, P<0.05.

	High RFI_{FAT}		Low RFI_{FAT}	
	LSM	**SE**	**LSM**	**SE**
Daily DMI (kg day^{-1})	8.13[a]	0.28	7.88[a]	0.28
Initial BW (kg)	304.6[a]	9.9	309.3[a]	10.0
Final BW (kg)	342.3[a]	10.4	341.6[a]	10.4
Weight Gain (kg)	31.3[a]	2.33	27.9[a]	2.73
Initial Backfat (mm)	3.5[a]	0.29	3.3[a]	0.35
Final Backfat (mm)	4.9[a]	0.34	3.9[b]	0.34

DMI – dry matter intake
BW – body weight

Table 22. Summary ANOVA results for CH_4 production and CH_4 yield of high and low RFI_{FAT} heifers (n=16) while grazing on pasture.

	Daily CH_4 Production (g head^{-1})	
	F-Value	**P-Value**
RFI Group	$0.42_{(1, 194)}$	0.52
3-Hr Time Bin	$3.96_{(1, 194)}$	0.048
	Weight Adjusted CH_4 Production (g kg^{-1} BW day^{-1})	
	F-Value	**P-Value**
RFI Group	$0.43_{(1, 194)}$	0.51
3-Hr Time Bin	$3.79_{(1, 194)}$	0.053
	Weight Adjusted CH_4 Yield (g kg^{-1} DMI day^{-1})	
	F-Value	**P-Value**
RFI Group	$0.65_{(1, 14)}$	0.44
3-Hr Time Bin	$31.90_{(1, 79)}$	< 0.0001

Table 23. Summary of least square means for CH_4 production and CH_4 yield of high and low RFI_{FAT} heifer groups while grazing on pasture.

	High RFI_{FAT}		**Low RFI_{FAT}**	
	LSM	**SE**	**LSM**	**SE**
CH_4 production (g day^{-1})	203.3^a	27.46	195.6^a	27.46
CH_4 production (g kg^{-1} BW)	0.61^a	0.083	0.58^a	0.083
CH_4 yield (g kg DM^{-1})	21.7^a	0.93	20.7^a	0.93

