EFFECTS OF METABOLIZABLE PROTEIN SUPPLEMENTATION AND INTAKE ON COW PRODUCTION

by

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ABSTRACT

In 2008, two-yr-old Angus and Simmental x Angus pregnant, non-lactating heifers (n = 120, initial BW = 448 ± 36 kg) had individual feed intake determined using a GrowSafe feeding system. Dietary treatments were based on approximately 85% grass hay and 15% supplement. Supplements contained whole soybeans plus corn (102% MP) or dried distillers grains plus soybean meal (119% MP). After 35 d of intake measurement, heifers were placed into adjacent pens and fed their diets for an additional 50 or 82 d. Upon completion of the feeding trial, heifers were transported back to the ranch, managed as a single group, and production data were measured. Level of dietary MP had no effect ($P > 0.17$) on calf birthweight, adjusted 205-d weight, preweaning ADG, age at weaning, cow BW at calving, proportion of cows cycling at bull exposure, or proportion of cows to conceive. Dry matter intake per unit of $BW^{0.75}$ and RFI did not differ because of treatment and had no effect ($P > 0.17$) on any variables measured. In 2009, 24 of these heifers that had the highest and lowest RFI were selected to be fed a similar diet as in 2008 to determine the correlation of DMI per $BW^{0.75}$ and RFI between heifers (2008) and later as cows (2009). Cows were adapted to the diet for 10 d followed by a 70 d trial to determine individual feed intakes and weight gain. Dry matter intake per $BW^{0.75}$ was highly correlated (r = 0.71, $P < 0.01$) between first and second parities, as was residual feed intake (r = 0.83, $P < 0.01$). For 5 d, fecal samples were collected twice daily and indigestible ADF was used to estimate DM digestibility. Residual feed intake was negatively correlated with DM digestibility (r = -0.51, $P = 0.03$). Production traits from 2008 were analyzed to determine if cows found to be either high or low RFI in 2009 had similar levels of production. Low and high RFI cows did not differ ($P > 0.45$) in cow BW at calving, calf birthweight, calf ADG, 205-d weaning weight, or weaning age.

INTRODUCTION

Overall profitability of beef cattle herds is a function of animal output (weaning weight, yearling weight, carcass weight, etc.) as well as input costs (feed, land, labor, etc.). Potential increased profitability results from either an increase in animal output or reduced input costs. Animal output has been the focus of producers for many years as a means for increasing profits. This is exemplified by substantial increases in carcass weights over the past 30 years (NASS, 1997). However, this increase in production has also been paralleled by an increase in mature cow body weights. Cow carcass weights increased over 100 pounds from 1974 to 1997 (NASS, 1997). Due to this, mature cow weight is estimated at having increased by 300 lbs over the past 30 years This becomes a drawback when facing limited resources coupled with recent increases in cost for these limited resources. Feed costs for the U.S. cow-calf operator rose $161.57/cow between 2000 and 2008, a 59% increase (ERS, 2008). Also, feed costs represented 63% of the total annual cow cost and accounted for 50% of herd to herd variation in profit for producers in Illinois and Iowa (Miller et al., 1999). Research has shown a five percent improvement in postweaning feed conversion (F:G) to have an economic impact four times greater than a five percent improvement in postweaning average daily gain (ADG) (Gibb and McAllister, 1999). These numbers suggest the greatest capability for financial improvement lies in reducing input costs in the form of improved feed efficiency.

While research has focused on improving feed efficiency by measuring feed to gain ratios, bull selection based upon feed to gain ratios has shown to be correlated with ADG (r_g=-0.62, r_p=-0.74, Arthur et al., 2001) and mature cow size (-0.29±0.24, Herd and

Bishop, 2000; and -0.54, Archer et al., 2002). Over 40 years ago, Koch et al. (1963) described feed efficiency in terms of residual feed intake (RFI). Most often, RFI is derived by regressing feed intake against the animal's bodyweight (BW) and growth rate. However, a number of other factors may be added into the regression model based upon whatever production is considered to be (e.g., body composition, milk production, etc.) (Basarab et al., 2007). This linear regression is the animal's expected intake. The RFI value is calculated as the difference between actual feed intake by an animal and its expected intake. Thus, an animal with a negative RFI consumes less feed than expected to, and is therefore more efficient. Conversely, an animal with a positive RFI consumes more feed than expected and is less efficient.

Researchers have reported moderate and positive phenotypic correlations between RFI and DMI ranging from 0.60 – 0.72 depending upon breed. Similarly, correlations between RFI and F:G have ranged from 0.53 – 0.70 in the same studies (as reviewed by Basarab et al., 2004). Residual feed intake is not correlated with ADG (r_g = -0.04, r_p = -0.06; Arthur et al., 2001) and genetic correlations between post-weaning RFI and mature cow size are low (Herd et al., 2003). According to Herd et al. (2003), selecting for RFI could potentially result in lower feed inputs without sacrificing cow performance or increasing cow mature body size.

The biological mechanisms behind RFI are an increasingly researched area. How are animals able to eat less feed yet perform at a similar level to their counterparts? Greater digestibility of feed by low RFI animals is one hypothesis that has received some attention (Cruz et al., 2010; Krueger et al., 2007; Krueger et al., 2009).

Residual feed intake is moderately heritable (h^2=0.16-0.43) and implies selection of breeding stock for RFI could result in genetic improvement (Herd et al., 2003). The lowest heritability value of RFI was considered "modest" and had a high measurement error (Herd and Bishop, 2000). Research has shown that genetic variation in feed efficiency exists among growing and mature cattle; however, little evidence exists as to whether total production efficiency is improved (Archer et al., 1999). According to Kennedy et al. (1993), selection for RFI and production leads to the same responses as selection for feed intake and production. This leads us to question the relationship between dry matter intake (DMI) and production efficiency as well.

Although reducing feed costs represents the greatest opportunity to positively impact profitability, adequate nutrition must be provided to the animal so that optimum productivity is maintained, especially in growing heifers. This is due to the reproductive system being the last major organ system to mature and the nutritional status of the animal being the major environmental factor contributing to the speed of this process (Patterson et al., 1992). Burris and Priode (1958) showed that 6.1% more cows failed to calve for every delay of 20 d in the previous calving date. This illustrates the importance of developing heifers to reach puberty and conceive at an earlier age in order to maintain these animals within the herd for an extended period of time. In order to achieve this, the protein and energy content of the diet must be adequate during the development phase from weaning to breeding. Lately, more attention has been paid to the importance of nutrition during gestation. Inadequate nutrition during this stage can hurt production through lesser weaning weights and decreased reproductive performance of the dam and her female progeny (Patterson et al., 2003b). Few studies have examined whether or not feeding excess nutrients during gestation impacts subsequent production.

Therefore, the objectives of these studies were to: 1) determine if feeding gestating 2-yr-old heifers metabolizable protein (MP) in excess of NRC requirements would impact heifer production, 2) determine the repeatability of DMI and RFI over parities 3) determine relationships among RFI, DMI, and production measures, and 4) determine the relationship between RFI and digestibility.

LITERATURE REVIEW

Repeatability of DMI Measurements

The repeatability of DMI over parities is not well-researched. The repeatability of RFI is however. Due to the high correlation of RFI and DMI, the literature on the repeatability of RFI will be presented.

In order for RFI to be considered an economically relevant trait to be used in selection for breeding females, this measure must be repeatable later in an animal's lifetime to ensure that efficiency is maintained. Research was conducted at Trangie Agricultural Research Centre, N.S.W., Australia using 96 Angus heifers to determine post-weaning RFI. Fifty-six animals remained in the herd after having had 2 calves and were re-tested as 4-yr-old non-pregnant, non-lactating cows. Mature cow RFI was correlated with post-weaning RFI ($r = 0.39$; $P < 0.01$) when re-tested on an *ad-libitum* pelleted diet (Herd et al., 2006). Arthur et al. (1999) found similar correlations ($r = 0.36$; $P < 0.05$) using 284 Angus, Hereford, Polled Hereford, and Shorthorn females which were tested for RFI as weaned calves and re-tested as 4-yr-olds on a pelleted ration consisting of 70% hay. Dry matter intake was also correlated ($r = 0.30$; $P < 0.05$) between the two tests. Nieuwhof et al. (1992) reported a genetic correlation between post-weaning RFI in dairy heifers and RFI during first lactation of 0.58. Genetic and phenotypic correlation coefficients between post-weaning and mature mice RFI also fall within this range with values of 0.60 and 0.29, respectively (Archer et al., 1998). One study reported an extremely high genetic correlation between post-weaning and mature cow RFI of 0.98 when using 751 females (Archer et al., 2002).

