

UTILIZATION OF FORAGES IN BEEF COW-CALF NUTRITION

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The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled

UTILIZATION OF FORAGES IN BEEF COW-CALF NUTRITION

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A candidate for the degree of Master of Science,

And hereby certify that in their opinion it is worthy of acceptance.

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DEDICATION

To my parents, Alan and Kathy Meyer,

*who taught me to work hard,
fight for what I believe in,
and love cattle.*

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS	ii
LIST OF FIGURES	vii
LIST OF TABLES	viii
ABSTRACT.....	x
Chapter	
1. LITERATURE REVIEW	1
Introduction.....	1
Feed Efficiency and Feed Intake	3
Measures of Feed Efficiency	3
<i>Residual Feed Intake</i>	5
The Effect of RFI on Economically Relevant Traits in Beef Cattle	6
<i>RFI, Intake, and Performance</i>	7
<i>RFI and Mature Size</i>	10
<i>RFI and Maternal Traits</i>	11
<i>RFI and Body Composition</i>	13
Mechanisms of RFI Differences	14
Interactions of RFI and Physiological State.....	15
Future Directions in RFI Research.....	17
RFI Summary	19
Use of Stockpiled Forage in Extended Grazing Systems	19
Stockpiled Tall Fescue	20
<i>Management of Stockpiled Tall Fescue</i>	21
<i>Stockpiled Tall Fescue Yield and Quality</i>	22

<i>Beef Cow Performance While Grazing Stockpiled Tall Fescue</i>	23
Stockpiled Tall Fescue Summary	24
Summary	24
2. THE EFFECT OF FEED EFFICIENCY RANK ON BEEF COW GRAZED FORAGE INTAKE	26
Abstract.....	26
Introduction	27
Materials and Methods.....	29
Determination of Residual Feed Intake	29
Experiment 1	29
<i>Experimental Design</i>	29
<i>Forage Yield and Quality Measurement</i>	30
<i>Animal Performance Measurements</i>	31
<i>Statistical Analysis</i>	32
Experiment 2	32
<i>Experimental Design</i>	32
<i>Animal and Paddock Management</i>	33
<i>Forage Yield and Quality Measurement</i>	34
<i>Animal Performance Measurements</i>	35
<i>Statistical Analysis</i>	35
Results and Discussion	35
Heifer Residual Feed Intake	35
Animal Performance	36
Forage Yield and Quality	39
Forage Intake.....	40
Conclusion	45

3. COMPARISON OF GRAZING STOCKPILED TALL FESCUE VERSUS FEEDING HAY OR HAY PLUS SUPPLEMENT TO GESTATING BEEF COWS DURING WINTER	58
Abstract.....	58
Introduction	59
Materials and Methods.....	60
Experimental Design.....	60
Animal and Pasture Management	61
<i>Hay Treatments</i>	62
<i>Stockpiled Tall Fescue Treatment</i>	62
Animal Performance Measurements	62
Forage Measurements	63
<i>Sample Collection</i>	63
<i>Forage Quality Analysis</i>	64
<i>Weather</i>	65
Statistical Analysis.....	65
Results and Discussion	66
Hay and Stockpiled Forage Quality and Yield.....	66
Stockpile Utilization and Dry Matter Intake and Hay Offered.....	68
Animal Performance	69
<i>Winter Trial</i>	69
<i>Post-trial Monitoring Phase</i>	73
<i>Calf Performance</i>	74
Observed Management Differences	75
Conclusion	76
LITERATURE CITED	89
VITA.....	96

LIST OF FIGURES

Figure	Page
2.1. Paddock design for Exp. 1.....	46
2.2. Paddock design for Exp. 2.....	47
2.3. Temperature and precipitation data for May to August 2006 (Exp. 1) compared to a 30-year average	48
2.4. Temperature and precipitation data for August 2006 to April 2007 (Exp. 2) compared to a 30-year average	49
3.1. Experimental design and animal performance measurement timeline for years 1 and 2.....	77
3.2. Temperature and precipitation data for stockpiling and trial dates of years 1 and 2 compared to a 30-year average	78

LIST OF TABLES

Table	Page
2.1. Nutrient composition of mineral supplement offered ad libitum in Exp. 1 and 2....	50
2.2. Performance of cows with low or high residual feed intake (RFI) in Exp. 1.....	51
2.3. Performance of cows with low or high residual feed intake (RFI) and their calves (Exp. 2)	52
2.4. Average forage yield and quality by sampling date and residual feed intake (RFI) group (Exp. 1).....	53
2.5. Average forage yield and quality by sampling date and residual feed intake (RFI) group (Exp. 2).....	54
2.6. Average temperature and total precipitation for grazing periods of Exp. 2.....	55
2.7. Average forage intake and pasture carrying capacity measures of cows with low and high residual feed intake (RFI) in Exp. 1	56
2.8. Average forage utilization and intake of cows with low and high residual feed intake (RFI) and their calves (Exp. 2).....	57
3.1 Nutritional composition of mineral supplements offered ad libitum in years 1 and 2.....	79
3.2. Pre-grazing stockpiled tall fescue forage yield and quality versus quality of hay fed during year 1	80
3.3. Post-grazing stockpiled tall fescue forage yield, quality, and utilization rates during year 1	81
3.4. Pre- and post-grazing stockpiled tall fescue forage yield, quality, and utilization versus quality of hay fed during year 2.....	82
3.5. Hay offered to hay, hay plus supplement (HS), and stockpiled tall fescue (STF) treatments and estimated stockpile dry matter intake of STF during years 1 and 2.....	83

3.6. Body weight change of cows wintered on hay, hay plus supplement (HS), or stockpiled tall fescue (STF) during years 1 and 2	84
3.7. Body condition score change of cows wintered on hay, hay plus supplement (HS), or stockpiled tall fescue (STF) during years 1 and 2	85
3.8. Back fat thickness change of cows wintered on hay, hay plus supplement (HS), or stockpiled tall fescue (STF) during year 1	86
3.9. Pregnancy rates of cows wintered on hay, hay plus supplement (HS), or stockpiled tall fescue (STF) during year 1	87
3.10. Average date of birth, birth weight, and weaning weight of calves born to dams wintered on hay, hay plus supplement (HS), or stockpiled tall fescue (STF) during years 1 and 2	88

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ABSTRACT

Two studies investigated methods of decreasing feed costs of cow-calf operations. In the first study, two experiments were conducted to determine the difference in grazed forage intake of beef cows of known residual feed intake (RFI) rank. Low RFI (highly efficient) cows had a 21% lower average numerical forage intake ($P = 0.23$) than high RFI cows (lowly efficient) during mid to late gestation in Experiment 1. In Experiment 2, an 11% numerical difference in forage intake ($P = 0.12$) was observed between low and high RFI cows in late lactation, while in both experiments RFI groups had similar body weight (BW) and body condition score (BCS) change. Further research is necessary to confirm these differences due to low numbers used in this study. A second 2-year study compared performance differences between spring-calving crossbred beef cows wintered on one of three treatments: grass hay only, grass hay with grain supplementation, or non-endophyte infected stockpiled tall fescue (STF) pasture. Cows grazing STF ended the trial with higher BW and BCS than cows fed hay only in both years and cows fed hay with supplement in year 1. Differences in performance did not extend past winter grazing, and calves born had similar birth and weaning weights among treatments. Grazing STF is a viable option for wintering spring-calving beef cows, and because typical grass hay is of lower quality than STF, cows fed hay require supplementation to achieve similar performance to that observed while grazing STF.

CHAPTER 1

Review of Literature: Potential to Reduce Feed Inputs in Cow-calf Production by Increasing Feed Efficiency of the Cowherd and Extending the Grazing Season

INTRODUCTION

It is well established that feed inputs are the greatest annual cost for cow-calf producers. Using 1996 to 1999 Standardized Performance Analysis (SPA) data from Illinois and Iowa producers, Miller et al. (2001) reported financial feed costs per cow to be \$205.44. Additionally, they found the economic feed costs per cow to be \$239.04 when the opportunity cost of inputs and capital investment and value of operator and family labor were included. On a percentage basis, feed costs translated to 63% and 53% of the total financial and economic annual costs, respectively. This agrees with research from the USDA Economic Research Service (2005), which estimated feed to account for 59% and 56% of total operating costs for US cow-calf producers in 2004 and 2005, respectively. Within total feed costs, Lawrence and Strohbehn (1999) found pasture to make up 45%, harvested forage 27%, purchased feed 16%, non-forage raised crops 11%, and crop residues 1% of Iowa producers' feed inputs using 1997 SPA data.

Although feed costs are high, it is essential for cow-calf producers to provide their herds with adequate nutrition in order to maintain productivity. Cows in poor body condition at calving or in negative energy balance during early lactation have longer

postpartum intervals to first estrus and lower pregnancy rates (Wettemann et al., 2003; Hess et al., 2005). Poor postpartum nutrition also decreases milk production and thus calf weaning weight (Houghton et al., 1990; Spitzer et al., 1995; Jenkins et al., 2000; Stalker et al., 2006). Additionally, prepartum nutrition may affect calves through fetal programming. When dams had a lower nutritional plane before calving, their calves had lower weaning weights (Stalker et al., 2006; Martin et al., 2007) and their daughters had reduced prebreeding weights and pregnancy rates (Martin et al., 2007) in one recent study.

In order to increase profitability of cow-calf operations, feed input costs must be reduced while still maintaining at least a moderate level of production. Two alternatives to achieve this are to 1) decrease the amount of feed necessary to maintain cows or 2) decrease the cost of the feed used to maintain cows.

A reduction in feed intake while maintaining production is possible only if the cowherd is more efficient, or requires less nutrient intake for the same output. Cattle exhibit individual differences in feed efficiency, which is a moderately heritable trait (Arthur et al., 2001b), making this a viable option for decreasing feed inputs with proper understanding. Residual feed intake is a good representation of this trait, and current research has investigated its effect upon feed inputs and production outputs.

In their SPA data analysis, Lawrence and Strohbehn (1999) developed a model to predict annual cow cost, and found that extending the grazing season is less costly than purchasing or producing harvested forage for Midwestern producers. Thus, extending the grazing season is an option to decrease feed input costs. Stockpiling fall growth of a

forage for winter grazing is one method of this extension that has been researched to maintain cows during both gestation and lactation.

The objective of this review is to present relevant research from the literature pertaining to feed efficiency of the cowherd and extending the grazing season with stockpiled forage.

FEED EFFICIENCY AND FEED INTAKE

Many factors influence feed intake, including capacity of the gastro-intestinal tract, metabolites, hormones, regulatory proteins, nutrient requirements, production stage, environmental effects, and quality and quantity of feedstuffs available (NRC, 1987). Still, when extrinsic factors are similar for a group of cattle, the feed intake varies between individuals. This variation occurs due to differences in feed efficiency, or the amount of feed necessary for maintenance and production of the individual, and allows for selection to improve the feed efficiency of livestock and thus decrease feed inputs.

Measures of Feed Efficiency

The feed efficiency of an individual can be expressed using many different calculations and units. Traditionally, ratios have been formed from production outputs and feed inputs as either gross efficiency (gain:feed, **G:F**) or feed conversion ratio (feed:gain, **F:G**) to describe feed efficiency. For meat animal species, gain is typically the production output used in these ratios, but other outputs such as milk yield and egg mass

can also be used. Although G:F and F:G are easy to calculate and understand, both of these expressions are correlated with growth rate and mature size (Archer et al., 1999). Consequently, if selection for more efficient animals occurs using these measures, growth and mature size will also increase. Because size is a determinant of energy requirements, larger cattle will require more feed inputs, and thus may not be truly more efficient even though they have been selected for improved feed efficiency. This may be especially detrimental for cow-calf operations as mature size has the largest impact upon this segment of production. Additionally, the ratio of gain and feed implies an assumption that these two components have a linear relationship, which is most likely biologically untrue (Koch et al., 1963).