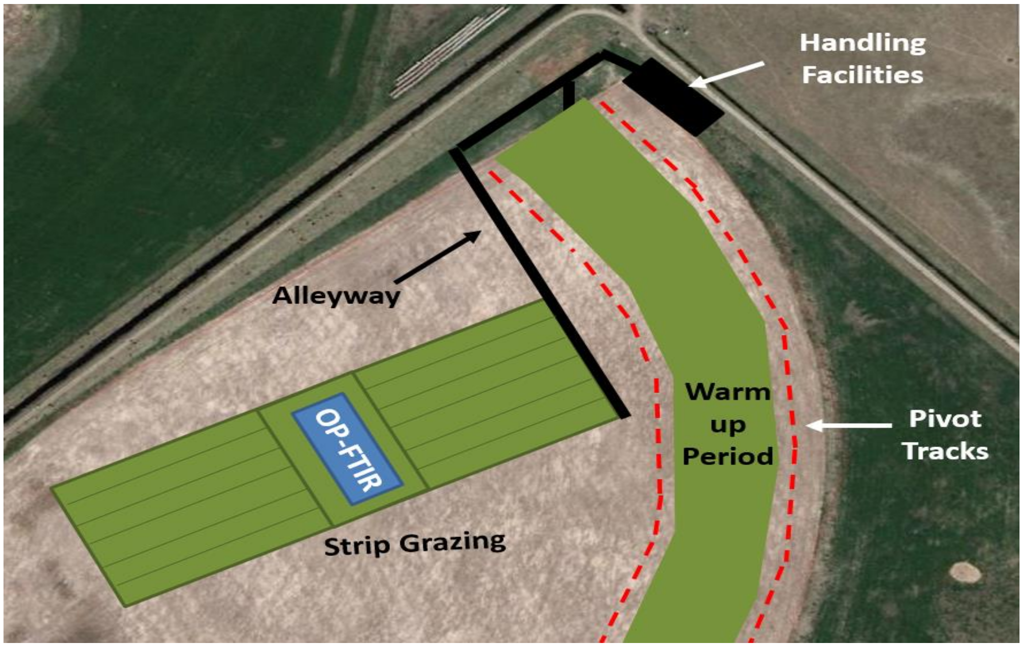


Fig. 25. Pivot 4 at the University of Alberta Mattheis Research Ranch, fenced off and set-up for grazing during the warm-up period and for strip grazing during collection of CH_4 observations. The warm-up area was positioned between pivot tracks to prevent interference with pivot use. Long, fenced off alleyways were used to move cattle between the handling facilities, warm-up area, and the grazing strips. The original image was sourced from Google Earth.

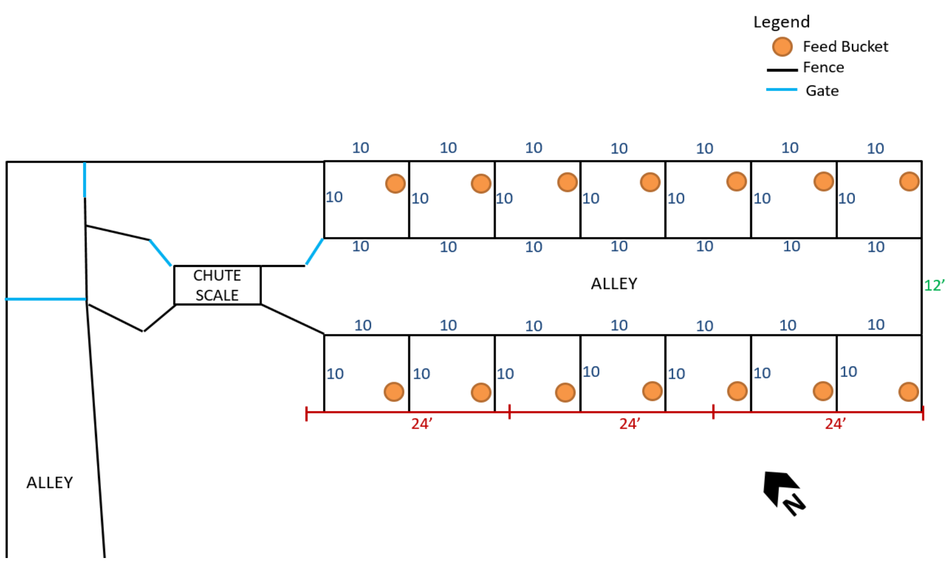


Fig. 26. Layout of individual feeding pens, scale and chute set-up for individual feeding of alkane pellets to heifers and the collection of animal weight and fecal samples during the pasture intake trial on Pivot 4 at the University of Alberta Mattheis Ranch.