Conversely, Basarab et al. (2007) concluded that cow RFI is a different trait than post-weaning RFI. Cows and their progeny were tested for RFI in the same year and the magnitude of the relationship was reported as "low" with a simple phenotypic correlation of 0.30. No studies discussed here reported significant correlations between RFI and ADG or mature cow weight (Arthur et al., 1999; Archer et al., 2002; Basarab et al., 2007).

All previous studies reviewed were conducted as confined feeding experiments using pelleted rations. Cow-calf producers need to know whether differences in efficiency, detected through traditional RFI testing, remain when cows move to pasture.

Pasture intake by either high or low RFI Angus cows (3 yrs old, 2^{nd} lactation) was investigated by Herd et al. (1998) where 44 cows (22 high RFI, 22 low RFI) were selected from a group of 56 that had been previously tested for RFI. Dry matter intakes did not differ between high and low RFI cows (13.2 vs. 12.5 kg/d; $P > 0.05$). Similar results were found by Meyer et al. (2008) where 28 purebred Hereford cows (mid to late gestation with second calf) were used to determine pasture intake of beef cows of known RFI classification. Low RFI cows had numerically lower intakes (12.4 vs. 15.6 kg/d) but were not statistically significant. This may be due to procedures used to calculate DMI or small numbers of animals.

Previous studies indicate that improved feed efficiency established at post-weaning is maintained into adulthood. However, these efficiencies have been confirmed only in confined feeding situations. Further research is warranted in the area of sustained feed efficiency on pasture with greater numbers and more accurate methodologies.

RFI and Production

Questions still remain on the reproductive performance and productivity of cows when selection pressure is placed on RFI. The effects of RFI selection on pregnancy rates, weaning rates, postpartum interval, etc. require more investigation. These findings could have a great impact on the acceptance of this measure into breeding programs.

Some concern exists that reproductive performance may be impaired due to genetic correlations of RFI and subcutaneous rump fat depth (0.42) found in steers and heifers tested in a feedlot (Herd et al., 2003) and greater deposition of lumbar fat in high RFI heifers (Kelly et al., 2009). One might hypothesize that if more efficient heifers have a different body composition with less fat stores, then age at puberty may possibly be delayed. Basarab et al. (2009) found that average age at puberty was similar in crossbred heifers selected for low and high RFI, however, a trend was measured for fewer low RFI heifers to reach puberty by 12 ($P = 0.09$) and 13 ($P = 0.09$) mo of age compared to high RFI heifers. Lancaster et al. (2006) found no difference in the onset of cycling between low, medium, and high RFI phenotypes or age at puberty of purebred Brangus heifers (114 and 115 heifers in yr 1 and 2, respectively). However, over the two years, only 29% of those heifers were pubertal by d 70. Shirley et al. (2006) found no significant correlation between RFI and age at puberty using 19 Brangus heifers.

Other important factors which describe reproductive efficiency include pregnancy rate, calving rate, and weaning rate. Arthur et al. (2005) examined maternal productivity of Angus cows divergently selected for post-weaning RFI. Data were collected on 185 Angus cows across 3 mating seasons. These cows were the result of 1 to 2.5 generations of selection and differed in estimated breeding value (EBV) for RFI by 0.8 kg/d. No differences were found for pregnancy rate, calving rate, and weaning rate between cows selected for high or low RFI. Conversely, trends have been reported for low RFI heifers to have lower pregnancy rates than high RFI heifers at d 27 (66.7 vs. 87.1%; P = 0.06) and 32 (70.0 vs. 87.1%; *P* = 0.10), the end of the breeding season (Basarab et al., 2009).

Delays in the calving date of cows can negatively affect profit by decreasing weaning weights. Arthur et al. (2005) found calves born to cows selected for low RFI were born 5 d later (*P* = 0.07) than calves born to cows selected for high RFI. Also, 22% of calves born to low RFI cows were conceived by natural service versus 13% of calves born to high RFI cows (*P* = 0.07). This can also be critical due to the increased value of calves born to proven artificial insemination (AI) sires and an ability to make quicker genetic change in a herd through AI. Although 1.5 generations of divergent selection for RFI did not affect maternal productivity, the authors suggested that further generations of selection should be monitored closely to determine if these differences become significant.

A different approach was taken by Basarab et al. (2007) to examine the relationship between RFI and dam productivity. This was determined using 222 yearling calves over 4 yrs and 10 production cycles after which dams (n = 136) were grouped into low, medium, or high RFI classifications based upon the efficiency of their calves. Progeny RFI ranged from -3.95 to 2.72 kg/d (as-fed basis) while progeny RFI adjusted for off-test backfat thickness ranged from -2.48 to 1.53 kg/d (as-fed basis). No differences were rerported among cows that produced low, medium, or high RFI calves adjusted for off-test backfat thickness in terms of pregnancy (95.6 vs. 95.3 vs. 96.0%; $P = 0.90$), calving (84.9 vs. 83.4 vs. 86.3%; $P = 0.62$), or weaning (81.5 vs. 80.2 vs. 82.3%; $P = 0.79$) rates. Calf birth weight, pre-weaning ADG, 200 d weight, cow production efficiency [((calf wean weight/cow weight at weaning) x 100))], and calving interval were also similar among dams which produced high, medium, or low RFI calves.

In the same study, a subset of cows was taken each year (37 in 2003-2004, 39 in 2004-2005, and 40 in 2005-2006) at the end of the fall grazing period (second trimester of pregnancy) and tested for RFI. Selection for testing was random based on progeny RFI. Dams producing low RFI progeny had lower feed intakes than dams producing high RFI progeny (10.80 vs. 12.22 kg DM/d; $P = 0.003$) and lower RFI values (-0.05 vs. 1.88 kg/d as fed; $P = 0.018$). Also, in agreement with Arthur et al. (2005), the subsequent calving date of cows producing low RFI progeny was 5-6 d later ($P < 0.001$) than cows producing medium or high RFI calves.

Researchers at Kansas State University conducted a study using 49 heifers sired by bulls with high or low RFI EBV. Heifers were synchronized and bred by timed AI followed by natural service. No differences ($P > 0.05$) in first service or overall pregnancy rates were found between heifers sired by high or low RFI EBV bulls. However, there was also no difference found in heifer RFI due to sire. The authors stated that "genetic differences in RFI calculated in growing bulls may not have been expressed on the lower plane of nutrition of these developing heifers (Bormann et al., 2009)." Therefore, in this study it is impossible to tell whether RFI has any effect on reproductive performance due to reproductive performance data being analyzed by sire group, not heifer RFI.

The literature provides no conclusive evidence for the relationship between RFI and reproduction. It would suggest that no detrimental effects on cow or calf performance are likely, but reproductive efficiency should be monitored over several lactations due to evidence of later calving dates with low RFI animals. Larger data sets are needed to determine if significant differences exist among reproductive efficiency measures due to RFI.

RFI and Digestibility

According to Richardson and Herd (2004), many biological mechanisms contribute to variation in RFI as determined from experiments on divergently selected cattle. These include body composition (5%), feeding patterns (2%), protein turnover, tissue metabolism, and stress (37%), heat increment of fermentation (9%), activity (10%), digestion (10%), and other factors such as ion transport not measured in their studies (27%). Differences in digestibility due to RFI are fairly well researched.

Krueger et al. (2009) fed growing Brangus heifers (273 ± 28 kg) high roughage diets over 4 yrs (n = 114 – 116/yr) to determine correlation coefficients between RFI and nutrient digestibilities. Within year, heifers with the highest (n = 18-20) and lowest (n =

18-20) RFI were selected to measure nutrient digestibilities using acid insoluble ash (AIA) methods. Residual feed intake was negatively correlated with dry matter (DM), neutral detergent fiber (NDF), acid detergent fiber (ADF), crude protein (CP), P, Ca, Zn, and Cu digestibilities ($P = 0.001$), but correlation coefficients were not stated. Low RFI heifers had higher DM digestibilities (DMD) (762.2 vs. 734.7 ± 33 g/kg DM; $P < 0.05$) compared to high RFI heifers. Digestion of NDF, ADF, CP, and P was also 4.0 to 5.5% greater ($P < 0.05$) in low RFI heifers compared to high RFI heifers. Similar results were found in Santa Gertrudis steers fed high roughage diets using AIA methods. Fifty-seven steers were randomly selected out of 120 tested for RFI for a 10 d collection of fecal samples. Residual feed intake was negatively correlated with DMD (-0.46; $P < 0.001$) and low RFI steers had greater DMD (722 vs. 659 ± 14 g/kg; $P < 0.01$) than high RFI steers (Krueger et al., 2007). However, differences in digestibility were not found using similar numbers of Brangus heifers in a second study.