Feed efficiency can also be expressed in terms of maintenance efficiency and partial efficiency of growth (**PEG**) or other production outputs (Archer et al., 1999). Maintenance efficiency, or the ratio of body weight to feed intake at maintenance, is difficult to measure because an animal must be held at a constant body weight for a long period to obtain its maintenance requirement. Partial efficiencies are ratios of the measured output and feed intake minus that which is required for maintenance. Because they disregard differences in efficiency of maintenance, PEG and similar calculations probably have limited use in selection.

An additional measure of feed efficiency is cow-calf efficiency, or production efficiency. To arrive at this expression, the weaning weight of a cow's calf is divided by the pair's feed intake since the last calf was weaned (Shuey et al., 1993). Although this calculation may be particularly useful to evaluate the overall efficiency of an operation, it

is difficult to accurately measure the intake of an individual cow and her offspring over the course of an entire year.

Residual Feed Intake. In an attempt to more accurately describe feed efficiency in beef cattle, Koch et al. (1963) first expressed the trait as a residual of either feed or gain not accounted for by growth and intake. These researchers first adjusted intake for gain and mid-weight and adjusted gain for intake and mid-weight, then found the deviation of these values from the regressions of intake on gain and gain on intake, respectively. More recently, this concept has been revisited and residual feed intake (**RFI**), also referred to as net feed intake, has resurfaced in the literature.

Residual feed intake is defined as the difference between an animal's actual intake and expected intake, which is predicted using body weight and production outputs such as average daily gain or milk yield (Kennedy et al., 1993). By definition, a negative RFI implies a more efficient animal, as it consumed less feed than predicted for its size and production outputs, and a positive RFI implies a less efficient animal, as its intake was above that predicted for its size and outputs. RFI can also be expressed as its inverse, net feed efficiency, for which the opposite is true (Pitchford, 2004). Because of the way it is calculated, RFI should be independent of its component traits of size and the production output used such as growth rate (Archer et al., 1999). This makes it possible to compare animals of different production levels using RFI, in addition to allowing for selection based upon RFI without affecting growth rate and body weight.

Arthur et al. (2001b) compared RFI and feed conversion ratio (F:G) and found that RFI is correlated to F:G both phenotypically ($r = 0.53$) and genetically ($r = 0.66$), although RFI showed little to no phenotypic or genetic correlation to average daily gain

(**ADG**) or metabolic mid-weight (**MWT**), unlike F:G. Additionally, these researchers concluded that as a linear index trait, RFI is more suited to predicting genetic change than F:G, a ratio of its components. In other studies, Arthur et al. (2001c) and Nkrumah et al. (2004) compared RFI and F:G to PEG, metabolizable energy intake per unit metabolic mid-weight (**MEI**, only included in Nkrumah et al.), relative growth rate (**RGR**), and Kleiber ratio (**KR**). RGR and KR are calculated using only growth data but have been suggested to be useful as indirect measures of efficiency. Both studies found that PEG behaved similarly to RFI in its correlation to F:G, growth, and intake traits. RFI remains a more accurate expression of efficiency, however, as PEG does not include contributions of maintenance energy requirements to efficiency.

The Effect of RFI on Economically Relevant Traits in Beef Cattle

A major comprehensive research project focused upon feed efficiency took place from 1993 to 2000 at the Agricultural Research Centre in Trangie, New South Wales (Arthur et al., 2004). This project tested the RFI of growing calves and mature cows, while also investigating the impacts of efficiency upon other production traits. In addition, divergently selected herds of low and high RFI were established for use in realizing what opportunities lay in selection. The group of researchers associated with this project has been active in elucidating the mechanisms by which feed efficiency varies between animals and how these affect production. Although the Australian group has been prolific in published work, prior to this, little research had been conducted in feed efficiency of beef cattle other than to study differences between breeds (Archer et al., 1999). In the last decade, however, groups in the United States and Canada have also

taken an interest in feed efficiency and RFI. The greater availability of equipment and technology with which to record individual intake of animals in a group setting, such as the GrowSafe feed intake system (GrowSafe Systems Ltd., Airdrie, AB, Canada), has allowed this research to be done more accurately and efficiently.

RFI, Intake, and Performance. The intake and performance of low and high RFI growing cattle have been studied both in animals for which RFI has been determined and animals resulting from divergent RFI selection. It has been well established that steers determined to have low RFI have lower dry matter intake (**DMI**) than high RFI steers, despite both groups maintaining similar ADG, when tested on concentrate-based diets (Nkrumah et al., 2004; Kolath et al., 2006; Nkrumah et al., 2006; Castro Bulle et al., 2007). Dry matter intakes of low RFI steers have been reported between 12 and 17% lower ($P < 0.05$) than that of high RFI steers in these studies. After one divergent selection, low RFI line steers had 6% lower DMI and no difference in ADG in the feedlot (Richardson et al., 1998). In another study by Arthur et al. (2001a), low RFI line steers after five years, or about 2 generations, of divergent selection had 11% lower DMI than high RFI line steers while maintaining similar ADG. When these traits are measured in the postweaning phase, RFI has a high genetic correlation to feed intake at 0.64 to 0.79, although it is not correlated to ADG (Herd and Bishop, 2000; Arthur et al., 2001b; Arthur et al., 2001c).

When RFI were re-determined for 4-year old open, non-lactating cows on a pelleted diet containing 70% hay, cows with low postweaning RFI had 4.5% lower DMI ($P < 0.05$) than cows with high postweaning RFI, while no difference in ADG was observed over the test period (Arthur et al., 1999). Because of the limited literature

available on this subject, it is unclear whether the intake difference between low and high RFI animals actually lessens in maturity or why this occurs. It does appear, however, that animals likely remain in their postweaning RFI group later in life. In the same study described above, Arthur and coworkers (1999) found the phenotypic correlation between postweaning RFI and cow RFI to be 0.36 and between postweaning RFI and cow DMI to be 0.30. Archer et al. (2002) reported a similar phenotypic correlation between these traits at 0.40 and 0.34, respectively. Additionally, they found high genetic correlations of 0.98 between postweaning RFI and cow RFI and 0.64 for postweaning RFI and cow DMI. The phenotypic and genetic correlations between RFI and DMI when both were measured as cows were still high at 0.88 and 0.71, respectively. In another study, the RFI and feed intake of bulls on test were found to be highly correlated to themselves when determined at 15 and 19 months of age, although these were part-whole correlations due to overlapping measurement periods (Arthur et al., 2001c). If the postweaning RFI of an individual can predict its efficiency throughout life, selection for a greater efficiency may be accurately performed prior to an animal entering the breeding herd.

Although intake and performance of growing cattle of known RFI rank or divergent RFI selection have been well researched while feeding concentrate diets, little work has been done for stocker cattle or developing heifers grazing pasture. Using the alkane method to measure grazed forage intake, Herd and coworkers (2002) studied the intake and performance of steers resulting from about one generation of divergent RFI selection. Dry matter intake was not significantly different between lines, but low RFI line steers had a 5.8% numerically lower DMI. Low RFI line steers also tended ($P < 0.10$) to have increased ADG and had 25% numerically better F:G. No forage quality or

yield data was presented for this study, and thus it is possible that forage quality, availability, or a combination of these factors limited intake. In contrast to earlier described studies in which feed intake was ad libitum and no differences were noted in gain, if intake was limited in this trial it may have forced a difference in ADG instead of intake.

Little previous research exists that investigates forage intake differences between low and high RFI cows grazing pasture. In the only such work known to the author, Herd et al. (1998) determined the grazed forage intake of mature cows for which RFI had been determined postweaning. Forage DMI was again measured using the alkane method during the third month of lactation. Although not significant, DMI was 5.3% numerically less for low RFI than high RFI cows. Low RFI cows also tended ($P = 0.07$) to maintain 15% more calf weight per unit of cow intake ($\text{kg calf weight}/(\text{kg}\cdot\text{d}^{-1} \text{ cow intake})$). Once again, no forage quality or availability data were presented, and thus may have limited intake.

It may be assumed that a major reason why few researchers have investigated the effects of RFI status upon grazed forage intake is the difficulty of measuring intake for individuals on pasture. Few reliable methods exist to determine forage intake of intact, uncannulated animals. Alkanes were probably used in the previously cited studies due to the labor necessary for and inability to determine individual intakes with more traditional methods involving forage measurements and grazing exclosures. Unfortunately, however, alkanes have their own problems, as their fecal recovery is often incomplete and variable and alkane composition differs greatly between species and plant component, making it essential that diet composition is correctly characterized (Dove and Mayes, 1996; Lippke,

2002). For these reasons, alkanes are not reliable enough to accurately estimate individual intake for use in RFI-based studies (Arthur and Herd, 2005). It is therefore unknown how the grazed forage intake differs between cattle of low and high RFI rank or selection. Improved methodologies and continued research are necessary to provide insight into this question.

RFI and Mature Size. Although RFI should be phenotypically independent of body weight and ADG by definition, research indicates that a negative correlation may exist between RFI and mature size. This concept is supported by a study conducted by Herd and coworkers (1998) in which they found low RFI cows to be significantly heavier than high RFI cows in a pasture intake trial. Concurrently, another study examining the effect of selection for RFI in the cowherd over 4 years observed that low RFI line cows were numerically heavier at all time points, although this difference was not significant (Arthur et al., 2005). Conversely, Arthur et al. (1999) found no difference in mature cow BW between RFI groups when redetermining RFI of 4-year old cows.

Genetic correlations between RFI and MWT or BW during the postweaning or feedlot test phase have been variable in many studies. While phenotypic correlations between these traits have followed the definition of RFI and remained at or near zero, genetic correlations have been reported from -0.06 to 0.32 (Herd and Bishop, 2000; Arthur et al., 2001b; Arthur et al., 2001c). This is in contrast to the relationship of RFI and mature BW. Although genetic correlations between post-weaning RFI and mature weight have been reported to be low at -0.09 ± 0.26 (Herd and Bishop, 2000), another study found the genetic correlation of postweaning RFI and cow MWT to be -0.22 while the phenotypic correlation was negligible at -0.02 (Archer et al., 2002).

Kennedy et al. (1993) suggested calculating RFI using genotypic rather than phenotypic regression to prevent this genetic correlation of RFI to its component traits, or in this case body size. When RFI were calculated using both phenotypic and genetic covariances, Nkrumah and coworkers (In press) found that RFI determined by genotypic regression had a lower correlation to MWT than when determined via phenotypic regression (0.12 ± 0.30 vs. 0.27 ± 0.33), although SE were high for both measures. In this same study, both the phenotypic and genetic correlations between RFI calculations were above 0.90, proving that they are similar for individuals.

This data from divergent selection and genetic correlations, although limited in quantity, presents the possibility that although by definition RFI is not correlated to body weight, selection for more efficient cattle may cause an increase in mature cow size due to a low negative genetic correlation for the trait. Calculating RFI using genotypic regression may present the opportunity to remove some or all of this correlation.

RFI and Maternal Traits. Little research has investigated the effects of RFI upon reproduction, probably due to the animal numbers necessary to detect differences in reproductive performance and the relative difficulty of determining RFI for large groups of cattle. One study that examined this relationship by Arthur and coworkers (2005) found no differences in pregnancy rate, calving rate, or weaning rate between low and high RFI lines resulting from 1 to 2.5 generations of selection over 3 mating seasons (4 years). Low RFI cows tended ($P < 0.10$) to have a later calving date (215 vs. 210 Julian date) and greater percentage of calves sired by natural service (22% vs. 13%) than high RFI cows in this study, however. Because all cows were given two opportunities to

conceive via estrus synchronization and artificial insemination, this means that fewer low RFI cows became pregnant at these times.