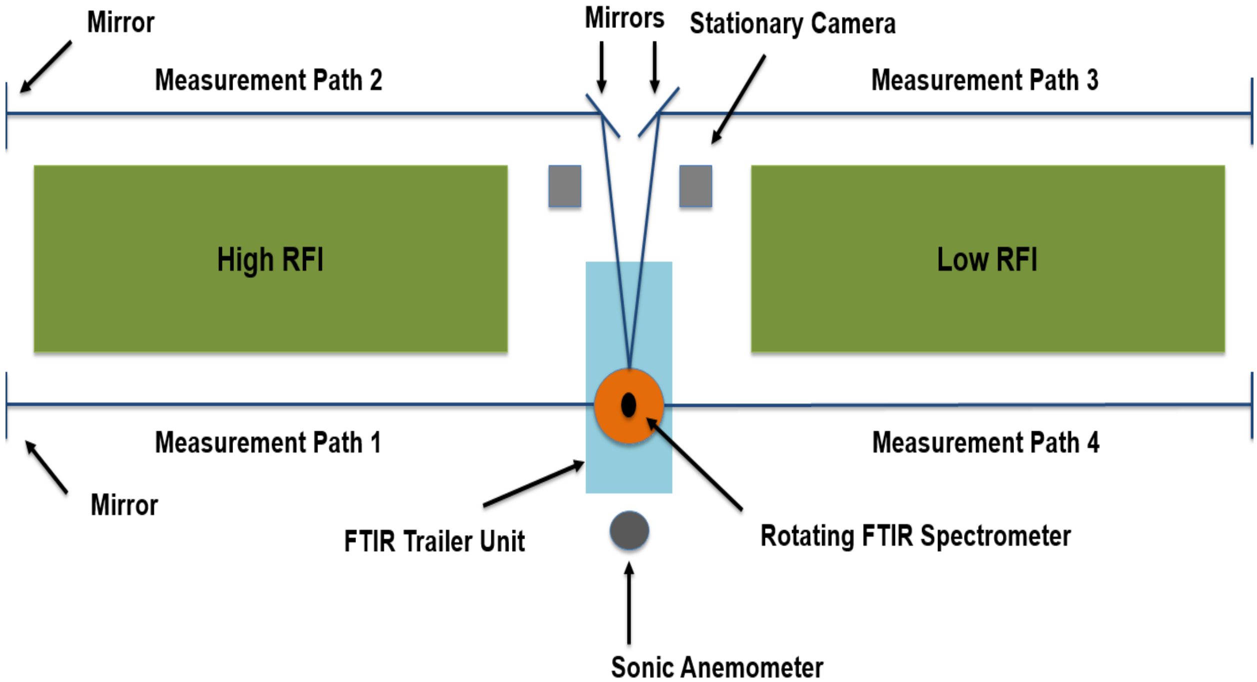


Fig. 27. Pasture CH_4 emissions set-up on Pivot 4 at the University of Alberta Mattheis Research Ranch. Four different measurement paths are depicted, one along either side of the high and low RFI_{FAT} paddocks with a rotating OP-FTIR spectrometer in the center, positioned on a portable OP-FTIR trailer.

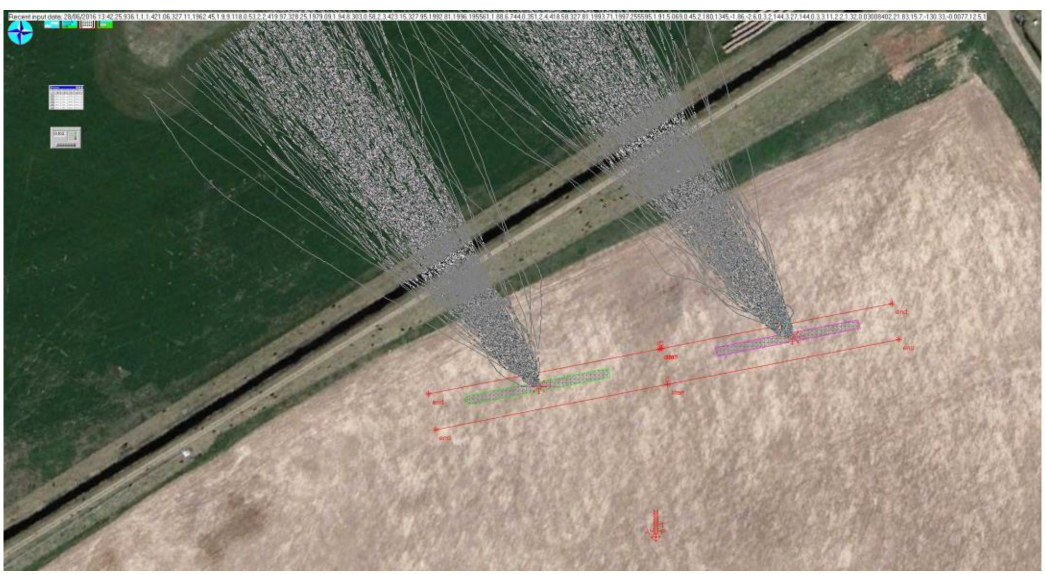


Fig. 28. Image produced by the WindTrax software showing CH_4 emissions emitted from within the high and low RFI_{FAT} grazing strips. The low RFI_{FAT} cattle are grazing the green strip on the left while the high RFI_{FAT} cattle are grazing the red strip on the right. With winds out of the south-east, emissions are nearly perpendicular to the measurement paths, as desired.