Using alkane methods over two tests (n = 18 and 40), Richardson et al. (1996) found a trend for low RFI cattle to have a slight advantage in digestion of feed over high RFI cattle (DMD = 68.1 vs. 67.1 ± 0.5%; $P < 0.10$). The authors point out that this difference is not trivial. A 1% improvement in digestibility could reduce the amount of feed required by 2.3% for a 450 kg animal growing at 1.3 kg/d on feed with a DMD of 69%, a scenario typical of cattle on these tests (Richardson et al., 1996).

First generation steer progeny (n = 33) of parents previously selected for high or low post-weaning RFI were used in an experiment to investigate possible metabolic differences in Angus steers. The study consisted of two parts. First, the animals were

RFI tested in a feedlot and second, the animals were transported to an enclosed barn where more intensive variables (e.g. hormone levels, protein turnover, etc.) were measured while intake and gain data continued to be collected until harvest. Among the variables measured in the enclosed barn were DMD. Steers were fitted with fecal collection bags in the enclosed barn and feces were collected for 8 d. Dry matter digestibility did not differ ($P > 0.10$) between low and high RFI steers. However, DMD was negatively correlated with RFI (r = -0.44; $P < 0.05$) in the enclosed barn, but DMD was not significantly correlated RFI measured over both phases of the study (Richardson et al., 2004). The authors claim to have unpublished data showing a 2% difference in digestibility by feedlot steers following divergent selection for RFI but suggest caution in assigning variation in digestion as a major factor in explaining differences in RFI, assuming a conservative estimate of 10% (Richardson and Herd, 2004).

Richardson and Herd (2004) imply differences in rate of passage may contribute to differences in digestibility of low and high RFI cattle. Dittmar et al. (2007) addressed this question by evaluating digestive kinetics of 20-mo Brahman heifers (n = 25) fed a 12% complete ration at 2.2% of BW once daily in Calan gates for 77 d. Residual feed intake was calculated and on d 77 the heifers were pulse-dosed with an ytterbium chloride digesta marker. No significant differences ($P > 0.10$) were found between low and high RFI heifers for fecal output (2.9 ± 0.78 vs. 3.4 ± 0.78 kg fecal DM/d), turnover of material in the rumen (18.8 ± 3.92 vs. 20.6 ± 3.92 g DM/d), rumen residence time (5.4 ± 2.5 vs. 7.0 ± 2.5 hr), complete residence time for the system (61.5 ± 18.2 vs. 78.7 ± 18.2 hr), or gastro-intestinal residence time (68.4 ± 16.4 vs. 84.1 ± 16.4 h). A reduction in fecal output and reduced turnover of material in the rumen would agree with traditional thinking of increased DM digestibility. However, traditional thinking would also tend to correlate increased DM digestibility with increased rumen residence time, complete residence time for the system, and gastro-intestinal residence time; all of which are not the case in these data. This is the only data known to the author that has examined the relationship between RFI and digestion kinetics. Further research is warranted in this area as well as continued research into the relationship between RFI and nutrient digestion.

Metabolizable Protein

Protein supplementation of spring-calving beef cows is a necessary practice in many places due to the winter forage not fulfilling nutritional requirements. This has been demonstrated by Stalker et al. (2006) where they found prepartum supplementation of protein increased the proportion of live calves at weaning and weaning weights. Martin et al. (2007) also found that supplementing cows with protein during late gestation increased adjusted 205-d weaning weight, percent that calved in the first 21 d of the calving season, and overall pregnancy rate. Similar results including a delay in calving date of 5 d for non-supplemented cows grazing winter range was found by Larson et al. (2009).

The studies discussed thus far were designed using CP requirements to determine supplementation strategies; however, two systems exist in beef cattle production for determining protein requirements of the animal, CP (NRC, 1984) and MP (NRC, 1996).

Metabolizable protein requirements take into account the amount of protein needed to bypass the rumen (undegradable intake protein, UIP) and be absorbed in the small intestine, whereas CP does not. Therefore, designing supplementation programs on the CP system may result in MP deficiencies.

Lardy (1997) found the MP value of grazed winter forage to be low, therefore creating an MP deficiency in spring-calving heifers. Research was conducted at the Corona Range and Livestock Research Center in New Mexico that evaluated the effects of increasing levels of MP fed to 2-yr-old lactating, primparous cows. Metabolizable protein was fed at three levels: 1) 261 g of MP, met the MP requirement; 2) 31 g of excess MP; or 3) 36 g of excess MP. The authors showed that as MP in the diet increased, postpartum interval of the cow decreased (P = 0.03), however, pregnancy percentage was not influenced ($P = 0.54$). Excess MP also improved BCS at nadir, which indicates it may be easier for these cows to retain body condition. Milk production was also increased greater ($P = 0.10$) which paralleled calf weaning weights (Waterman et al., 2006).

The previous study looked at supplementation during lactation. Patterson et al. (2003b) examined BW and BCS change, and pregnancy rates in 2-yr-old heifers when supplementing prepartum heifers based upon the CP or MP system. Data was measured on 2,120 pregnant yearling heifers over 2 yrs at a commercial ranch in the Nebraska Sandhills. Results showed that supplementation of UIP to meet MP requirements versus conventional CP supplementation improved subsequent pregnancy rates in 2-yr-old heifers, but showed no increase in calf weaning weight. Interestingly, the increased pregnancy rate due to MP supplementation was not explained by improved body condition scores or greater weight change prior to calving. Heifers supplemented with MP were heavier in October at the time of weaning; however, the fact that calf weaning weights were not increased does not provide evidence of differences in milk production. This study provides evidence that basing gestational feeding programs on MP rather than CP provides an avenue to increase production and profitability of the herd.

Feed Intake

An alternate way to increase profitability is by decreasing cow dry matter intake (DMI) without sacrificing production, essentially improving feed efficiency. The drawback to selecting solely for DMI is that relationships exist between DMI and production traits in most instances. The objective of Jenkins and Ferrell (2004) was to evaluate different crossbred cows and their ability to convert varying levels of feed resources to calf weaning weight. The diet consisted of corn silage and soybean meal (2.60 Mcal of ME/kg of DM, 13% CP, and 38.6% DM). Cows were fed one of three feeding rates, 49 or 76 g of DMI/$BW^{0.75}$, or ad libitum to mimic marginal, adequate, and high DM availabilities. Cows were housed in pens (3-4/pen) with a total of 10-12 cows/feeding rate group. Pens were equipped with electronic headgates allowing for measurement of individual feed intake. There was no linear effect of DMI on calf birthweight, but a positive linear relationship was reported between calf weaning weight adjusted to 200-d and cow DMI.

Jenkins et al. (2000) examined differences in lactation traits and calf weights under varying energy availabilities. Cows were fed a corn silage based diet with alfalfa haylage and subjected to three feeding rates, 132 or 189 kcal ME/BW$^{0.75}$, or ad libitum. Several breed groups were tested according to sire of the cow. The number of observations per breed group was 24, therefore n = 8 per feeding rate. The authors reported a quadratic relationship between calf BW at 140 d and daily cow metabolizable energy intake when pooled over sire breed groups, however, daily metabolizable energy intake during the prepartum period did not affect calf birthweight.

Current measures of feed efficiency such as RFI account for body size and growth rate so that other production variables are not influenced. A drawback to this measure is that it requires a 70 d test period, whereas DMI can be accurately measured over 35 d (Archer et al., 1997); and body weight may also be easily measured. This leads to the question of whether or not DMI adjusted for bodyweight when fed in a pen setting with competition is related to production traits.