A negative correlation has been observed between feed efficiency and litter size in mice and hogs and between RFI and egg number, egg mass, and age at first laying in poultry (Pitchford, 2004). Although the physiology of single and multiple ovulators differs, these correlations found in multiple ovulators and the calving date data observed by Arthur et al. (2005) make further research necessary to determine if selection for low RFI also has a negative effect upon reproductive efficiency in beef cattle.

In their 4-year study, Arthur et al. (2005) found low and high RFI line cows had similar milk yields using the weigh-suckle-weigh technique and supporting an earlier finding by this group (Arthur et al., 1999). The long-term study also found no difference between RFI lines for calf birth weight, weaning weight, or pre-weaning ADG (Arthur et al., 2005). Other research has found that low RFI cows tended to maintain 15% more calf weight per unit of cow DMI ($\text{kg calf weight}/(\text{kg}\cdot\text{d}^{-1} \text{ cow intake})$) as their calves were numerically heavier and their intakes were numerically lower (Herd et al., 1998). Calves born to more efficient dams in this trial were also 6 days numerically older, however, confounding these findings. The RFI rank of the calves' sires was not reported for this work, although because it was published by researchers involved in the divergent selection project at Trangie, the calves were most likely divergently selected. Based upon these three studies, it is more likely that any preweaning performance differences observed due to RFI selection stem from the calves' efficiency status than from a difference in their dams' milk production.

RFI and Body Composition. Many researchers have investigated the relationship between RFI and body composition, especially as it affects carcass characteristics, and have generally observed a positive correlation between RFI and fat deposition. Richardson and coworkers (1998) first reported this difference when they found that after one generation of divergent selection low RFI line steers had 15% less rib fat and 19% less rump fat at the end of the feeding period, when both measurements were determined ultrasonically. In this study, low RFI line steers also had 6% less ribeye area than their high RFI counterparts. Later work by the same group (Richardson et al., 2001) observed that although low RFI line steers began their test period with 19% and 25% less rib and rump fat, respectively, by the end of the trial these differences had decreased and lost statistical significance. They also found that low RFI steers had a 30% larger increase in ribeye area during the feeding period of this trial. After harvest, high RFI line animals were observed to have more carcass fat and total dissected fat, and these measures remained significantly different when expressed as a percent of final body weight rather than as the amount alone. Additionally, Nkrumah et al. (2004) found low RFI steers had 23% less carcass grade fat than high RFI steers, giving low RFI steers an advantage in yield grade and percent lean meat yield. More recent work by the same researchers (Nkrumah et al., In press) confirms this relationship. Conversely, Castro Bulle et al. (2007) reported low RFI steers to have 14% numerically greater carcass back fat than high RFI steers. Despite observed differences in fat deposition between RFI groups, work cited above has reported little difference in intramuscular fat or ribeye area. The genetic correlation between RFI and rib fat has been determined at between 0.17 and 0.33 (Arthur et al., 2001b; Nkrumah et al., In press). None of the cited work reported

decreased fat thickness of carcasses from low RFI animals to negatively affect carcass or meat quality.

This difference in adiposity may or may not continue into maturity. While Herd et al. (1998) and Arthur et al. (1999) found no differences in rib or rump fat between low and high RFI cows, in a 4-year study, low RFI line cows had numerically greater rib fat depths at all times measured (Arthur et al., 2005). This difference was significant at 3 points during which cows were at their highest body condition. Although the relationship between efficiency and decreased fat thickness, which translates to increased percent of lean yield, is not negative for the feedlot sector, it may present a problem in the cow-calf segment as body condition score is known to affect reproductive efficiency (Wettemann et al., 2003; Hess et al., 2005). Arthur et al. (2005) found that rib fat depth was not correlated to or a covariate of prebreeding and reproductive performance measures including pregnancy rate and calving date, however. Further research is warranted to determine if the difference in the amount of adipose stored or efficiency of building these energy stores exists between low and high RFI cows. If differences exist, it will be important to understand how they impact physiology during times of stress and body condition loss, such as early lactation and limited forage availability.

Mechanisms of RFI Differences

In a review of proposed biological mechanisms responsible for differences in RFI between individuals, Herd et al. (2004) attributed these percentages to each mechanism's contribution to variation in feed efficiency: heat increment of feeding (9%), digestion (14%), body composition and energy retention (5%), activity (5%), and other metabolic

processes, such as protein turnover, ion balance, and proton leakage (67%). Some of these are easily explainable, such as that as intake increases, the energy expenditure of digestion (heat increment of feeding) also increases while the digestion of feed decreases. Many of these processes are extremely complex and not well understood, however. Herd and coworkers (2004) concluded in their review that due to the number of factors influencing the trait, it has been and will continue to be difficult to elucidate the exact variations in biology that give rise to variation in feed efficiency.

Interaction of RFI and Physiological State

Because most of the RFI research in beef cattle has been conducted using the growing animal and the knowledge of causative biological mechanisms of RFI variation is in its infancy, it is largely unknown how physiological state affects RFI or how these interact to influence feed intake. This is especially important when considering feed efficiency and the cowherd. Differences in the efficiency of fetal growth, lactation, maintenance, and energy store deposition for the cow may explain some of the remaining questions pertaining to her intake.

Although no work has been done to the author's knowledge investigating the interaction of these physiological states or production phases and RFI in beef cows, recent mouse research explored this concept. Hughes and Pitchford (2004) studied the difference in performance, intake, and RFI between lines of female mice after 9 to 10 generations of divergent RFI selection during pre-pregnancy (maintenance), gestation, and lactation. No differences were observed in mid-weight or ADG at any point in the experiment for dam or dam plus litter after parturition. When at maintenance, low and

high RFI lines exhibited a significant difference of ~20% in both DMI and RFI. During gestation this difference in DMI decreased slightly, while the variation in RFI also lessened to 12%. The DMI difference then diminished and RFI for the 2 lines converged during early lactation. Although RFI rediverged in late lactation, intakes remained similar between the 2 lines.

Hughes and Pitchford hypothesized that efficiency converged for low and high lines because high RFI mice had increased, previously wasted, feed intake available to repartition toward fetal growth and lactation, whereas the low RFI line did not have this buffer. Therefore, although the low RFI line had the advantage in efficiency while at maintenance or when requirements for gestation and lactation were low, as requirements increased due to conceptus gain and milk production, they became less efficient. The low RFI line thus had to increase intake to make up for this reduction in efficiency, while the high RFI line used their buffer of residual intake.

Partial efficiencies of end product formation have been reported to be greatest for lipid, followed by milk, then protein, and finally fetal tissue (Johnson et al., 2003). Potential then exists that because milk production is a more efficient process than protein accretion, less differences exist in efficiency between low and high RFI animals during lactation than during growth or protein turnover associated with maintenance. Because lipid synthesis is the most efficient, this may also explain some of the differences in adiposity observed between low and high RFI cattle.

Hughes and Pitchford accounted for energy expenditure of offspring growth, to at least some extent, by using dam plus litter weights during lactation when calculating ADG and RFI. Work reviewed previously researching RFI in beef cows either used open,

non-lactating cows (Arthur et al., 1999) to calculate RFI, or in another study did not calculate RFI and used calf body weight/ unit cow DMI to account for energy put into the calf (Herd et al., 1998). Actual efficiency differences in cattle during gestation and lactation may be more accurately portrayed when the difference in energy output into fetal development and milk production is considered. In the dairy industry, RFI is calculated using milk yield in addition to midweight (Ngwerume and Mao, 1992). Because calf birth weights and milk production have been similar between low and high RFI cows when studied (Arthur et al., 1999; Arthur et al., 2005), this may not have a large effect for beef cows, however.

Future Directions in RFI Research

Research has been underway over the past decade in attempt to find a reliable marker for RFI. The time, labor, and cost associated with determining RFI for cattle limit the practicality of using it as a selection tool, even with advances in feed intake and body weight data collection system technology and better understanding of limitations existing with the RFI calculation. In a recent review on advances in RFI research, Arthur et al. (2004) reported that IGF-1 is the most likely physiological marker, although further research is necessary to confirm its use. In addition, research is underway to locate gene markers and quantitative trait loci for RFI components. Although some progress has been made in this area, it is unlikely that any one marker will be sufficient on its own, due to the large number of physiological factors that contribute to this trait (Arthur and Herd, 2005).

Because of the economic impact that feed efficiency can have, researchers and breed associations have and are currently attempting to calculate accurate expected progeny differences (**EPD**) that can be used to select for more efficient cattle. BREEDPLAN, the Australian genetic improvement and evaluation system, implemented estimated breeding values (**EBV**) for RFI in 2002, and began including IGF-1 information in 2004 (Arthur and Herd, 2005). American breed associations have incorporated feed conversion ratio data or into feedlot-based indexes or used mature size and milk production data to formulate cow efficiency indexes, but problems still exist with creating an EPD for feed efficiency, feed intake, or RFI alone. Probably the biggest challenge is collecting data from producers for feed intake, due to the difficulty already discussed (Crews, 2006).

Although RFI is known to be moderately heritable, environmental effects also play a role. The dam's nutrition during gestation and its influence upon offspring performance, or fetal programming, may impact individual RFI. Research relating fetal programming to RFI is very limited, but RFI was found to be affected by an interaction of pre- and postpartum nutrition in one study (Martin et al., 2007). In this research, daughters of dams that had received a lower plane of nutrition in both late gestation and early lactation (unsupplemented range and grass hay) had the lowest feed intakes and most favorable RFI ($P < 0.10$), while having no difference in ADG. Conversely, heifers born to cows on a high plane of nutrition during both periods (protein supplemented range and meadow grazing) had the next lowest intake and next best RFI. This interaction is difficult to explain and may be due to low experimental numbers, but raises interesting questions. In another study investigating the effect of postpartum cow nutrition giving

calves either a high or low preweaning growth rate found no difference in RFI, although calves from the high growth rate treatment had greater BW at the beginning and end of the feedlot test and great DMI throughout (Hennessy and Arthur, 2004). Further research is necessary to determine if dam nutrition during fetal development or nutrition during the growth phase influences efficiency later in life.

RFI Summary

The amount of knowledge available pertaining to feed efficiency and the use of residual feed intake as an expression of the trait in beef cattle has increased tremendously in the last 20 years. Many questions are still left unanswered, however, especially in the areas of grazed forage intake, mechanisms of efficiency, the interaction of RFI and physiological state or production phase, environmental effects upon lifelong RFI of animals, and possible blood metabolites or gene markers to use as a test for RFI.

USE OF STOCKPILED FORAGE IN EXTENDED GRAZING SYSTEMS

Harvesting forage for winter use comes with high costs, including labor, machinery, fuel, and storage. These costs have been estimated to be 18 to 24% of the total cost of every weaned calf for Nebraska producers (Adams et al., 1994). It is generally more economical for cattle to harvest forages themselves via grazing rather than for producers to bale or ensile hay or haylage. For this reason, many different options of extending the grazing season have been developed including stockpiled fall

growth of forages for winter grazing, planting annual cereal grains for winter or early spring use, grazing crop residues in the fall, and planting brassicas such as turnips or rape for winter grazing (Barnes et al., 2003). Although many of these options require planting extraneous annuals, stockpiling forage can be accomplished with perennial species in already established pastures. Cool season grasses generally have two main growth periods, one in the spring and a lesser one in the fall, with a “summer slump” in between, while warm-season grasses have one large growth period in summer (Barnes et al., 2003). Stockpiling refers to allowing the fall growth of a cool season forage or late summer growth of a warm season forage to accumulate for grazing in the late fall or winter.