Fig. 29. The schedule of CH_4 observations over an eight day period. Low RFI_{FAT} cattle are depicted by the green strips and high RFI_{FAT} cattle are depicted by the red strips on either side of the OP-FTIR unit. Strips are not shown to scale. Cattle were adjusted to strip-grazing on day one and CH_4 measurements were not collected.

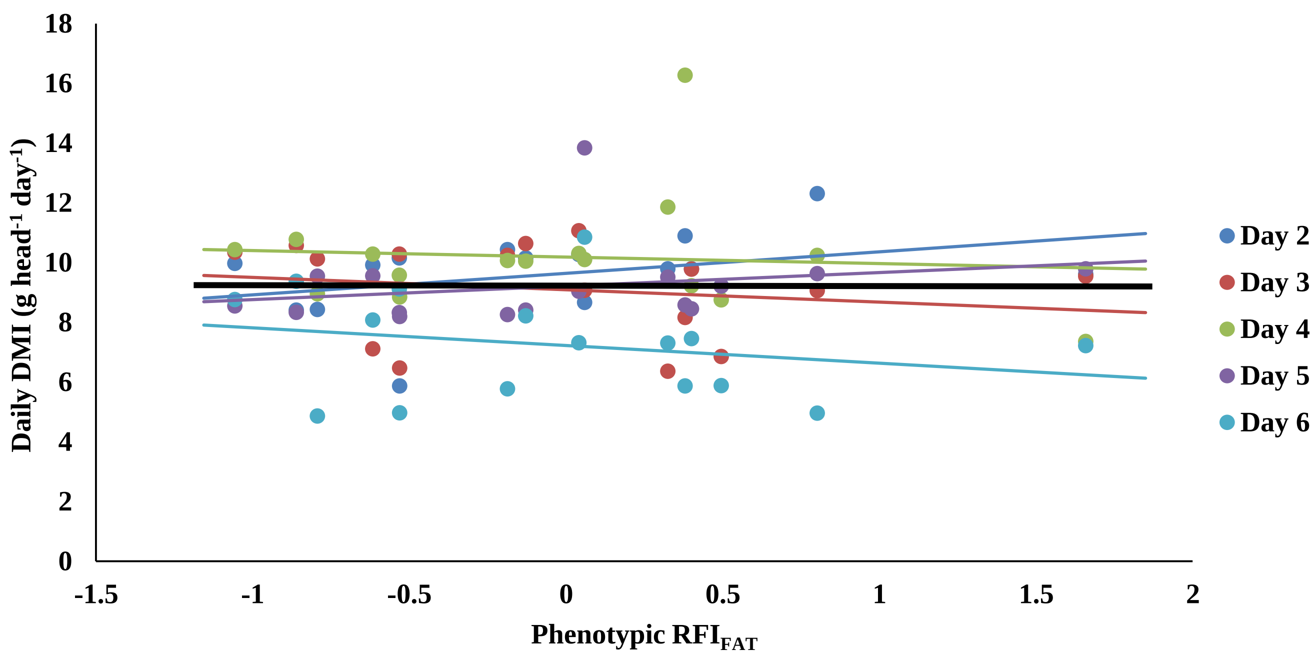


Fig. 30. Regression of daily DMI (g head^{-1} day^{-1}) and individual RFI_{FAT} value for each day of the pasture DMI trial. The black line represents the overall trend of DMI.
Total data: y = 8.97 – 0.03x, R^2=0.0001, Adjusted R^2=- 0.011, P=0.92.
Day 1: y = 8.93 + 0.96x, R^2=0.17, Adjusted R^2=0.007, P=0.11
Day 2: y = 8.17 – 0.05x, R^2=0.001, Adjusted R^2=- 0.07, P=0.90
Day 3: y = 8.47 – 0.28x, R^2=0.06, Adjusted R^2=- 0.011, P=0.38
Day 4: y = 8.66 + 0.08x, R^2=0.004, Adjusted R^2=- 0.067, P=0.81
Day 5: y = 7.27 – 0.09x, R^2=0.002, Adjusted R^2=- 0.069, P=0.86
Day 6: y = 6.52 – 0.75x, R^2=0.096, Adjusted R^2=0.031, P=0.24