EFFECTS OF GESTATIONAL METABOLIZABLE PROTEIN AND DRY MATTER INTAKE ON SUBSEQUENT PRODUCTION TRAITS IN PRIMIPAROUS HEIFERS

Summary

The objective of this experiment was to determine if feeding two levels of dietary metabolizable protein (102% vs. 119% of NRC requirements) and biological variation in feed intake during the second and third trimesters of gestation influenced subsequent production traits in primiparous heifers. Two-yr-old Angus and Simmental x Angus heifers (n = 120, initial BW = 448 ± 36 kg) had individual DMI determined using a GrowSafe feeding system. Dietary treatments were based on approximately 85% grass hay and 15% supplement. Supplements contained whole soybeans plus corn (102%) or dried distillers grains plus soybean meal (119%) and each supplement was assigned to two pens. Heifers were randomly assigned to one of three periods (P; 40/P) followed by random assignment to one of four pens (10/pen). Diets were fed at approximately 10.3 kg DM·heifer^{-1}·d^{-1}. After 35 d of intake measurement, heifers were placed into adjacent pens and fed their diets for an additional 50 (P1 and 2) or 82 d (P3). The next 40 heifers (P2) were placed in the facility and DMI was again determined over 35 d. Upon completion of the feeding trial, heifers were transported back to the ranch, managed as a single group, and production data were measured. Level of dietary MP had no effect (P > 0.17) on calf birthweight, adjusted 205 d weight, ADG, age at weaning, cow BW at calving, proportion of cows cycling at bull turnout, or proportion of cows to conceive. Dry matter intake per unit of BW$^{0.75}$ (range = 0.057 – 0.187 kg/kg) and RFI (range = -4.26 to 4.24) also had no effect (P > 0.16) on any of the variables measured. Under the

conditions of this study, feeding MP in excess of NRC recommendations during mid- to late-gestation did not enhance heifer productivity. Heifers that consumed less DM/kg $BW^{0.75}$ produced similarly to heifers that consumed more DM/kg $BW^{0.75}$.

Introduction

Protein supplementation of spring-calving beef cows is a necessary practice in many places due to the winter forage not fulfilling rumen microbial and animal nutritional requirements. Metabolizable protein is defined as the true protein absorbed by the intestine, supplied by microbial protein and undegraded intake protein (UIP). Lardy (1997) found the MP value of grazed winter forage to be low, resulting in an MP deficiency. Patterson et al. (2003b) demonstrated that supplementation of UIP to meet MP requirements vs. conventional CP supplementation improved pregnancy rates in 2-yr-old heifers, but did not increase calf weaning weight.

An alternate way to decrease breakeven cost is by decreasing cow feed intake (input) without sacrificing weaning weights or reproductive efficiency (output). Jenkins and Ferrell (2004) reported a positive linear relationship between calf weaning weight adjusted to 200 d and cow DMI. Earlier, Jenkins et al. (2000) reported a quadratic relationship between calf BW at 140 d and daily cow ME intake when pooled over sire breed groups. However, neither of these studies allowed for biological variation and competition to have an effect on DMI. Also, a protein deficiency can decrease feed intake. Nitrogen deficiency is common when feeding low-nitrogen, high-fiber forage, and supplemental nitrogen often increases DMI (Galyean and Goetch, 1993).

The objectives of this study were to: 1) determine if feeding gestating 2-yr-old heifers MP in excess of NRC requirements would impact heifer BW at calving, weaning weight, calf age at weaning, proportion of heifers cycling at bull turnout, and proportion of cows to conceive the following year; and 2) determine if heifer DMI, DMI per unit of $BW^{0.75}$, and RFI during the second and third trimesters of gestation influenced the same production variables.

Materials and Methods

Animals

The research protocols in this study were approved by the Montana State University Animal Care and Use Committee (AA-301). In September 2008, one hundred twenty primiparous Angus and Simmental x Angus heifers (average initial BW = 448 ± 36 kg) in the second trimester of pregnancy were transported from the Bair Ranch Foundation, Martinsdale, Montana, to Bozeman Agricultural Research and Teaching Farm (latitude 45˚ 39’ N, longitude 110˚ 04’ W, altitude 1495 m), Montana State University, Bozeman, Montana. Heifers used were purebred Angus (n = 26), 50% Simmental x 50% Angus (n = 60), or 25% Simmental x 75% Angus (n = 27). All animals were individually identified by an electronic identification transponder button in the middle of the left ear allowing for measurement of individual feed intake in a GrowSafe feed intake system (GrowSafe Systems Ltd., Airdrie, Alberta, Canada).

Design and Treatments

Upon arrival, heifers were randomly assigned to one of three periods (**P1, P2,** and **P3**; 40 heifers/period). Heifers were then randomly assigned to one of four pens (10 head/pen). Pens with GrowSafe feeders measured 7.3 m x 11.0 m. The GrowSafe feeders were covered by an open sided metal barn that prevented precipitation from entering the feeding stations. Pens used while not on the intake trial were covered by a sloped shed which protected the feed bunks from precipitation. Wood chips were used as bedding and placed in the pens twice monthly.

Dietary treatments were based on approximately 85% grass hay and 15% supplement. Supplements contained whole soybeans plus corn (**102% MP**) or dried distillers grains plus soybean meal (**119% MP**) and each supplement was assigned to two pens; Table 1. Diets were fed twice daily at approximately 10.3 kg DM/d. Diets were fed in this manner so that ADG did not exceed 0.63 kg/d. The grass hay was chopped to a length of 10 cm through a hammer mill. Cows had ad libitum access to water and trace mineralized salt blocks (White Block, North American Salt Company; Overland Park, KS). The rations were mixed for each feeding in a Roto-Mix TMR Mixer/Feeder (Dodge City, KS) and fed at 0730 and 1630 h.

Data Collection

Individual DM intakes were recorded using the GrowSafe system (two feeders/pen). After 35 d of intake measurement (Archer et al., 1997), heifers were placed into adjacent pens and fed their treatment for an additional 50 (P1 and P2) or 82 d (P3). The next 40 heifers (P2) were placed in the facility and DMI was again determined over

35 d. Weights were taken on 2 consecutive days upon arrival and the average was used as the initial weight. Single weights were then taken on heifers every two weeks. After intake data had been collected, heifers were returned to the ranch.

Table 1. Composition and analysis of experimental diets (DM basis) formulated to provide 102 or 119% of MP requirements for mid- to late-gestation heifers

Item	102 % MP	119% MP
Ingredient, %		
Grass hay	84.5	82.5
Whole soybeans	10.2	
Dried distillers grains		12.8
Soybean meal		2.0
Corn grain, cracked	3.8	
Calcium carbonate	0.6	0.6
Mineral supplement[a]	0.9	0.8
Nutrients		
CP, %	10.7	12.6
CP intake, g/d	1112	1273
DIP, % of requirements[b]	100.0	100.0
MP, % of requirements[b]	102.0	119.0
NE_m	0.68	0.69
NE_g	0.41	0.41
Ca	0.79	0.78
P	0.38	0.44

[a]Contained 12.10% Ca, 4.00% P, 20.00% NaCl, 1.00% Mg, 2500 ppm Cu, 35.20 ppm Se, 5000 ppm Zn.
[b]Calculated as requirements for 409 kg gestating heifers gaining 0.63 kg/d according to NRC (1996).

Rump fat was measured ultrasonographically using a PIE scanner-200 (PIE Medical Equipment Co., Maastrict, The Netherlands) equipped with an 18-cm, 3.5-MHz linear array transducer. Measurements were taken on d 16 and 83 to calculate rate of fat deposition, with d 0 being the day of arrival to the testing facility. Images were obtained at the juncture of the gluteus medius and biceps femoris muscles between the hook and pin bones, parallel to the backbone. Upon completion of the trial, heifers were returned to the ranch, managed as a single group, and production data were measured.

Calving began on January 31, 2009 and ended on March 22, 2009. Upon calving, male calves were castrated by the elastic band method, vaccinated for clostridial diseases; and birthweights, calving scores, and cow weights were collected. Calving ease scores were recorded as follows: 1 = calved with little or no assistance; or 2 = difficult assisted delivery, caesarean delivery, or abnormal presentation. Calf vigor scores were recorded as: 1 = nursed on its own; or 2 = required assistance to suckle, dead on arrival, or dead shortly after birth. Calves were vaccinated for IBR, PI3, BVD, BRSV, *haemophilus somnus*, *pasteurella multocida* and clostridial diseases, and treated with a pour-on parasiticide at weaning, then given their booster vaccinations two weeks after weaning. At weaning, all calves were weighed and tagged with a half-duplex radio frequency transponder button in the left ear.

Blood Collection and Radioimmunoassay

Blood samples were collected from the lactating cows via coccygeal venipuncture on May 28 and June 11, 2009. Samples were immediately placed on ice and centrifuged within 2 h. Serum was decanted and stored until assays were performed to determine concentrations of progesterone. Concentrations of progesterone were determined directly without extraction by solid-phase RIA (Coat-a-Count kit; Diagnostic Products Corp., Los Angeles, CA) as described by Bellows et al. (1991). All samples were analyzed in one assay. The interassay CV was 6.68% and assay sensitivity was 0.08 ng/mL.