Stockpiled Tall Fescue

Tall fescue has become the forage of choice for fall stockpiling and winter grazing for many reasons. Over 35 millions acres of tall fescue are in production in the United States (Barnes et al., 2003), making it readily available for many producers. In addition, tall fescue is known for its persistence, hardiness, and tolerance of drought, flooding, heat, and cold and has many characteristics that make it good for stockpiling. These include its formation of a dense sod and extensive root system, increased fall growth, preservation of quality through winter, persistency after winter grazing, nonstructural carbohydrate concentration increasing palatability, tolerance to soil temperature changes, and upright leaf growth (Archer and Decker, 1977b; Bagley et al., 1983; Poore et al., 2000; Riesterer et al., 2000a; Riesterer et al., 2000b; Barnes et al., 2003; Kallenbach et al., 2003).

Management of Stockpiled Tall Fescue. A considerable amount of research in the 1960s to 1990s investigated timing of initiation of the stockpiling period and the effects nitrogen fertilization upon forage yield and quality. In a review on stockpiled tall fescue, Poore et al. (2000) concluded from these studies that although yield is increased with earlier initiation dates and nitrogen application, the best initiation practices are dependent upon the location, climate, and soil conditions of a specific area. They did note that one commonality was the importance of grazing or harvesting the lower-quality summer growth before stockpiling for improved stockpiled forage quality. Gerrish and coworkers (1994) found that initiation and fertilization of stockpile in early August was the most beneficial practice in Missouri, and advised that over 40 lb/A of nitrogen may not be economical. Although increased nitrogen up to 120 lb/A was shown to increase stockpile yield, the cost of nitrogen fertilizer, quality of the forage stand, and soil conditions need to be considered when determining the nitrogen application rate.

Little research has been conducted to determine the best method of grazing stockpile, but strip-grazing is often used. When strip-grazing, small strips of pasture are allocated on a regular basis, and animals have access to old strips along with the current new strip at all times (Barnes et al., 2003). The nature of strip-grazing gives potential to reduce amount of grazing selection that can take place when allocated correctly, and can therefore achieve high utilizations. Because the forage has generally gone dormant for the winter, cattle do not need to be moved off of previously grazed stockpile, lending it well to strip-grazing. Poore and coworkers (2000) created a case study simulation and found that allocating stockpile daily versus every two weeks reduces daily feed cost (\$0.74 vs. \$0.95) due to the higher utilizations possible.

Stockpiled Tall Fescue Yield and Quality. Although yield and quality of stockpiled tall fescue vary due to many factors, it is generally high enough quality to maintain beef cows that are in either gestation or lactation (thus spring or fall calving) and is often of better quality than grass hay fed by beef cow-calf producers (Hedtcke et al., 2002; Kallenbach et al., 2003). Archer and Decker (1977a) found that the proportion of dead leaves increased from 20% to 46% of total stockpile over winter. They found green leaves to contain less neutral detergent fiber, acid detergent fiber, lignin, and silica, and to be more digestible than dead leaves. This leaf death data follows the decline in stockpiled tall fescue quality during the winter that is usually reported (Ocumpaugh and Matches, 1977; Fribourg and Bell, 1984; Hedtcke et al., 2002).

Peak stockpile yield has been observed in November or December (Taylor and Templeton, 1976; Archer and Decker, 1977b; Fribourg and Bell, 1984; Kallenbach et al., 2003), after which point dry matter yield decreases due to temperatures dipping below freezing and growing conditions becoming less favorable. Kallenbach et al. (2003) has suggested that warm temperatures in winter may initiate new tall fescue growth, however, although these warm periods may also hasten decay of stockpiled forage.

Grazing stockpile may or may not affect dry matter yield of winter grazed pastures during the following spring and summer. Although Hall and coworkers (1998) found spring production was decreased by 15% after stockpiling and grazing, Riesterer et al. (2000a) observed no effect of stockpiling unless grazing continued into March. Both reported tall fescue to have good persistence after winter grazing. It has also been suggested that some of the nitrogen applied at stockpile initiation may be carried over for spring growth and thus improve yields, although not consistently (Gerrish et al., 1994).

One negative aspect of tall fescue is the adverse effect of the ergot-like alkaloids produced by the endophytic fungus that infects most tall fescue varieties. Although the fungus gives tall fescue some of its hardiness, it also causes animals to experience “fescue toxicosis,” characterized by decreased gain, lowered milk production, poor conception rates, and reduced bloodflow to extremities and peripheral tissues, causing inability to dissipate heat and loss of toes, ears, and tails due to frostbite and necrosis (Paterson et al., 1995). Most research dealing with stockpiled tall fescue has utilized endophyte infected varieties. Kallenbach et al. (2003) observed 20% lower dry matter yields for novel, nontoxic endophyte infected and non-endophyte infected tall fescue varieties versus their endophyte infected counterpart. In the same study, these researchers found ergovaline, a marker for the ergot-like alkaloids produced by the endophyte, concentrations to be highest in December, then decrease to safer levels in January or February. Performance problems associated with fescue toxicosis can therefore be avoided by stockpiling novel or non-endophyte infected tall fescue pastures or by grazing infected pastures later in the winter.

Beef Cow Performance While Grazing Stockpiled Tall Fescue. Beef cows in gestation and lactation have been shown to have adequate performance when wintered on stockpiled tall fescue (Waller et al., 1988; Tucker et al., 1989; Allen et al., 1992; Hitz and Russell, 1998; Janovick et al., 2004; Curtis, 2006). Allen et al. (1992) observed higher weight gains from November to January for spring-calving cows grazing stockpiled tall fescue compared to stockpiled orchardgrass-red clover or orchardgrass-alfalfa, while cows grazing stockpiled tall fescue also required less hay to maintain condition through the winter. Spring-calving cows grazing stockpiled tall fescue-alfalfa had greater body

weight and body condition score increases while also being fed less supplementary hay than cows wintered on hay, stockpiled smooth brome-grass-red clover pasture, or corn crop residue in another study (Hitz and Russell, 1998). Little research has been done, however, to compare the performance of cows grazing stockpiled tall fescue to feeding hay alone or with supplementation.

Stockpiled Tall Fescue Summary

Stockpiling tall fescue provides producers with an opportunity to extend the grazing season and decrease the use of harvested forage to winter beef cows. Because quality of the stockpiled forage is generally adequate for meeting beef cow requirements and declines less than other forage species in winter, it is likely a better feedstuff than most grass hay fed to beef cows. Although initiation dates, nitrogen fertilization, and the resulting forage yield and quality were studied extensively in the past, little current research has compared grazing stockpile to more traditional wintering methods.

SUMMARY

Although feed makes up the greatest proportion of annual costs for beef cow-calf producers, providing the herd with adequate nutrition is vital to its productivity and profitability. If decreasing costs from feed inputs is possible, it can greatly affect the producer's bottom line. Two means to achieve this goal are to increase the feed efficiency of individuals within the cowherd and extend the grazing season. Both of these

approaches have the potential to decrease feed input cost while maintaining production levels. The objective of the following studies was therefore to further investigate these strategies and their effects upon cow intake and performance.

CHAPTER 2

The Effect of Feed Efficiency Rank on Beef Cow Grazed Forage Intake

ABSTRACT

Although feed intake and efficiency differences in growing cattle of low and high residual feed intake (**RFI**) rank have been established, little is known about the difference in grazed forage intake between beef cows of known RFI rank. Two experiments were conducted using purebred Hereford cows for which RFI had been determined as heifers using the GrowSafe 4000E feed intake system. During Exp. 1, two replicates of low and high RFI cows ($n = 7/\text{rep}$) were blocked to 1 of 4 non-endophyte infected tall fescue paddocks which they grazed continuously for 84 d during summer. Using grazing enclosures, weekly rising plate meter readings, and forage harvests every 21 d, average forage DMI was calculated. Although low and high RFI groups did not differ ($P > 0.05$) in BW change or BCS change over the trial (19.5 vs. 22.1 kg and 0.11 vs. 0.10 BCS), low RFI cows had a 21% numerically lower DMI than high RFI cows (12.4 vs. 15.6 kg, $P = 0.23$). The average area needed per paddock over the trial was numerically less for low RFI than high RFI cows (1.71 vs. 1.82 ha, $P = 0.35$), and the average DM on offer over the trial tended to be lower for low RFI than high RFI cows (4215 vs. 4376 kg, $P = 0.06$). During Exp. 2, three replicates of low and high RFI cows with their calves ($n = 4$ pair/rep) strip-grazed stockpiled tall fescue and early spring growth for 60 d in late winter

and early spring. Due to limiting forage availability and quality at trial initiation, cow-calf pairs were also fed 3.31 kg/pair pelleted soyhulls daily. Pre- and post-grazed forage samples were harvested before and after each of 4 grazing periods, and forage growth was estimated using a growing degree days calculation and on-site weather station data. Cow performance did not differ ($P > 0.05$) between low and high RFI cows throughout the experiment (18.4 vs. 26.6 kg and -0.04 vs. 0.15 BCS changes, respectively). Calves from low and high RFI dams also did not differ ($P > 0.05$) in ADG (0.85 vs. 0.95 kg/d). Despite the utilization of forage offered being similar for low and high RFI cow-calf pairs ($P > 0.05$), low RFI cows and their calves consumed 11% numerically less forage per day than their counterparts (12.5 vs. 14.1 kg/d, respectively; $P = 0.12$). Although forage intake differences measured between low and high RFI cows were only numerically different, this could be due to the difficulty of measuring forage intake by grazing cattle and the low number of experimental units. Additional studies are necessary to confirm these differences.

INTRODUCTION

Providing adequate nutrition for their animals is the greatest operating cost for cow-calf producers. The USDA Economic Research Service has estimated that in 2004 and 2005 feed-associated costs made up 59.2% and 55.7%, respectively, of all non-fixed costs of US cow-calf operations (USDA-ERS, 2005). Traditionally, more selection emphasis in the beef industry has focused upon increasing outputs, which can often

increase inputs as well. Because feed makes up such a great portion of total inputs, any reduction in feed intake while maintaining production could have a great impact upon profitability of cow-calf operations.

One means to reduce feed inputs is through improvement in feed efficiency. It has been well established that individual differences for this trait exist in beef cattle, making selection possible. Although feed conversion ratio (**F:G**) or gross efficiency (**G:F**) are often used, residual feed intake (**RFI**) may be a more accurate representation of the actual genetic and biological differences in feed efficiency (Archer et al., 1999). RFI is calculated as the difference between an animal's actual measured intake and its predicted intake based on its growth rate and body weight. This makes RFI, a trait that has been shown to be moderately heritable (Arthur et al., 2001b), phenotypically independent of growth and body size, unlike F:G or G:F.

Although feed intake has been shown to be reduced in growing cattle that were either determined to have low RFI rank (high efficiency) or resulted from herds divergently selected for low RFI, little is known of the difference in grazed forage intake of mature cows due to RFI or selection for this trait (Herd et al., 2003). We hypothesized that cows of low RFI rank would consume less forage DM than their high RFI counterparts, while still maintaining similar body weight and condition. Therefore, the objective of this research was to determine the effect of RFI rank on the grazed forage intake of beef cows and the subsequent pasture carrying capacity.

MATERIALS AND METHODS

Determination of Residual Feed Intake

Forty-two purebred Hereford heifers were donated to the University of Missouri by 19 Missouri producers to develop a purebred herd to study the physiological and production effects of selecting for metabolic efficiency. During the summer of 2005, a 51-day trial was conducted using these heifers to determine their RFI. Using the GrowSafe feed intake system (model 4000E, GrowSafe Systems Ltd., Airdrie, AB, Canada). Heifers were randomly allocated to 8 pens (5 to 6/pen, 7.3 x 16.5 m), each with 2 GrowSafe bunks. After an acclimation period, heifers were given ad libitum access to water and square-baled alfalfa-grass mixed hay (86.2% DM, 13.7% CP, 58.6% NDF, 39.2% ADF) for the duration of the feeding trial. Individual daily hay intakes were recorded by the GrowSafe system, and the RFI was calculated for each individual as the difference between actual feed intake and expected feed intake. Expected feed intake was calculated by regressing the actual feed intake against the metabolic midweight and average daily gain during the trial (Basarab et al., 2003). Heifers were then categorically ranked as low RFI (highly efficient), mid RFI, and high RFI (lowly efficient).