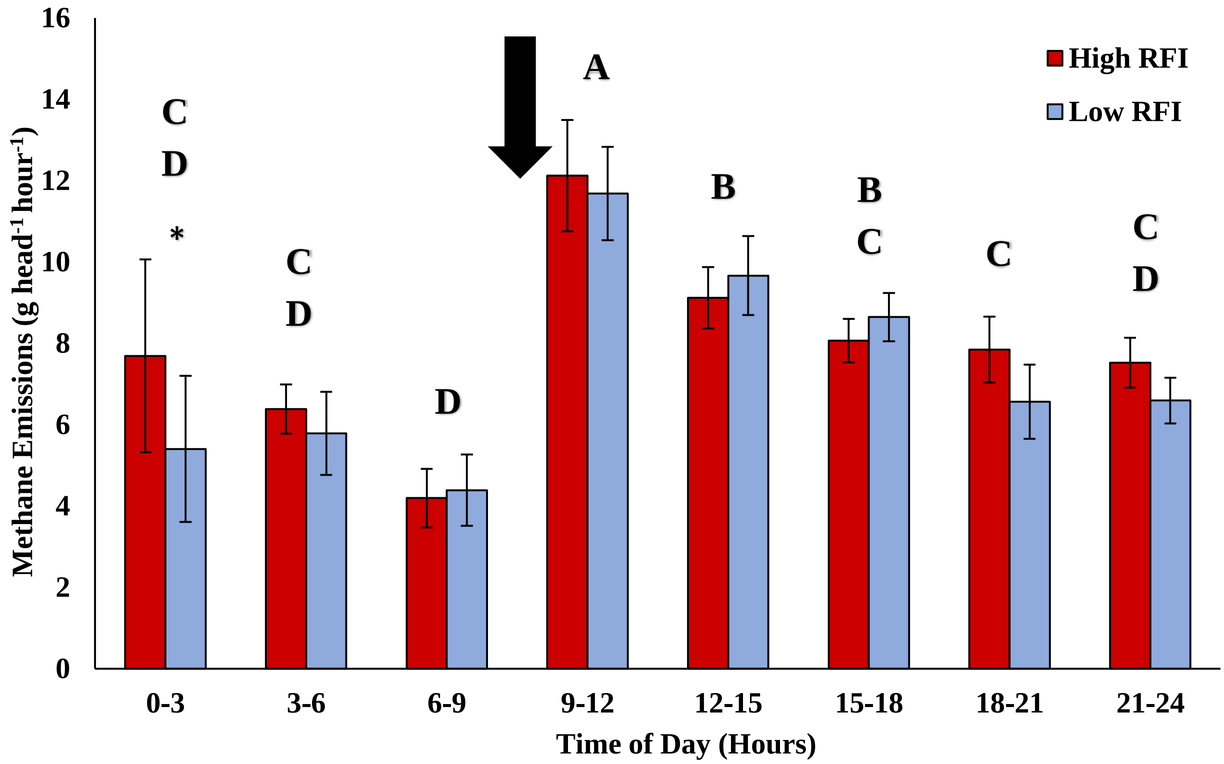


Fig 31. Mean diurnal pattern of CH_4 production (g head^{-1} hour^{-1}) for high and low RFI_{FAT} heifers grazing on pasture over a 24-hour period of time, separated into three hour time bins. Arrow indicates the timing of pasture entry.

* Indicates significant differences in CH_4 production between high and low RFI_{FAT} groups ($P<0.05$). Upper case letters indicate overall differences among sampling times ($P<0.05$).

2.3.6. Metabolomics

Table 24. Serum samples collected for metabolomics analysis.