Determination of Estrual Status and Pregnancy

Concentrations of progesterone were used to determine estrual status (estrual or anestrual) of the heifers before exposure to bulls. Females with concentrations of progesterone > 1 ng/ml of serum on either date were considered to have luteal function and categorized as estrual. Heifers were evaluated for pregnancy status via rectal palpation on September 15, 2009 by an experienced technician.

Statistical Analysis

Seven heifers were removed from the study due to late term abortions or abnormally low intakes. A total of 113 animals were included in the analysis. Gain was determined in two ways: 1) initial and final weights for the 35-d intake test with measures of BW obtained within 6 d after entering and within 6 d before leaving the GrowSafe pens to calculate ADG; and 2) multiple weights taken (P1 = 5, P2 = 6, P3 = 7) that coincided best with the intake test and spanning 70 (P1) or 84 d (P2 and P3). The multiple weights of individual heifers were then modeled by linear regression of BW against time using the regression procedure of SAS (SAS Inst., Inc., Cary, NC). This is referenced as Modeled ADG. All heifer weights were adjusted for conceptus growth. Weight of the conception products were calculated by days of pregnancy, as determined from subsequent calving date, assuming a gestation period of 282 d and using the equation relating time of pregnancy to conceptus weight (NRC, 1996): Conceptus (kg) = (subsequent calf birth weight in kg × 0.01828) × $e^{((0.02 \times t) - (0.0000143 \times t^2))}$ where t is the number of days of pregnancy. Residual feed intake was calculated as the residual from the linear regression average daily DMI on modeled ADG and mid-test $BW^{0.75}$. To examine the relationships among DMI, DMI/$BW^{0.75}$, RFI, and performance and production traits, partial correlation coefficients were determined using the MANOVA function of PROC GLM of SAS with treatment, breed, period, and pen included in the model as class variables. Cow production traits, excluding percent cycling at bull turnout, pregnancy rate, calving ease, and calf vigor were subjected to an analysis of variance using PROC MIXED of SAS. Treatment and breed were fit as fixed effects with period and pen fit as random effects. Treatment was tested by the error term pen (period x treatment). Breed was tested using the residual error term. Dry matter intake per unit of $BW^{0.75}$ was fit as a continuous variable in the same model and tested by the residual. All interactions of DMI/$BW^{0.75}$, treatment, and breed were tested by the residual error term. Differences due to treatment in percent cycling at bull exposure and percent conceiving were tested by Chi Square analysis using PROC FREQ of SAS. Calving ease and calf vigor scores were analyzed by Chi Square. Differences in percent cycling, pregnancy rate, and calving scores due to DMI and DMI/$BW^{0.75}$ were examined by separating feed intake into low, medium, and high groups that were < 0.5SD, ± 0.5 SD, and > 0.5 SD from the mean and analyzing by Chi Square.

Results and Discussion

Cow BW at calving was greater (*P* = 0.05) for breeds with greater Simmental influence. Angus, 25% Simmental x 75% Angus, and 50% Simmental x 50% Angus heifers weighed 464, 479, and 489 kg, respectively, at calving. This weight difference is most likely attributable to increased heterosis as the percentage of Simmental influence increases.

Feeding MP in excess of NRC (1996) recommendations to heifers in mid- to late-gestation did not affect ($P > 0.17$) any of the performance or production variables measured (Table 2). Waterman et al. (2006) reported that BCS at nadir was slightly improved by supplementing 2-yr-old primiparous cows with 31 g of excess MP. Similarly, Patterson et al. (2003a) found supplementing prepartum cows to meet MP requirements exhibited a greater ADG compared to cows supplemented to meet CP requirements. In the present study, ADG was not changed by feeding additional MP. Waterman et al. (2006) reported increased weaning weights as well as a decrease in postpartum interval, but found no difference in pregnancy rates due to additional amounts of dietary MP; while Anderson et al. (2001) also found no difference in pregnancy rates when supplements met either MP or CP requirements postpartum.

Richards et al. (1986) suggested that the BCS of cows entering the calving season influenced whether or not a supplementation response was measured. Cows with a BCS ≥ 5 and consuming a high-quality postpartum diet showed no improvements in return to estrus at the beginning of the breeding season or subsequent pregnancy rates compared to cows with lower BCS. Postpartum supplementation of excess MP has shown increased milk production (Waterman et al., 2006). Likewise, results from other studies have also shown cows supplemented with UIP had increased milk production (Appeddu et al., 1997; Sawyer, 2000). However, in those experiments cows were supplemented postpartum rather than during gestation as in the current study.

Table 2. Performance and production characteristics of 2-yr-old heifers when fed 102 vs. 119% of dietary metabolizable protein (MP) requirements in mid- to late-gestation

	MP, % of NRC requirement			
Trait	102%	119%	SEM[a]	*P* – value[b]
Heifers				
Initial BW, kg	447.6	445.9	9.1	0.62
ADG, kg/d[c]	.61	.53	.07	0.32
Modeled ADG, kg/d[d]	.57	.59	.16	0.52
FCR[c]	18.77	21.25	7.44	0.74
Modeled FCR[d]	27.80	22.61	8.41	0.22
Rate of fat deposition, cm/d[e]	.0012	.0020	.00034	0.31
Cow BW @ calving, kg	478.0	476.0	9.5	0.65
Cycling at bull turnout, %	95.9	98.0		0.53
Pregnancy rate, %	84.3	89.6		0.44
Calves				
Birth weight, kg	37.0	38.8	.64	0.94
Calving ease[f], %	77.8	72.6		0.54
Calf vigor[g], %	90.7	88.2		0.68
ADG, kg/d[h]	.94	.96	.03	0.23
205 d weaning weight, kg	235.5	242.6	6.4	0.17
Weaning age, d	199.8	199.8	3.6	0.35

[a]For n = 6.
[b]*P*-value for Type 3 test of fixed effects except for traits expressed in percent which is the probability from analysis by Chi Square.
[c]FCR = feed conversion ratio; ADG and FCR were calculated using initial and final weights on 35-d intake test.
[d]Modeled ADG and FCR were calculated using linear regression of BW measured over 70 or 84 d.
[e]Calculated from two ultrasound measurements taken 67 d apart during feeding trial.
[f]Determined as the percentage of calves that calved with little or no assistance.
[g]Determined as the percentage of calves that suckled with no assistance.
[h]From birth to weaning.

The mechanisms of postpartum supplementation and its effects on production are different than prepartum supplementation. Prepartum supplementation of pregnant heifers to meet MP vs. CP requirements has increased pregnancy rates in 2-yr-old cows without affecting calf weaning weight, which does not support a hypothesis of increased milk production (Patterson et al., 2003b). The exact mechanism of increased pregnancy rate due to prepartum MP supplementation is not fully understood. However, Patterson et al. (2003b) hypothesized the mechanism may be similar to the response measured after fat supplementation during gestation (Bellows, 1997), and may be associated with changes in hormonal status of the postpartum cow. The response measured by Patterson et al. (2003b), but not in this study, may be a result of an MP deficiency. However, in the current study, both treatment groups were fed to meet MP requirements.

Dry matter intake was not different between treatments ($P = 0.65$). Dry matter intake ranged from 5.86 to 20.46 kg/d and averaged 12.05 ± 2.76 kg/d. The range of $DMI/BW^{0.75}$ was 0.057 to 0.187 kg/kg and averaged 0.114 ± 0.024 kg/kg. Dry matter intake ($P > 0.20$) and $DMI/BW^{0.75}$ ($P > 0.17$) were not significant sources of variation in the model for any production variables measured, even though weaning weight has been shown to increase with increased DMI (Jenkins and Ferrell, 2004).

Positive correlations were measured ($P < 0.05$) between DMI and initial BW, ADG, modeled ADG, and cow BW at calving; whereas, $DMI/BW^{0.75}$ was only correlated ($P < 0.05$) with modeled ADG (Table 3). We believe the modeled ADG presents a better fit because the measurement of gain was longer and therefore more accurate. The coefficient of determination (R^2 x 100) for the model of BW on time was 98.0, 97.0, and 96.2% for period 1, 2, and 3, respectively. No interactions ($P > 0.05$) were found for any of the variables measured.

No differences in calving scores, percent cycling at bull turnout, or pregnancy rate were measured due to differences in DMI ($P > 0.35$) or $DMI/BW^{0.75}$ ($P > 0.17$; Table 4). The pregnancy rate of cows with a low $DMI/BW^{0.75}$ was 12 percentage units lower than the average of medium and high DMI/BW$^{0.75}$ cows but not significant. No studies known to the author have addressed the relationship between feed intake expressed per unit of bodyweight and reproductive performance.