Experiment 1

Experimental Design. An 84-day grazing trial was completed from May 18 to August 9, 2006 at the University of Missouri South Farm to determine the grazed forage intake of beef cows of known RFI rank. Purebred Hereford cows (n = 28, average initial BW = 578.1 ± 50.3 kg, average initial BCS = 5.26 ± 0.55) from the low RFI (highly

efficient) and high RFI (lowly efficient) groups determined during the previous trial were used after their first calving season. Fifteen of these cows had calved during the previous fall (7 low RFI, 8 high RFI), whereas the remainder had not yet calved due to young age or not conceiving during the breeding season. All animals will be referred to as “cows” for this study as all animals were over 2 years of age (date of birth: February 26, 2001 to February 20, 2004) when this experiment was conducted. Twenty-four cows were verified pregnant by rectal palpation pre-trial, with expected calving dates from September 1 to November 15, 2006. All but 4 cows were thus in mid to late gestation during this experiment.

Low and high RFI groups were allocated by BW, BCS, and RFI to 2 replicates each ($n = 7$). These were then blocked by pasture and allocated to graze 4 paddocks (1.8 to 2.4 ha/paddock) created from 2 non-endophyte infected tall fescue-based pastures (Figure 2.1). Paddocks were grazed continuously throughout the trial and cows had ad libitum access to water and mineral supplement (Table 2.1). To keep forage availability similar between paddocks, electric poly-tape and movable step-end posts were used to create a buffer area. This was adjusted in size as needed by using weekly electronic rising plate meter (**RPM**; FarmWorks, Feilding, New Zealand) readings to compute total RPM units/paddock. RPM units served as estimates of forage dry matter on offer, as each unit represented approximately the same dry matter yield on a given sampling date. Paddocks were adjusted in size to keep total RPM units within 10 per paddock for reps from each pasture (block).

Forage Yield and Quality Measurement. To measure forage growth, each paddock had 10 exclosures made from round bale feeders surrounded by wire fence.

Every 21 days, the exclosures were sampled by taking a cross-section at right angles with a tractor powered flail-type harvester (81.3 cm wide, down to 2 cm of forage height). Cross-section lengths were measured and recorded for use in calculating area sampled. After sampling, each exclosure was moved to a new location within the paddock to determine growth during the next sampling period. Coinciding with exclosure sampling, the grazed areas of the paddocks were also sampled to determine forage dry matter on offer by harvesting 10 strips (4.9 m x 81.3 cm each, down to 2 cm forage height) from each paddock.

Forage obtained from each cross-section and strip was weighed and subsampled in the field. Subsamples were then weighed, dried at 55°C, and ground to 1 mm using a Wiley Mill and Cyclotec grinder (model 1093, Tecator AB, Höganäs, Sweden). Ground forage samples were dried at 100°C for 24 hours to determine total dry matter (**DM**) and ashed at 600°C to determine inorganic matter content (AOAC, 1984). Neutral detergent fiber (**NDF**) and acid detergent fiber (**ADF**) were sequentially analyzed using an Ankom Fiber Analyzer (model 200, Fairport, NY). A LECO nitrogen analyzer (model FP-428, St. Joseph, MI) was used to determine nitrogen content by thermoconductivity, which was then used to calculate crude protein (**CP**, N x 6.25).

Temperature and precipitation data during the experiment were collected from a weather station located on South Farm, and 30-year average data were obtained from the National Oceanic and Atmospheric Administration's National Weather Service archive of climatology and weather records for Columbia, Missouri.

Animal Performance Measurements. Two-day consecutive body weights were taken at the beginning and end of the study. Cows were also weighed on days 21, 42, and

63, although d 42 weights were not used due to scale malfunction. All weights were taken in early morning without removal from feed and water. Additionally, cows were body condition scored (1 to 9 scale, 1 = emaciated, 9 = obese) by three trained technicians on days 0, 42, and 84. These three scores were averaged by date for each cow for use in data analysis.

Statistical Analysis. Weekly RPM readings and date of experiment were used in a stepwise model selection (SAS version 9.1, SAS Inst. Inc., Cary, NC) to predict forage DM yield. The total DMI per paddock per 21-d period was calculated by: $DMI_{\text{Paddock}} = \text{Area}_{\text{Grazed}} * [(\text{Yield}_{\text{Exclosure t1}} - \text{Yield}_{\text{Grazed t0}}) - (\text{Yield}_{\text{Grazed t1}} - \text{Yield}_{\text{Grazed t0}})]$, where t0 = the previous sampling and t1 = the current sampling. This was then used to calculate average individual DMI (kg/d).

The data were analyzed as a randomized complete block design using the GLM Procedure of SAS version 9.1 with paddock as the experimental unit and pasture as the block.

Experiment 2

Experimental Design. A second 60-day grazing trial was conducted from February 23 to April 23, 2007 at the University of Missouri South Farm to determine the forage intake of lactating beef cows of known RFI rank grazing stockpiled tall fescue and beginning spring growth. Purebred Hereford cows (n = 24, average initial BW = 563.3 ± 60.2 kg, average initial BCS = 4.92 ± 0.59) from the low RFI (highly efficient) and high RFI (lowly efficient) groups with calves at side (n = 24, average initial BW = 136.1 ± 21.6 kg, average initial age = 142.7 ± 20.9 d) were used. Cows from each group were

allocated with their calves by BW, BCS, RFI, and calf age to 3 replicates. Random mating occurred with respect to RFI, as calves were sired by bulls of unknown RFI rank.

Animal and Paddock Management. Twelve tall fescue-based paddocks (6 low endophyte infected, 6 high endophyte infected; 0.73 to 0.93 ha/paddock) were used to stockpile forage for this experiment (Figure 2.2). In mid-August 2006, 45 kg/ha N was applied to the paddocks used in this study, which had been previously grazed or mowed. After N application, forage was allowed to accumulate until the trial's initiation (February 23). Original experimental design was to begin the grazing trial earlier to avoid spring growth. However, due to an unusual amount of snow and ice accumulation during the winter, this was not possible.

Paddocks were strip-grazed using electric poly-tape and movable step-end posts and a new strip was allocated about every 3.5 days (2x/week). Initial strip allocations were determined using a set residual and assuming that cows would consume 1.2% of their BW in NDF per day (Mertens, 1987). After this, strip size was allocated based upon the residual left after grazing the previous strip. The goal of strip allocation was to not limit intake, while also keeping utilization similar between paddocks. Strip size was calculated based on the number of days expected for grazing each allocation when a 3.5 d moving schedule could not be kept. When strips were grazed more quickly than anticipated, new strips were given earlier than planned so that forage availability was not limiting for more than 12 hours.

The trial was divided into 4 grazing periods (period 1: d 1 to 18, period 2: d 19 to 37, period 3: d 38 to 47, period 4: d 48 to 60). During periods 1 and 2, all replicates except 1 (a low RFI replicate which had to be moved due to limited forage availability

after period 1) grazed low endophyte infected paddocks. High endophyte infected paddocks were then grazed during periods 3 and 4.

Forage quality and availability were limiting at trial initiation, therefore, in order to maintain body condition of cows, cow-calf pairs were supplemented daily with 3.31 kg of pelleted soyhulls (9.6% CP, DM basis), regardless of RFI rank. Pairs had adequate bunk space and ad libitum access to water and mineral supplement (Table 2.1).

Forage Yield and Quality Measurement. Forage was sampled 5 times throughout the trial (d -13, 18, 32, 47, and 60), so that pre-grazing samples were harvested before and post-grazing samples were taken after each grazing period. Post-grazing samples were harvested from the strips allocated since the previous sampling, and pre-grazing samples were taken from the area estimated to be allocated before the following sampling date. Sampling dates, and thus exact period lengths, were changed as necessary when precipitation prevented forage harvest resulting in periods of unequal length. On 2 dates (d 32 and 47), sampling was interrupted by rain after some paddocks had been harvested and the remaining paddocks were sampled as soon as weather and soil conditions allowed (d 33 and 49, respectively).

Forage was sampled as in Exp. 1, with 10 strips (4.6 m x 81.3 cm each, down to 2 cm forage height) harvested per paddock. Subsamples were dried, ground and analyzed for DM, ash, NDF, ADF, and CP as in Exp. 1.

Temperature and precipitation data during the experiment were again collected from the weather station located on the research farm, and 30-year average data were obtained from National Oceanic and Atmospheric Administration's National Weather Service archive of climatology and weather records for Columbia, Missouri.

Animal Performance Measurements. At the trial's initiation and conclusion, cows and calves were weighed on 2 consecutive days and cows were body condition scored by 2 trained technicians. Cows and calves were also weighed on d 29. All weights were taken without removal from feed and water, and BCS were averaged per cow and date for use in later analysis.

Statistical Analysis. Forage growth was estimated using growing degree days (base 4.4°C for tall fescue) and temperature data previously collected. The total forage DMI per paddock for each period was calculated by: $DMI_{\text{Paddock}} = \text{Area}_{\text{Grazed}} * [(\text{Yield}_{\text{Pre-grazed}} + \text{Growth}_{\text{Calc}}) - \text{Yield}_{\text{Post-grazed}}]$. This was then used to determine average forage DMI per pair (kg/d).

The data were analyzed as a completely randomized design with paddock as the experimental unit in the GLM procedure of SAS version 9.1 (SAS Inst. Inc., Cary, NC).

RESULTS AND DISCUSSION

Heifer Residual Feed Intake

Residual feed intakes of heifers in this study ranged from -9.21 to 10.26 kg/d. Average RFI for low and high groups used in Exp. 1 and 2 are shown in Tables 2.2 and 2.3, respectively. This range of RFI is larger than that which is typically reported for a group of growing cattle that are not the result of divergent selection for and against feed efficiency (Nkrumah et al., 2004; Kolath et al., 2006; Castro Bulle et al., 2007), but may be due to a variety of factors. One major difference is that RFI in the cited studies were

determined on a pelleted ration. Although some rations used to determine RFI are pelleted but have increased forage content (Arthur et al., 1999), to the author's knowledge, no other experiments have been published in which RFI has been determined using hay without grinding and pelleting. Because the heifers would be consuming a forage-based diet as cows, unprocessed hay was chosen to determine post-weaning RFI. The GrowSafe system is intended for pelleted or grain-based rations, and thus using it to feed hay most likely introduced error due to heifers wasting hay which was removed from the feeder but not consumed. This may not have seriously affected RFI rank, however, as heifers that consumed more hay must have spent more time eating, and thus also most likely wasted more forage.

Animal Performance

Cow performance for Exp. 1 is shown in Table 2.2. Although there was no difference in initial BCS due to treatment ($P = 1.00$), low RFI cows were heavier at trial initiation than high RFI cows ($P = 0.004$). There were no differences between low and high RFI cows for BW change ($P = 0.68$) or BCS change ($P = 0.86$) throughout the trial, and both groups gained weight and condition as the trial progressed.

Table 2.3 contains cow and calf performance for Exp. 2. When low and high RFI cows began the trial, there were no significant differences in BW ($P = 0.46$) or BCS ($P = 0.55$). In addition, there were no differences due to RFI group for cow BW change ($P = 0.59$) or BCS change ($P = 0.19$) throughout the experiment. Numerical differences did exist for BCS however, as high RFI cows both began the experiment at a higher average BCS and had a positive BCS change during the trial compared to low RFI cows' loss in

condition. There were no differences in calf age ($P = 0.87$), initial calf BW ($P = 0.34$), or calf ADG in Exp. 2 ($P = 0.45$) due to RFI group of dam, although calves from high RFI dams began the trial numerically lighter and had numerically higher ADG.