Animal Type	Number of Cattle	Total samples	Notes
Cows on pasture	65	127	62 cows were sampled in both spring and fall 2015
Heifers on pasture	55	107	52 heifers were sampled in both spring and fall 2015
Heifers before and after transport	6	12	February 2016
Heifers in feedlot	60	60	February 2016: 20 of these heifers were also sampled on pasture (19 in both spring and fall along with their dam).
TOTAL	**186**	**406**	

2.4. Summary of Literature Cited

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3. GREENHOUSE GAS & NON-GHG IMPACTS

4. OVERALL CONCLUSIONS

Beef production comprises the single largest agricultural commodity in Alberta, and contributes more than $3B in primary sales, with an estimated $15B in added value to the provincial economy. Despite its prominence to the Alberta economy, the beef industry has been subject to significant pressures from factors such as bovine spongiform encephalopathy (BSE), off-shore country of origin labeling, rising costs of production, strong competition from a profitable annual crop sector, as well as increasing concerns over the environmental impact of cattle production (e.g. greenhouse gas emissions, endangered species habitat, impacts on water quality, etc.). Variable returns from cow/calf production has led to significant challenges in the long-term sustainability of the beef industry, as seen by an increasing reliance on off-farm income, ongoing conversion of perennial forage land into cropland, and a decreasing number of young ranchers entering this industry, among others.

Results of this research provide greater insight into how current beef cattle genetic improvement programs may impact cow/calf production. More specifically, our findings 1) revealed that cows with different MBVs for RFI did not differ markedly in grazing behavior, had marginally different diets and activity budgets under open-range grazing, and which in turn, led to minimal differences in cow/calf production metrics (the main exception being an increase in calf weights from cattle with high pRFI, and an associated reduction in cow weight gain in older cows), 2) suggest that current MBVs for RFI may not consistently translate into more productive cattle while grazing on extensive pasture systems, and therefore may require further exploration of the beef cattle genome to identify enhanced markers for efficiency under these conditions, 3) reinforces other studies indicating cattle with low RFI in drylot tend to produce more CH_4 yield but similar overall CH_4 production, and 4) failed to detect significant differences in CH_4 emissions from heifers previously found to have different RFI_{FAT} in drylot. Ultimately, results from this study highlight the need to more fully understand how beef cattle selection programs can be catered to support the development of a profitable and environmentally sustainable beef production industry in Western Canada.

5. SCIENTIFIC ACHIEVEMENTS

Updates on the scientific nature of this project have been given at a total of 11 different venues over the last 3 years, thereby providing widespread coverage on the questions being addressed and the work undertaken, including sharing preliminary research results. These presentations include the following:

Moore, C., N. Lansink, J. Basarab, C. Fitzsimmons, S. Nielsen, G. Plastow, and E. Bork. 2015. Testing production performance and foraging behavior relationships of cattle on pasture with divergent molecular breeding values for residual feed intake. Poster presented at the Livestock Gentec Conference, Edmonton, Alberta. 13-14 October.

Lansink, N., J. Crowley, C. Moore, B. Karisa, M. Abo-Ismail, S. Miller, P. Stothard, E. Bork, J. Basarab, and G. Plastow. 2015. Developing a small SNP panel to predict feed efficiency in Canadian beef cattle. Poster presented at the Livestock Gentec Conference, Edmonton, Alberta. 13-14 October.

Moore, C., N. Lansink, J. Basarab, C. Fitzsimmons, S. Nielsen, G. Plastow, and E. Bork. 2016. Using GPS collars and pedometers to track cattle grazing behaviour under open-range grazing. Poster presentation at the 69th International Meeting of the Society for Range Management, Corpus Cristi, Texas. Feb. 1-5.

Moore, C., N. Lansink, J. Basarab, C. Fitzsimmons, S. Nielsen, G. Plastow, and E. Bork. 2016. Testing performance of cattle on pasture with divergent molecular breeding values for residual feed intake. Oral presentation at the 69th International Meeting of the Society for Range Management, Corpus Cristi, Texas. Feb. 1-5.

Moore, C., N. Lansink, E.W. Bork, G. Plastow, S. Nielsen, J. Basarab, and C. Fitzsimmons. 2016. A framework for separating genetic and environmental influences on cattle performance on open-range pasture. Poster presentation at the Xth International Rangeland Congress, Saskatoon, Saskatchewan. July 18-22. Paper is pp 1125-1126, In: The Future Management of Grazing and Wild Lands in a High-Tech World: Proceedings 10th International Rangeland Congress/ Editors: Alan Iwaasa, H.A. (Bart) Lardner, Walter Willms, Mike Schellenberg and Kathy Larson on behalf of the 2016 International Rangeland Congress Organizing Committee.