Residual feed intake ranged from -4.26 to 4.24 kg/d and averaged 0.0 ± 1.63 kg/d. The model of DMI = mid-test BW$^{0.75}$ + ADG resulted in an equation that accounted for 32.6% (P < 0.01), 13.5% (P = 0.08), and 37.7% (P < 0.01) of the variation in DMI for periods 1, 2, and 3, respectively. This model was used to predict expected feed intake. The deviation of actual cow DMI from expected DMI predicted by the model resulted in the RFI range reported above. Residual feed intake did not differ because of treatment (P = 0.48) and was not correlated (P > 0.16) to any variables measured over the study (Table 3). The proportion of cows cycling at bull exposure and calving scores did not differ because of RFI classification. Cows classified as medium RFI had lower pregnancy rates (P < 0.01, Table 5), but no biological reasoning supports this data. Residual feed intake, which is highly correlated with DMI, has been reported as not affecting pregnancy rates in multiparous cows (Arthur et al., 2005; Basarab et al., 2007). More discussion on the literature pertaining to RFI and production is presented in Exp. 3 of the second study (p. 42).

Implications

Feeding gestating heifers excess amounts of metabolizable protein above the recommendation made by the NRC (1996) provided no improvement in reproductive efficiency. Differences in gestational DMI and RFI did not alter subsequent calf productivity.

Table 3. Partial correlations of gestational DMI, DMI/BW$^{0.75}$, and residual feed intake (RFI) with performance and production measures in 2-yr-old heifers and calves

Trait	No.	DMI, kg/d	DMI/BW$^{0.75}$	RFI
Heifers				
Initial BW	113	.33**	.03	.03
ADG[a]	113	.20*	.16†	-.09
Modeled ADG[b]	113	.40**	.30**	-.02
FCR[a]	113	.09	.14	.01
Modeled FCR[b]	113	.17†	.13	.14
Rate of fat deposition[c]	113	.04	.03	.08
Cow BW at calving	110	.25*	.05	-.06
Calves				
Birth weight	112	.15	.04	.07
ADG[d]	83	.07	-.05	-.01
Adjusted 205 d weaning weight	83	.06	-.07	-.04
Weaning age	83	.01	.02	.07

*$P < 0.05$; **$P < 0.01$; †$P < 0.10$

[a]FCR = feed conversion ratio; ADG and FCR were calculated using initial and final weights on 35 d intake test.

[b]Modeled ADG and FCR were calculated using linear regression of BW measured over 70 or 84 d.

[c]Calculated from two ultrasound measurements taken 67 d apart during trial.

[d]From birth to weaning.

Table 4. Calving and reproduction characteristics of heifers classified as having low, medium, or high DMI per metabolic bodyweight[a] and low, medium, or high DMI[b]

	$DMI/BW^{0.75}$ level			DMI level			Contrast[c]	
Trait	Low	Medium	High	Low	Medium	High	$DMI/BW^{0.75}$	DMI
Calving ease[d], %	79.4	78.1	66.7	74.2	80.0	69.0	0.43	0.55
	(34)[f]	(41)	(30)	(31)	(45)	(29)		
Calf vigor[e], %	91.2	90.2	86.7	93.6	91.1	82.8	0.83	0.36
	(34)	(41)	(30)	(31)	(45)	(29)		
Cycling at bull exposure, %	97.1	97.5	96.0	93.9	100.0	95.8	0.94	0.29
	(35)	(40)	(25)	(33)	(43)	(24)		
Pregnancy rate, %	78.1	93.0	87.5	86.7	86.4	88.0	0.17	0.98
	(32)	(43)	(24)	(30)	(44)	(25)		

[a]Low, medium, and high $DMI/BW^{0.75}$ heifers were < 0.5 SD, ± 0.5 SD, and > 0.5 SD from the mean $DMI/BW^{0.75}$ of 0.114 ± 0.024 kg/kg, respectively.
[b]Low, medium, and high DMI heifers were < 0.5 SD, ± 0.5 SD, and > 0.5 SD from the mean DMI of 12.05 ± 2.76 kg/d, respectively.
[c]Probability of a Chi Square test.
[d]Determined as the percentage of calves that calved with little or no assistance.
[e]Determined as the percentage of calves that suckled with no assistance.
[f]Number of observations per treatment.

Table 5. Calving and reproduction characteristics of heifers classified as having low, medium, or high residual feed intake (RFI)[a]

	RFI level			
Trait	Low	Medium	High	*P* – value[b]
Calving ease[c], %	78.1	71.8	76.5	0.81
	(32)[e]	(39)	(34)	
Calf vigor[d], %	84.4	89.7	94.1	0.43
	(32)	(39)	(34)	
Cycling at bull exposure, %	96.9	100.0	93.3	0.27
	(32)	(38)	(30)	
Pregnancy rate, %	93.9	73.0	96.6	< 0.01
	(33)	(37)	(29)	

[a]Low, medium, and high RFI heifers were < 0.5 SD, ± 0.5 SD, and > 0.5 SD from the mean RFI of 0.0 ± 1.63 kg/d.
[b]Probability of a Chi Square test.
[c]Determined as the percentage of calves that calved with little or no assistance.
[d]Determined as the percentage of calves that suckled with no assistance.
[e]Number of observations per treatment.

REPEATABILITY OF DRY MATTER INTAKE OVER PARITIES AND RELATIONSHIPS AMONG RESIDUAL FEED INTAKE, DRY MATTER DIGESTIBILITY, AND PRODUCTION MEASURES

Summary

Feed costs account for approximately two-thirds of total cash inputs for cow/calf producers. Selecting cows that consume less DM, but maintain production, would lower breakeven costs. The objectives of these two experiments were to determine repeatability of DMI and RFI over parities, calculate residual feed intake (RFI), and examine the relationships among RFI, diet DM digestibility, and production traits. The previous study determined individual DMI and RFI for 120 gestating, primiparous heifers in 2008. In Exp. 1, twenty-four of these heifers that had the highest and lowest RFI were selected for this 2009 experiment. Cows (3-yr-old, BW = 593 ±50 kg, second trimester gestation) were fed a diet composed of 74% grass hay and 26% grain-based supplement (104% of MP requirement) to determine the correlation of DMI per $BW^{0.75}$ and RFI between heifers (2008) and later as cows (2009). Animals were in a similar gestational state both years. Diets were limit fed at 12.7 kg $DM \cdot cow^{-1} \cdot d^{-1}$ using a GrowSafe system. Cows were adapted to the diet for 10 d followed by a 70 d trial to determine individual feed intakes and weight gain. Residual feed intake was calculated as the residual from the linear regression of DMI on $BW^{0.75}$ and ADG. Dry matter intake per $BW^{0.75}$ was highly correlated ($r = 0.71$, $P < 0.01$) between first and second parities, as was RFI ($r = 0.83$, $P < 0.01$). Residual feed intake ranged from 4.46 kg/d to -4.58 kg/d. Immediately following Exp. 1, cows were fed for an additional 5 d for collection of feces (Exp. 2). Grab samples were collected daily at 0600 and 1800, and indigestible ADF was used to estimate DM

digestibility. Residual feed intake was negatively correlated with DM digestibility (r = -0.51, *P* = 0.03, range = 62.6% to 74.2%) but had no relationship with digestible DMI (*P* = 0.32). Results showed that DMI and RFI were repeatable over parities, and as RFI increased, DM digestibility of a forage-based diet decreased. In Exp. 3, production traits from yr 1 were analyzed to determine if cows found to be either high or low RFI in Exp. 1 had similar levels of production. Low and high RFI cows did not differ (*P* > 0.45) in cow BW at calving, calf birthweight, calf ADG, 205-d weaning weight, or weaning age.

Introduction

Genetic selection in the cattle industry during the past three decades has focused on growth and carcass traits. As a result, there has been a significant increase in mature cattle weights and consequently, DM consumption per animal. Breakeven costs could be lowered if input costs (feed) were reduced without a negative effect on output (e.g. weaning weights and reproduction; Archer et al. 1999). Selection for improved feed efficiency using G:F ratios has been questioned because of the correlation of ADG and G:F ratios. Therefore, animals have indirectly been selected for growth (Crews, 2005). Koch et al. (1963) first proposed using residual feed intake (RFI) as an alternative measure of feed efficiency because it is independent of growth. RFI is the difference between an animal's actual DMI and its expected DMI necessary to meet requirements for maintenance and production. Residual feed intake is calculated by a phenotypic regression of actual intake or DMI on $BW^{0.75}$ and predicted ADG (Crews et al. 2006).