Because cows were managed together prior to both experiments, the difference in initial cow BW (Exp. 1) and lack thereof (Exp. 2) could be either true biologically or simply a result of the small numbers and varied genetics of the animals used in this study. Using cows for which RFI had been determined postweaning, Herd et al. (1998) found that low RFI cows were significantly heavier than their high RFI counterparts in a pasture intake trial. In another study examining the effect of selection for RFI upon maternal productivity over 4 years, low RFI line cows were numerically heavier at all time points, but this difference was not significant (Arthur et al., 2005). This is in contrast to a study in which there was no difference in mature cow BW between RFI groups that had been determined postweaning when their RFI were redetermined as 4-year olds (Arthur et al., 1999). Recent mouse research conducted by Hughes and Pitchford (2004) agreed and found no differences in dam or dam plus litter mid-weight during gestation and lactation. Genetic correlations between postweaning RFI and mature weight have been found to be between -0.09 ± 0.26 and -0.22 (Herd and Bishop, 2000; Archer et al., 2002). Thus, although RFI by definition is not correlated to body weight, selection for low RFI may in fact cause an increase in mature cow size due to a low negative genetic correlation between the two traits.

Cattle of differing RFI rank are known to have similar performance, as shown in this study. Arthur and coworkers have reported that for both cows with RFI determined postweaning (1999) and cows from lines divergently selected for RFI (2005), low and

high RFI cows had similar ADG and BW change, respectively. Similarly, mice from low and high RFI lines have been shown to have similar dam and dam plus litter ADG during gestation and lactation (Hughes and Pitchford, 2004). Growing steers, either determined to have low and high RFI (Basarab et al., 2003; Kolath et al., 2006; Castro Bulle et al., 2007) or from lines divergently selected for RFI (Arthur et al., 2001a) have also exhibited no difference in ADG. The genetic correlation of postweaning RFI to postweaning ADG has been reported to be -0.06 (Arthur et al., 2001b), postweaning RFI to cow ADG to be 0.22, and cow RFI to cow ADG to be 0.02 (Archer et al., 2002).

A positive correlation may exist between RFI and body fat content, as observed numerically in Exp. 2. Arthur et al. (2005) found cows divergently selected for high RFI to have numerically greater rib fat depth at all points measured over 4 years, although this difference was significant at only 3 points during which all cows were at their highest condition. In addition, feedlot steers with high RFI or from high RFI lines have been shown to have increased carcass fat (Richardson et al., 1998; Richardson et al., 2001; Basarab et al., 2003). Conversely, low and high RFI cows have also been found to have similar back fat depth in one study (Arthur et al., 1999). Genetic correlations between RFI and back fat and rump fat have been calculated to be 0.17 ± 0.05 and 0.06 ± 0.06 , respectively (Arthur et al., 2001b).

Few examples of preweaning calf performance from dams of known RFI rank or divergent RFI selection exist in the literature. Arthur and coworkers (2005), in their 4-year study, found that calves from both RFI line dams had similar weaning weights and preweaning ADG. A study by Herd et al. (1998) showed that calves from low RFI dams were numerically heavier during their pasture intake study, although the calves were also

numerically older. Because it has been established that cattle from low and high RFI rank or lines have similar growth potential postweaning, any differences in preweaning calf performance is most likely due to another factor. One possibility is milk production, but this is unlikely as milk yield, when determined by the weigh-suckle-weigh method, has been shown to be similar between cows of low and high RFI rank (Arthur et al., 1999) and divergently selected RFI lines (Arthur et al., 2005). The preweaning gain of calves may also be affected by the interaction of calf efficiency and limited feed resources, as similar growth has been seen postweaning when ad libitum intake is possible. If cows are producing the same milk yields, then more efficient calves could gain more from their intake. No such conclusion may be drawn from this current study, however, as calves were not the result of divergent selection and the opposite numerical results were observed.

Forage Yield and Quality

Average forage yield and quality by RFI group and sampling date are shown in Table 2.4. DM yield, CP, NDF, and ADF were similar at all sampling dates ($P > 0.10$) except DM yield was greater for low RFI paddocks on d 63 ($P = 0.06$) and ADF was greater for low RFI paddocks on d 42 ($P = 0.09$). As expected, forage yield decreased as the experiment and summer progressed, following the normal growth curve of a cool-season grass. As growth decreased and cattle grazed more selectively, CP decreased and NDF and ADF increased. Although temperatures were near the 30-year average during Exp.1, precipitation during May and July was considerably less than the average (Figure 2.3). This lower rainfall likely decreased forage yield potential during this experiment.

Table 2.5 shows the average forage yield and quality by sampling date and RFI group for Exp. 2. There were no differences in DM yield, CP, NDF, or ADF for any sampling date ($P > 0.10$), except NDF being higher for low RFI paddocks on d 47 and 49 ($P = 0.03$). Temperature and precipitation data from stockpile initiation through the grazing trial of Exp. 2 are shown versus the 30-year average in Figure 2.4. Much lower than average rainfall in September and November, during the fall growth period of cool season grasses that makes stockpiling possible, likely decreased the initial forage yield. When the weather data were averaged for the 4 grazing periods (Table 2.6), warmer temperatures were seen in period 2, followed by a cool-down in period 3, and another warm-up in period 4. This warming trend during period 2 aided beginning forage growth, as seen the concurrent forage yield increase. Growth was then likely stunted by the cool temperatures in period 3, and resumed during period 4's warm-up. CP was highest and NDF and ADF were lowest in period 4 after the most growth had occurred and new forage was in large enough quantities to dilute the stockpile.

Forage Intake

Table 2.7 shows grazed forage intake and pasture carrying capacity data from Exp. 1. Low RFI cows had a 21% numerically lower average DMI than high RFI cows ($P = 0.23$). This decreased forage intake of low RFI cows led to a subsequent increase in pasture carrying capacity for low versus high RFI cows, illustrated by the average area per paddock needed to maintain cows over the trial being numerically less for low RFI cows ($P = 0.35$). Additionally, because low RFI cows were consuming less forage, the DM on offer averaged per paddock throughout the trial was less for low RFI than high

RFI cows ($P = 0.06$), even though both maintained similar BW, BCS, and DM yield (kg/ha) over the course of the trial.

Forage utilization and DMI for cow-calf pairs in Exp. 2 is shown in Table 2.8. Low RFI cow-calf pairs had an 11% numerically lower DMI on average than high RFI pairs ($P = 0.12$). There was no difference in forage utilization throughout the trial, however, per experimental design ($P = 0.84$).

Because of the difficulty in measuring grazed forage intake, there is little previous published research for which to compare these results. In a similar trial, Herd et al. (1998) found a small numerical difference in forage intake and a trend ($P = 0.07$) for a 15% increase in calf BW/cow DMI (kg calf weight/(kg•d⁻¹ cow intake)) between low and high RFI lactating cows on pasture. Another study, in which non-lactating, open cows for which RFI had been determined postweaning consumed a pelleted hay-wheat ration, low RFI line cows had a significant 4.5% decrease in DMI compared to their high RFI line counterparts (Arthur et al., 1999). This research helped to solidify the correlation between RFI determined postweaning and at maturity, as RFI remained significantly different between low and high RFI cows when measured at 4 to 4.5 years of age. The phenotypic correlation of postweaning RFI to cow RFI has been reported between 0.36 and 0.40, while the genetic correlation has been shown to be stronger at 0.98 (Arthur et al., 1999; Archer et al., 2002). Although this correlation is only moderate, the intake data presented here suggests that cows in this experiment remained in their postweaning efficiency group.

Herd et al. (1998) also found no difference in forage DM digestibility in their cow pasture intake study. This is in contrast to evidence that steer progeny from high RFI

lines may have decreased starch digestion (Channon et al., 2004), although it is unknown whether this is strictly an effect of intake alone. Data from these studies necessitates the question of whether efficiency differences between low and high RFI animals are more marked when fed higher concentrate diets compared to forage only. A study conducted by Herd et al. (2002) with stocker steers resulting from 1 generation of divergent selection for RFI found that low RFI steers consumed 10% numerically less forage, showed a trend ($P = 0.10$) towards improved ADG, and had 25% numerically better F:G. No forage quality data was presented, and thus it is possible that intake was limited due to fiber content, which then decreased DMI difference observed and forced a difference in ADG. Once again, no difference was observed in DM digestibility in this study. While differences in starch and fiber digestion may exist between RFI groups, this current study may not be affected, as postweaning RFI was determined using forage.

Although no significant differences due to RFI have been published to the author's knowledge, the literature contains intriguing numerical differences in grazed forage intake. The lack of significance from the pasture studies cited (Herd et al., 1998; Herd et al., 2002) may be due, as least in part, to the methods used to measure intake. These studies used alkane markers, which have many associated problems. Different forage species and plant parts have different alkane patterns, so to properly calculate intake using this method, the forage being consumed must be correctly characterized (Lippke, 2002), which can be difficult.

When fed a concentrate based diet, differences in DMI for steers with determined RFI have been documented to be decreased between 12% and 17% for low RFI steers (Nkrumah et al., 2004; Kolath et al., 2006; Nkrumah et al., 2006; Castro Bulle et al.,

2007). After one generation of divergent selection for RFI, a 6% difference was observed (Richardson et al., 1998), compared to an 11% difference after 5 years of divergent selection (Arthur et al., 2001a). Although the difference in efficiency and thus DMI has been well-established for growing cattle, it is largely unknown how this is affected by gestation and lactation.

Hughes and Pitchford (2004) studied the difference in intake and RFI during pre-pregnancy, gestation, and lactation between lines of female mice after 9 to 10 generations of selection for low or high RFI. Before the animals were pregnant, there was a significant difference of ~20% in DMI and RFI. The difference in DMI decreased slightly during gestation, during which the difference in RFI lessened to 12%. During early lactation, the DMI difference diminished and RFI for the 2 lines converged. Although RFI rediverged in late lactation, intakes remained similar between the 2 lines. These authors suggested that when mice were at maintenance requirements alone, the low RFI line had the advantage in efficiency, but when requirements increased due to gain and milk production during gestation and lactation, they became less efficient. They hypothesized that high RFI line mice were able to repartition previously wasted intake to fetal growth and milk production, while the low RFI line individuals did not have this buffer and thus had to increase intake.

Cows in Exp. 2 were in late lactation during the grazing trial, therefore if RFI phenotypes do converge during early lactation, this period was missed. The difference in intake between cows in gestation in Exp. 1 and lactation in Exp. 2 may be due in part to these production periods and the associated efficiencies of these physiological processes. The differences in intake reported here, although only numerical, are in line with DMI

differences published for growing cattle and mice during gestation of low and high RFI, however.

There are many potential reasons for the non-significance of the grazed forage intake data presented here due to the constraints of the experimental design. First, animals were low in numbers and of varied genetics. Also, calves used in Exp. 2 were sired by bulls of unknown RFI rank, as few US bulls currently have these data and no bulls had been produced from this breeding program yet. Because of this, RFI of calves may have differed from dam RFI groups, and thus their intake may have contributed to the decreased difference in Exp. 2 when compared to Exp. 1.

Finally, and perhaps most importantly, forage intake is difficult to measure on pasture, especially with intact animals. Because of the problems associated with alkanes and other fecal markers, more indirect means of intake measurement were employed for these experiments. These methods are known to be accurate, but become more so with each additional sampling due to the intrinsic error in each sampling date. In order to maintain a practical labor load, fewer sampling dates and experimental units (paddocks) were used than ideal. Weather can also have a large impact upon forage sampling and results and cannot be controlled. Larger numbers need to be used to further investigate the intake difference of beef cows due to RFI rank or selected divergence.