Moore, C., N. Lansink, J. Basarab, C. Fitzsimmons, S. Nielsen, G. Plastow, and E. Bork. 2016. Activity budgets of rangeland cattle with divergent residual feed intake molecular breeding values. Poster presented at the Livestock Gentec Conference, Edmonton, Alberta. October 18-19.

Lansink, N. 2016. Performance of RFI selected cattle under extensive cow/calf production systems. PowerPoint video, Biocleantech Forum – Innovation Showcase, Ottawa ON., November 1-3.

Lansink, N., C. Moore, C. Fitzsimmons, J. Basarab, G. Plastow, and E. Bork. 2017. Testing performance of RFI selected cattle under extensive cow/calf production systems. Oral presentation at the 70th International Meeting of the Society for Range Management, St. George, Utah. January 29-Feb. 2.

Moore, C., N. Lansink, E. Bork, G. Plastow, J. Basarab, C. Fitzsimmons, and S. Nielsen. 2017. Activity budgets of rangeland cattle with divergent residual feed intake molecular breeding values. Poster presentation at the 70th International Meeting of the Society for Range Management, St. George, Utah, USA, Jan. 29-Feb. 2, 2017.

Moore, C., N. Lansink, E. Bork, G. Plastow, J. Basarab, C. Fitzsimmons, and S. Nielsen. 2017. Exploring rangeland habitat use of cattle with divergent molecular breeding values for residual feed intake. Oral presentation at the 70th International Meeting of the Society for Range Management, St. George, Utah, USA, Jan. 29-Feb. 2, 2017.

Lansink, N., C. Moore, C. Fitzsimmons, J. Basarab, G. Plastow, and E. Bork. 2017. Testing performance of RFI selected cattle under extensive cow/calf production systems. ALES Graduate Research Symposium. University of Alberta, Edmonton, Alberta. March 17.

8. NEXT STEPS

This project has identified several important outcomes that could have implications for beef cattle production, including relative to the GHG footprint of this industry. Further research is needed to clarify the potential of genetic selection (via feed efficiency) or the alteration of cow/calf foraging behavior within extensively managed pastoral systems, to alter the GHG of this industry. While no (statistically significant) emissions in methane were detected between cattle with contrasting genetic markers for feed efficiency on pasture, we did see trends that may justify examination of a much larger number of cattle (and over longer periods of time) in order to more confidently detect differences in feed efficiency and associated GHG emissions. Should this be the case, additional refinement of techniques to measure GHGs are warranted that will enable researchers to address these questions at the appropriate spatial and temporal scale.

9. COMMUNICATIONS PLAN

No peer-reviewed papers have been published yet. However, we anticipate at least 5 different papers from this work, one reviewing the cow/calf performance metrics, 2 others on the replacement heifers intake and greenhouse gas emissions in both drylot and subsequently on pasture, and 2 others on the animal behavior and dietary selection patterns by cattle under open-range grazing. Once the peer-review process has been completed, we will be work with commercial media to ensure widespread dissemination of the results of this study (and its implications for the beef industry and its environmental sustainability relative to GHGs).

To date, we have also worked closely with commercial media to make as wide an audience aware of this work. This includes providing material for articles appearing in the Western Producer, the Edmonton Examiner, and the Edmonton Journal. Information on this project has been aired on talk radio (770 AM News Radio, Calgary). In addition, we have relayed the scope and nature of this study to numerous audiences at field tours, seminars and workshops, including the Southern Alberta Women’s Grazing School, the Mattheis Ranch Centennial Open House, the Ladies Livestock Lessons Learned Grazing School, Livestock Gentec meetings, the Western Beef Development Center annual field day, delegates from the International Rangeland Congress, the Gentec Annual Summer Meeting and Field Tour, the Mixedgrass Prairie Conservation Forum, representative from GrowSafe Systems, and the International Mountain section of the Society for Range Management. We will continue to engage with the public and media to continue to disseminate the key findings of this study.