Several questions remain unanswered regarding the biological factors which can be attributed to RFI results described in the literature. Richardson et al. (1996) reported that young bulls and heifers (sorted by low and high RFI) differed slightly in diet DM digestibility. The low RFI group exhibited only a 1% improvement in DM digestibility when compared to the high RFI group. In contrast, Cruz et al. (2010) reported no differences in DM digestibility between high and low RFI steers.

Additional questions have been raised regarding the repeatability of RFI. For example, do cows with a negative RFI early in their productive lives retain this trait after producing several progeny? Herd et al. (2006) and Arthur et al. (1999) both reported a significant correlation of RFI with heifers tested as calves post-weaning and again as 4-yr-old cows.

One of the major interests in RFI research is whether or not females determined as having low or high RFI differ in measures of production (progeny birthweight, weaning weight, etc.). Dams that produced low, medium, or high RFI calves produced calves of similar birthweights, pre-weaning ADG, and 200 d weight (Basarab et al., 2007). Pregnancy rate, calving rate, and weaning rate were also similar between cows selected for high or low RFI (Arthur et al., 2005).

The objectives of this research were to determine repeatability of DMI over first and second parities, determine RFI, and determine if a significant relationship existed between RFI and diet DM digestibility. A secondary objective was to determine if cows determined to have low or high RFI differed in production measures.

Materials and Methods

Animal care and handling techniques were approved by the Montana State University Institutional Animal Care and Use Committee (AA-301).

Experiment 1

Twenty-four cows (3-yr-old, BW = 593 ±50 kg, second trimester of gestation) with previously determined DMI differences (study one) were transported to the Bozeman Agricultural Research and Teaching Farm in 2009 to investigate the correlation of DMI and RFI between heifers (2008) and later as cows (2009). Animals were in a similar gestational (2^{nd} and 3^{rd} trimesters) stage both years. Twelve cows with the highest and twelve cows with the lowest RFI were assigned to one pen (30 x 11 m) which held eight GrowSafe (Airdrie, Alberta, Canada) feeders which are designed to determine individual feed intakes.

Cows were offered a total mixed ration comprised of 74% native grass hay and 26% supplement (Table 1) and were fed at approximately 12.7 kg $DM \cdot cow^{-1} \cdot d^{-1}$. The grass hay was chopped to a length of 10 cm through a hammer mill. Cows had ad libitum access to water and trace mineralized salt blocks (White Block, North American Salt Company; Overland Park, KS). The rations were mixed daily in a Roto-Mix TMR Mixer/Feeder (Dodge City, KS) and fed at 0730. Feed samples were collected every two weeks and dried with a forced-air oven at 60˚C for 48 h. Samples were then ground to pass through a 1-mm screen in a Wiley mill (Thomas Hill and Sons, Philadelphia, PA), composited and analyzed for DM, CP, NE, ADF, and minerals by Midwest Laboratories (Omaha, NE).

The experiment consisted of a 10 d adaptation period to the GrowSafe feeders followed by a 70 d feeding trial. Body weight measurements were recorded on d 1, 2, 14, 28, 42, 56, 69, and 70. Initial and final weights were recorded as the average of d 1 and 2 and d 69 and 70. Average daily gain and initial weight were predicted from a regression of BW on animal and the animal x day interaction. Predicted end weight was calculated by multiplying the predicted initial weight by the predicted ADG and days on feed. Then, $BW^{0.75}$ was computed by averaging the predicted initial and end BW and raising that result to the three quarter power. Residual feed intake was calculated as the residual from the linear regression of DMI on $BW^{0.75}$ and ADG.

Results of DMI and RFI over parities were compared by a Pearson correlation coefficient (Statistix 9, 2008). Coefficients were considered significant at the $P < 0.05$ level.

Table 6. Diet[1] composition fed to gestating cows to determine DMI, residual feed intake (RFI), and diet DM digestibility.

Item	% of DM
Chopped Native Grass Hay	74.20
Dried Distillers Grains	12.60
Soybean Meal	6.10
Cracked Corn	5.40
Calcium Carbonate	1.00
Mineral supplement[2]	0.70

[1] 15.1% CP, 104% of NRC (1996) MP requirement, 0.57 NE_m, 0.34 NE_g
[2] Calcium – 11.5%, Phosphorus – 10%, Salt – 14.5%,
Sodium – 5.8%, Magnesium – 1%, Potassium – 1.5%,
Cobalt – 20 ppm, Copper – 2,000 ppm,
Iodine – 200 ppm, Manganese – 4,000 ppm,
Added Selenium – 26 ppm, Zinc – 4,500 ppm.

Experiment 2

Immediately following Exp. 1, cows were fed an additional 5 d for collection of feces to determine diet DM digestibility. Grab samples were collected daily at 0600 and 1800. Feed and fecal samples were composited within animal and dried with a forced air oven at 60°C for 48 h. Samples were then ground to pass through a 1.0 mm screen in a UDY Cyclone Sample Mill (UDY Corporation, Fort Collins, CO) and analyzed for DM (AOAC, 1999). Feed and fecal samples were then analyzed for indigestible ADF using the procedures outlined by Bohnert et al. (2002). Relationships between RFI, DMI per $BW^{0.75}$, performance traits, and DM digestibility were analyzed as Pearson correlation coefficients (Statistix 9, 2008) with correlation coefficients considered significant at the $P < 0.05$ level.

Experiment 3

Production measures from the study conducted in 2008 were analyzed to determine if cows determined to be high or low RFI in 2009 produced similarly. Cows were classified into two groups dependent upon RFI. Cows with an RFI greater than zero were classified as high and cows with an RFI less than zero were classified as low. Cow BW at calving, calf birthweight, adjusted 205-d weaning weight, calf pre-weaning ADG, calf age at weaning, and on-test performance measures were analyzed using PROC MIXED of SAS with RFI level as a fixed effect. Data are presented as least squares means with differences considered significant at $P < 0.05$.

Results and Discussion

One cow was removed from the analysis of Exp. 1, 2, and 3 due to an abnormally low intake (failed to consume diet). Additionally, four cows were removed from the analysis of Exp. 2 due to the following reasons: one late term abortion, two contaminated fecal samples, and one determined to be an outlier using the rationale described by Cook (1977).

Experiment 1

The correlation of DMI per $BW^{0.75}$ was 0.71 ($P < 0.01$) between first and second parities. The correlation of RFI was 0.83 ($P < 0.01$) between first and second parities. There is limited literature discussing parity differences for DMI. However, Herd at al. (2006) reported that the calculation of RFI for post-weaned heifers and again as 4 yr old cows were significantly correlated (r = 0.39). However, in those studies, cows were fed a pelleted diet with ad libitum access and were not pregnant. In the current study, cows were in the second and third trimesters of gestation and were limit fed a chopped forage diet.

Additionally, Arthur et al. (1999) showed that weaned female calves, which were determined to be highly efficient (negative RFI), required less feed as 4-yr-old cows while maintaining the same level of performance as inefficient (positive RFI) cows. In that study, the correlations between parities for RFI and DMI were 0.36 and 0.30, respectively (both significant at $P < 0.05$ level). However, 4-yr-old cows had ad libitum access to a pelleted diet (15-17% CP) consisting of 70% lucerne hay and 30% wheat.

The RFI for cows in the present study ranged from 4.46 kg/d (less efficient) to 4.58 kg/d (more efficient). The coefficient of determination (R^2 x 100) for the model of BW on time was 97.0%. The model of DMI = mid-test $BW^{0.75}$ + ADG resulted in an equation that accounted for 29.5% (P = 0.03) of the variation in DMI. This model was used to predict expected feed intake. The deviation of actual cow DMI from expected DMI predicted by the model resulted in the RFI range reported above. Correlations among performance measures, intake, feed efficiency, and digestibility are presented in Table 6.

Table 7. Phenotypic Pearson correlations among performance, intake, feed efficiency, and digestibility in 3-yr-old cows[a]

	RFI	DMI	$DMI/BW^{0.75}$	ADG	FCR[b]	Mid-test BW
DMI	0.81**					
$DMI/BW^{0.75}$	0.81**	0.97**				
ADG	0.11	0.46*	0.39†			
FCR	0.77**	0.69**	0.71**	-0.29		
Mid-test BW	0.22	0.45*	0.23	0.44*	0.19	
DMD[b]	-0.51*	-0.39†	-0.37	0.17	-0.46*	-0.08

*$P < 0.05$; **$P < 0.01$; †$P < 0.10$
[a]For n = 23 except for correlations with DMD where n = 19.
[b]FCR = feed conversion ratio; DMD = dry matter digestibility.