CONCLUSION

Low RFI cows had numerically lower grazed forage intakes than high RFI cows in gestation and late lactation while maintaining similar body weight and condition and weaning calves of similar weight. Results of this study indicate, however, that low RFI cows may be heavier at mature weight and have less fat deposition than their high RFI counterparts. Further research is necessary to confirm these differences.

Figure 2.1. Paddock design for Exp. 1

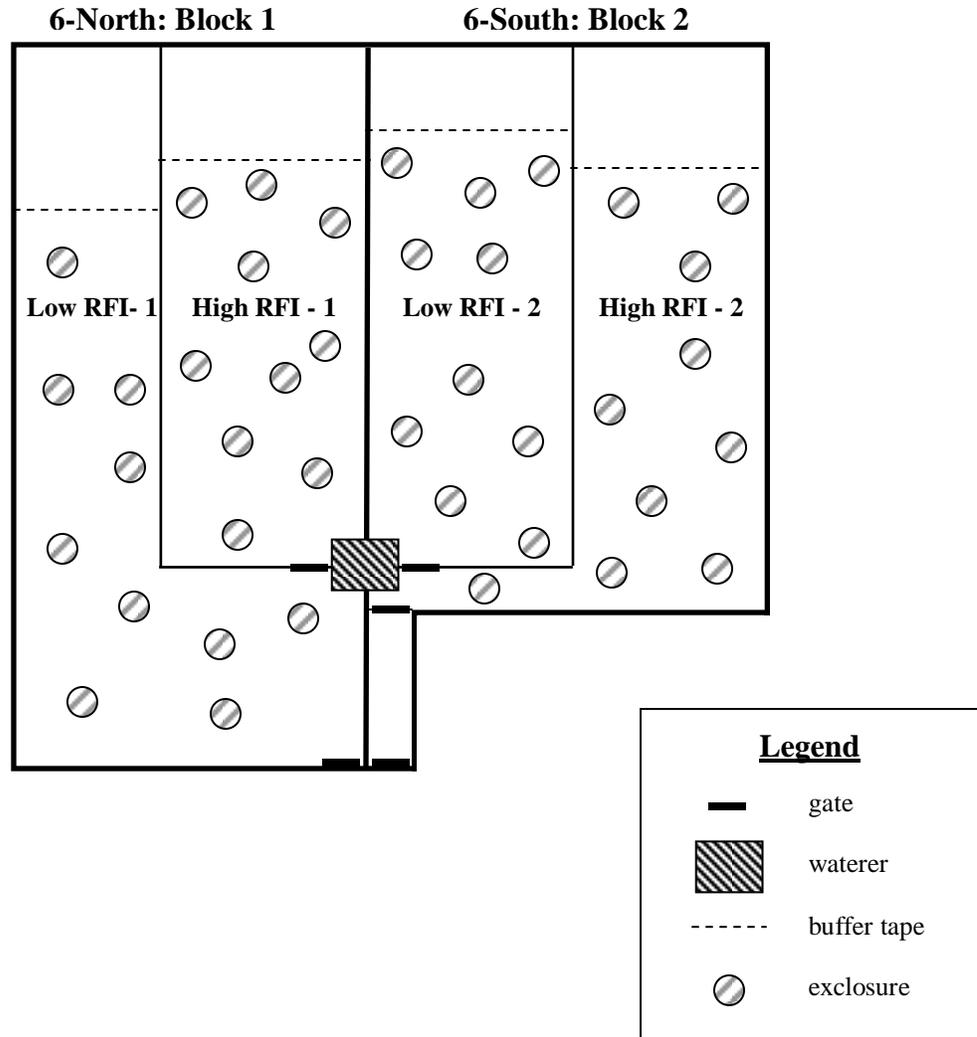


Figure 2.2. Paddock design for Exp. 2

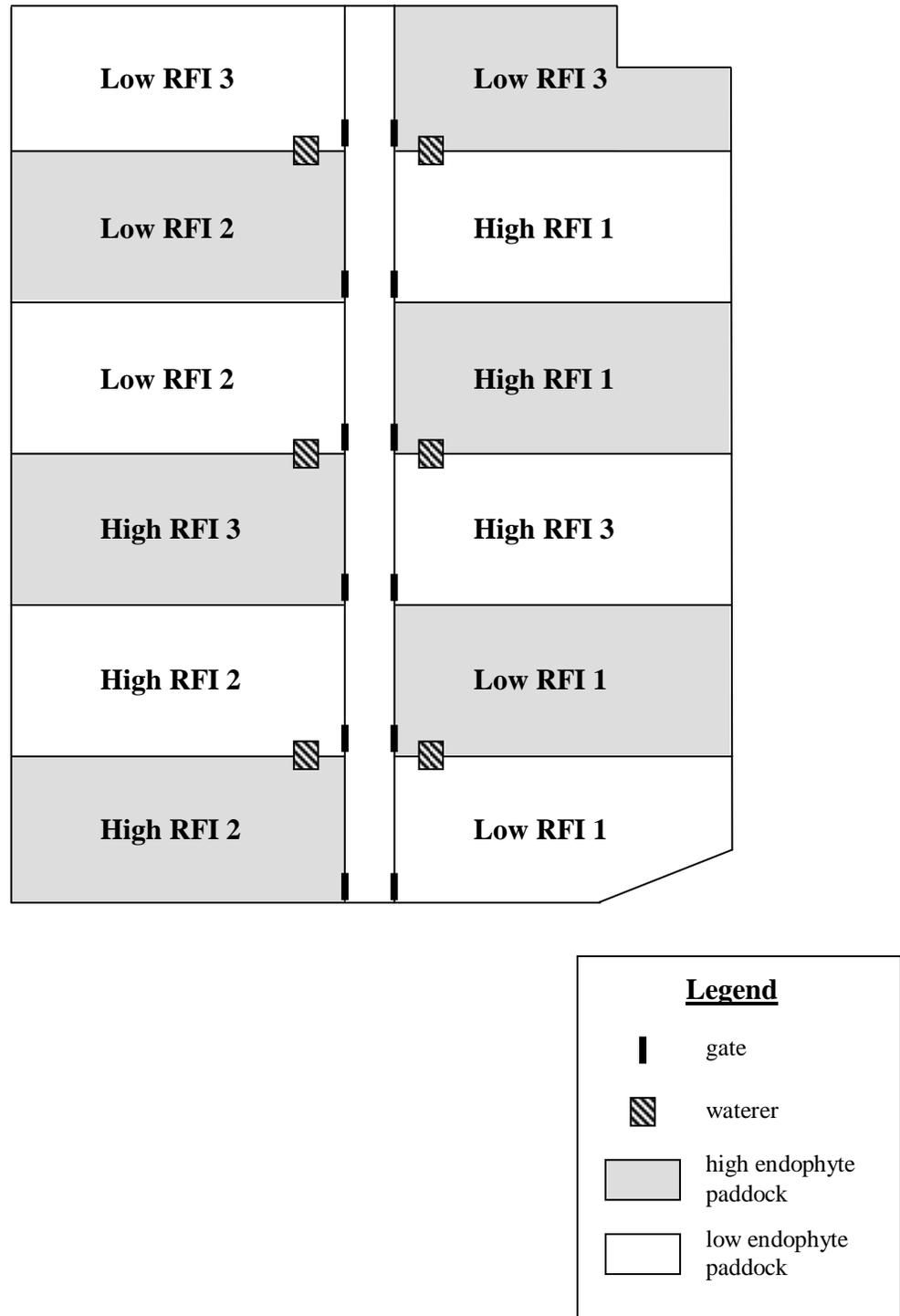


Figure 2.3. Temperature and precipitation data for May to August 2006 (Exp. 1) compared to a 30-year average

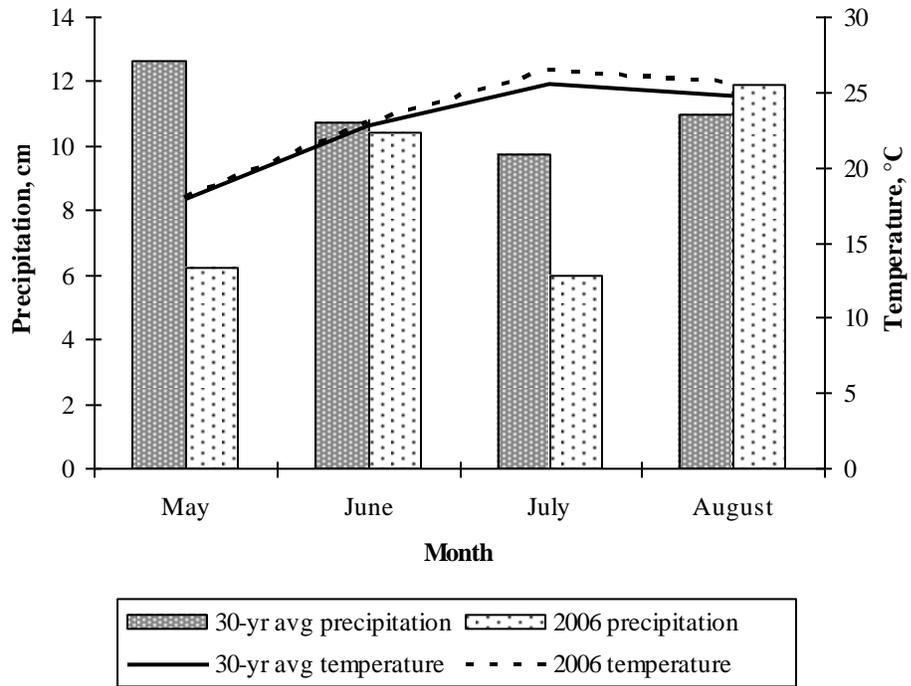


Figure 2.4. Temperature and precipitation data for August 2006 to April 2007 (Exp. 2) compared to a 30-year average

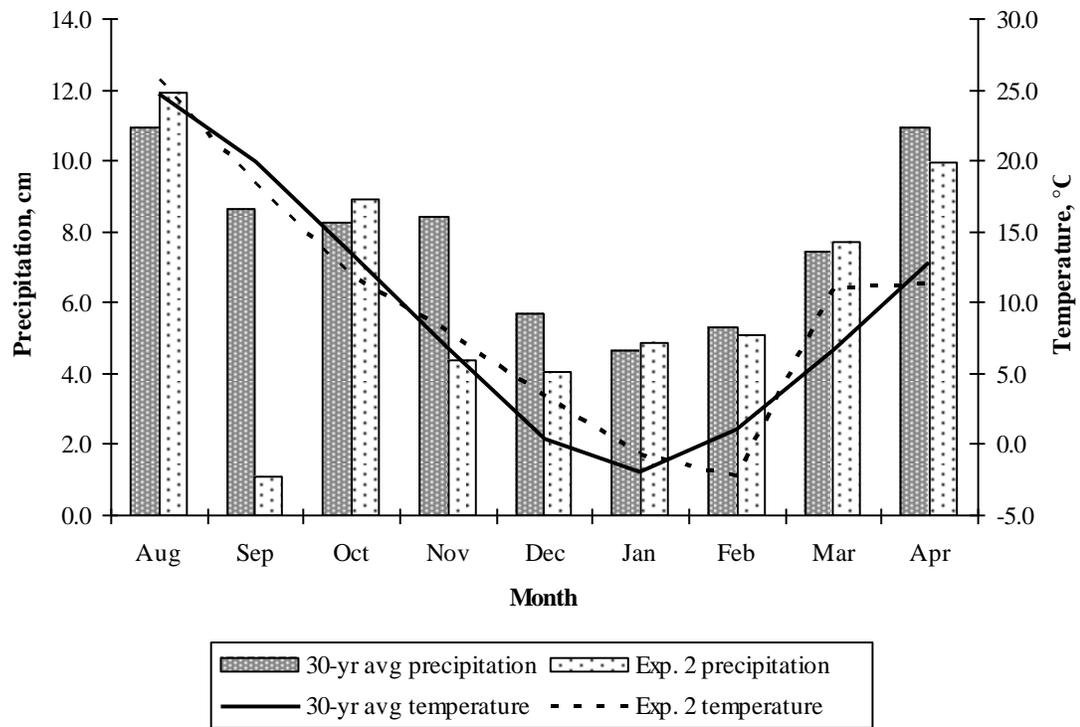


Table 2.1. Nutrient composition of mineral supplement offered ad libitum in Exp.1 and 2

Item	Concentration
Active Drug Ingredient	
Lasalocid ¹ , g/kg	1.58
Guaranteed Analysis	
Calcium (min), %	13.0
Calcium (max), %	15.5
Phosphorus (min), %	6.5
Sodium Chloride (min), %	18.0
Sodium Chloride (max), %	21.5
Magnesium (min), %	1.4
Potassium (min), %	0.8
Manganese (min), ppm	1,250
Copper (min), ppm	650
Cobalt (min), ppm	30
Iodine (min), ppm	69
Selenium (min), ppm	23
Zinc (min), ppm	2,188
Vitamin A (min), IU/kg	330,000
Vitamin D-3 (min), IU/kg	33,000
Vitamin E (min), IU/kg	330

¹ Lasalocid included as lasalocid sodium.