Residual feed intake was positively related to DMI and feed conversion ratio (Table 6) meaning that more efficient cows consumed less feed and had more favorable feed efficiency without differences in ADG. These results agree with Basarab et al. (2007) who reported high correlations (r_p = 0.83; P < 0.001) between cow RFI and feed intake with no relation to ADG. These findings are also in agreement with correlation values reported in young, growing cattle (Arthur et al., 2001; Basarab et al., 2003; Herd et al., 2003; Nkrumah et al., 2004).

Experiment 2

Table 6 shows the relationship of RFI to DMI and diet utilization. RFI was correlated (R^2 = 0.26; P = 0.03) to diet DM digestibility (Figure 1) but was not related to digestible DMI. Dry matter digestibility ranged from 62.6% for the high RFI cows to 74.2% for the low RFI cows. This suggests that cows with a higher RFI consumed more DM but digested less. The net effects were similar digestible DM intakes.

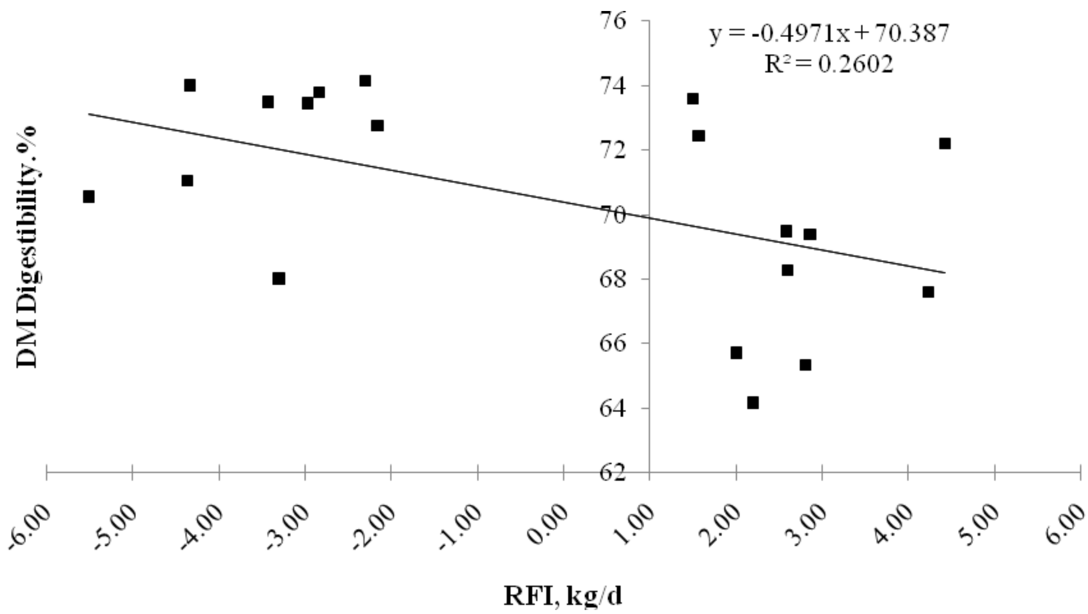

Figure 1. The linear relationship of residual feed intake (RFI) vs. DM digestibility for 3-yr-old cows selected for high and low RFI.

Krueger et al. (2009) also reported differences in digestibility in growing Brangus heifers fed high roughage diets with predetermined high or low RFI. Low RFI heifers had an increased digestibility of 3.7% over high RFI heifers using acid insoluble ash methods. The correlation reported in the present study was very similar to the correlation for DM digestibility and RFI (-0.46; *P* < 0.001) reported by Krueger et al. (2007) when randomly selecting 57 steers out of 120 tested for RFI.

Present results differ from the findings of Cruz et al. (2010) who reported no differences between RFI and diet DM digestibility for feedlot steers. Steers were fed a corn-based finishing ration and placed on two separate 60 d trials. In the first 60 d, half of the steers were placed in individual pens while the other half was placed in one of six group pens. After the first 60 d trial, steers were switched. Steers were assigned to low or high RFI groups if they reached or exceeded 0.5 SD below or above the RFI mean. DM digestibility ranged from 70 to 75% for the low RFI group and averaged 74% for the high RFI group over both periods.

Discrepancies between Cruz et al. (2010) and the results of the present study may be attributed to the 60 d test period which was less than the recommended 70 d (Archer et al. 1997). Additionally, differences could be credited to composition of diets (high concentrate vs. high roughage) and the mechanisms which control feed intake (chemostatic vs. gut fill). Furthermore, different techniques were used to determine DM digestibility.

<u>Experiment 3</u>

Low RFI cows consumed an average of 4.75 kg/d less than high RFI cows (Table 7). Feed conversion was decreased 28.6% for low RFI cows compared to high RFI cows. Cows determined to be high or low RFI did not differ in mid-test BW or ADG. Cow bodyweight at calving, calf birthweight, pre-weaning ADG, adjusted 205-d weaning weight, and weaning age did not differ due to RFI level.

Divergent selection for RFI by Arthur et al. (2005) showed low RFI cows to be heavier than high RFI cows, though not significant ($P > 0.05$) at any points of the production cycle, even though RFI is phenotypically independent of bodyweight by definition. Interestingly, although our data did not show a difference, numerically our weights were the inverse of those reported by Arthur et al. (2005).

Basarab et al. (2007) reported a low negative relationship ($r_p = -0.16$) between calf birthweight and calf RFI. This relationship was not significant when RFI was adjusted for on-test backfat thickness. However, the subsequent calf born to cows that produced low or medium RFI progeny tended ($P = 0.07$) to be heavier than calves born to cows that raised high RFI progeny. No difference in calf birthweight was reported by Arthur et al. (2005) between high and low RFI cows.

Neither Basarab et al. (2007) nor Arthur et al. (2005) reported differences in pre-weaning ADG or adjusted weaning weights. However, calves from high RFI cows tended ($P = 0.07$) to be older (mean = 5 d) at weaning than calves born to low RFI cows (Arthur et al., 2005). Basarab et al. (2007) also reported dams that produced low RFI progeny calved 5 d later ($P < 0.001$) in the year than high RFI cows.

Implications

The repeatability of DMI over parities helps to prove the significance of RFI as cows that exhibit lower DMI early in their life retain that characteristic as they continue to produce progeny. Furthermore, differences in RFI can now be partially attributed to increased intakes and decreased DM digestibility. Cows determined as being low RFI (more efficient) produced similarly to their less efficient herdmates. However, further research with a greater number of animals is warranted to verify these results.

Table 8. On-test performance data of 3-yr-old cows determined to be high or low residual feed intake (RFI)[a] and their production characteristics as 2-yr-old heifers

	RFI			
Trait	Low	High	SEM[b]	*P* - value
Test				
Mid-test BW, kg	551.7	568.7	13.9	0.38
DMI, kg/d	11.47	16.22	0.64	< 0.001
ADG, kg/d	0.99	1.00	0.06	0.93
FCR[c], kg/kg	11.76	16.46	0.61	< 0.001
Production				
Cow BW at calving, kg	485.8	493.9	13.4	0.66
Calves				
Birthweight, kg	37.4	39.0	1.5	0.45
ADG[d], kg/d	0.97	0.99	0.04	0.72
205-d weaning weight, kg	244.8	248.8	8.2	0.73
Weaning age, d	200.3	204.0	5.1	0.61

[a]High and low RFI cows determined by being either less than or greater than zero.
[b]For n = 23.
[c]FCR = feed conversion ratio.
[d]From birth to weaning.

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APPENDIX A:

DIGESTIBILITY OF HEIFER DIETS

Table 9. Digestibility and nitrogen retention of wether lambs fed gestating heifer diets containing 102 or 119% of metabolizable protein (MP) requirements

	MP, % of NRC requirement			
Item	102%	119%	SE[a]	*P* - value
DM digest., %	53.61	55.78	.96	0.04
NDF digest., %	38.01	41.83	1.29	0.01
N digest., %	64.22	69.41	.87	< 0.001
N retention, g/d	6.34	8.35	.84	0.04
N retention, %	4.78	5.67	.60	0.17

[a]Number of observations per treatment = 8.