Table 2.2. Performance of cows with low or high residual feed intake (RFI) in Exp. 1

Variable	Low RFI	High RFI	SEM	<i>P</i>
RFI, kg/d	-4.37 ^b	5.04 ^a	0.70	0.006
Initial BW, kg	591.2 ^a	565.0 ^b	1.2	0.004
Initial BCS ¹	5.26	5.26	0.07	1.00
BW Change, kg	19.5	22.1	3.4	0.68
BCS ¹ Change	0.11	0.10	0.05	0.86

^{a,b} Means within a row lacking a common superscript differ, $P < 0.01$.

¹ BCS evaluated on 1 to 9 scale (1 = emaciated, 9 = obese)

Table 2.3. Performance of cows with low or high residual feed intake (RFI) and their calves (Exp. 2)

Variable	Low RFI	High RFI	SEM	<i>P</i>
Cows				
RFI, kg/d	-4.22 ^b	5.13 ^a	0.26	<0.001
Initial BW, kg	569.4	557.2	10.5	0.46
Initial BCS ¹	4.85	4.98	0.14	0.55
BW Change, kg	18.4	26.6	10.0	0.59
BCS ¹ Change	-0.04	0.15	0.08	0.19
Calves				
Age, d	144	143	7	0.87
Initial BW, kg	140.7	131.5	6.0	0.34
ADG, kg	0.85	0.95	0.08	0.45

^{a,b} Means within a row lacking a common superscript differ, *P* < 0.001.

¹ BCS evaluated on 1 to 9 scale (1 = emaciated, 9 = obese)

Table 2.4. Average forage yield and quality by sampling date and residual feed intake (RFI) group (Exp. 1)

Sampling Date ¹	d 21		d 42		d 63		d 84		SEM
	Low RFI	High RFI	Low RFI	High RFI	Low RFI	High RFI	Low RFI	High RFI	
DM Yield, kg/ha ²	2587	2562	2537	2520	2442 ^a	2256 ^b	1405	1540	59
CP, %	7.20	6.97	7.21	7.23	7.14	7.17	5.99	5.80	0.37
NDF, %	67.8	67.9	70.6	69.0	71.5	73.3	79.0	78.1	0.8
ADF, %	39.1	39.3	41.6 ^a	40.3 ^b	42.8	43.1	46.9	46.1	0.5

^{a,b} Means within a row and sampling date column lacking a common superscript differ, $P < 0.10$.

¹ d 21 = June 8, d 42 = June 29, d 63 = July 20, d 84 = August 10

² Yield calculated by regression equation derived from rising plate meter readings and harvested yield data

Table 2.5. Average forage yield and quality by sampling date and residual feed intake (RFI) group (Exp. 2)

Sampling Date ¹	-13		18		32, 33 ²		47, 49 ²		SEM ³
	Low RFI	High RFI	Low RFI	High RFI	Low RFI	High RFI	Low RFI	High RFI	
DM Yield, kg/ha ⁴	1827	2063	2866	2189	2469	2370	2469	2303	414
CP, %	9.79	8.66	7.21	7.87	11.26	10.68	12.05	12.07	0.78
NDF, %	69.8	70.3	73.9	72.1	69.0	68.3	64.8 ^a	59.9 ^b	1.3
ADF, %	41.3	42.1	43.1	40.7	40.6	42.7	37.4	37.0	1.0

^{a,b} Means within a row and sampling date column lacking a common superscript differ, $P < 0.05$.

¹ d -13 = February 9, d 18 = March 12, d 32 (33) = March 26 (27), d 47 (49) = April 10 (12)

² On 2 dates, sampling was interrupted by rain after some paddocks had been harvested. The remaining paddocks were completed on the second date shown, as soon as conditions allowed.

³ SEM presented is for all but Low RFI during periods 3 and 4, due to removal of erroneous data. These are 507, 0.95, 1.5, and 1.2 for DM yield, CP, NDF, and ADF, respectively.

⁴ Yield and quality data shown are averages of forage harvested at the beginning of each grazing period.

Table 2.6. Average temperature and total precipitation for grazing periods of Exp. 2

Grazing Period	1 Feb 23 to Mar 12	2 Mar 13 to Apr 1	3 Apr 2 to 11	4 Apr 12 to 23
Total Precip, cm	6.3	4.9	3.8	2.0
Avg Temp, °C	12.1	19.7	10.5	18.4
Avg Daily Max Temp, °C	5.1	14.7	5.2	12.4
Avg Daily Min Temp, °C	-0.7	9.7	-1.3	5.9

Table 2.7. Average forage intake and pasture carrying capacity measures of cows with low and high residual feed intake (RFI) in Exp. 1

Variable	Low RFI	High RFI	SEM	<i>P</i>
DMI, kg•cow ⁻¹ •d ⁻¹	12.4	15.6	0.9	0.23
Area Grazed, ha ¹	1.71	1.82	0.05	0.35
DM on Offer, kg ²	4215 ^b	4376 ^a	11	0.06

^{a,b} Means within a row lacking a common superscript differ, *P* < 0.10.

¹ Average area of paddock (2/RFI group) over 84-d trial

² Average dry matter on offer per paddock (2/RFI group) over 84-d trial, determined using paddock size per week and yield calculated by regression equation derived from rising plate meter readings and harvested yield data

Table 2.8. Average forage utilization and intake of cows with low and high residual feed intake (RFI) and their calves (Exp. 2)

Variable	Low RFI	High RFI	SEM	<i>P</i>
Utilization ¹ , %	75.5	76.3	2.5	0.84
DMI, kg•pair ⁻¹ •d ⁻¹	12.5	14.1	0.7	0.12

¹ Utilization calculated as the percent of forage consumed using the pre- and post-sampling forage yield data and estimated growth for each period.

CHAPTER 3

Comparison of grazing stockpiled tall fescue versus feeding hay or hay plus supplement to gestating beef cows during winter

ABSTRACT

A 2-year study was conducted to compare performance differences between spring-calving crossbred beef cows (year 1, n = 106; year 2, n = 93) wintered on one of 3 treatments (3 paddocks each): grass hay only (**HAY**), grass hay with grain supplementation (**HS**), or non-endophyte infected stockpiled tall fescue pasture (**STF**). The trial began in mid November of year 1 and mid December of year 2, ending in late March for both years. Hay was fed ad libitum to HAY and HS in dormant, grazed paddocks, and STF pastures were strip-grazed. The supplement for HS was 0.40 kg corn during gestation and 1.23 kg corn with 1.44 DDGS after the calving midpoint in year 1. For the second year, 1.07 kg corn and 0.90 kg DDGS were fed daily. The trial was split into 2 periods: from initiation to shortly precalving (period 1), and from precalving until conclusion (period 2). Cows were then monitored through weaning the next fall. Average nutrient composition was better for STF than hay fed in both years. No differences in period 1 BW, BCS, or back fat changes were observed during year 1, but HS and STF cows gained BW while HAY cow lost weight in year 2 ($P < 0.05$). In year 1, STF cows lost less BW than HAY and HS cows during period 2 ($P < 0.05$), and numerical trends

mirrored this in BCS and back fat changes. Weight losses were similar among treatments during period 2 of year 2, but HS and STF cows lost less BCS than HAY cows ($P < 0.05$). Over the entire trial in year 1, STF cows gained more BW than HS ($P < 0.05$) and HAY ($P < 0.10$) cows, and HS cows lost back fat ($P < 0.05$) compared to HAY and STF gaining back fat. Cows in HS ($P < 0.05$) and STF ($P < 0.10$) lost less weight during year 2's trial than HAY cows. When both years were pooled, STF ($P < 0.05$) and HS ($P < 0.10$) cows had lower BCS losses than HAY cows throughout the entire trial. No significant differences were seen in BW change prebreeding, although in year 2, HAY cows gained BCS versus STF ($P < 0.05$) and HS ($P < 0.10$) cows losing condition. In year 1, STF cows lost more weight until weaning than HS ($P < 0.05$) and HAY ($P < 0.10$) cows. Calves born to dams on trial had similar birth and weaning weights. Cows grazing STF had the numerically highest pregnancy rates in year 1, followed by HS and HAY. Grazing stockpiled tall fescue is a viable option for wintering spring-calving beef cows. Because typical hay is of lower quality than STF, cows fed hay require supplementation to achieve similar performance to that observed while grazing STF.

INTRODUCTION

Feed inputs are the greatest annual cost for cow-calf producers (Miller et al., 2001), significantly affecting profitability while also having a large impact upon herd productivity. In a traditional spring-calving system typical to the Midwest, the cow's highest nutrient requirements during late gestation and early lactation often occur before

spring forage growth, making feeding higher quality harvested forages or grain supplements necessary to maintain body condition.

Extended grazing systems, such as stockpiling the fall growth of a cool-season forage like tall fescue for later winter grazing, provide the opportunity to decrease the amount of hay fed. Due to the costs of harvesting and baling or purchasing hay, extending the grazing season has been found to be less costly than feeding hay (D'Souza et al., 1990; Lawrence and Strohbehn, 1999). In addition, stockpiled tall fescue is often of higher quality than much of the summer-harvested hay fed to beef cows (Kallenbach et al., 2003).

Although stockpiled tall fescue has been shown to have value as a winter feed source (Allen et al., 1992; Hitz and Russell, 1998; Janovick et al., 2004; Curtis and Kallenbach, In press), it has rarely been compared with the more traditional wintering methods of feeding hay with or without grain supplementation. The objective of our research, therefore, was to compare the performance of spring-calving beef cows, both during the winter feeding period and through the subsequent fall, wintered on hay, hay plus a grain supplement, or stockpiled tall fescue pasture.

MATERIALS AND METHODS

Experimental Design

A 2-year study was conducted at the University of Missouri South Farm from November 18, 2005 to March 27, 2006 (year 1) and December 14, 2006 to March 26,

2007 (year 2). Crossbred beef cows (year 1, n = 106, average initial BW = 619.6 ± 6.2 kg, average initial BCS = 5.53 ± 0.07 , average initial age = 6.1 ± 0.3 yr; year 2, n = 93, average initial BW = 624.5 ± 6.8 kg, average initial BCS = 4.95 ± 0.08 , average initial age = 6.4 ± 0.4 yr) were allocated by body weight, body condition score, age, expected calving date, and previous treatment (year 2) to one of three treatments: grass hay only (**HAY**), grass hay with grain supplementation (**HS**), and stockpiled tall fescue pasture (**STF**). All treatments had three replicates, each assigned to one paddock (year 1, HAY n = 10/rep, HS n = 10/rep, STF n = 15 to 16/rep; year 2, HAY n = 11/rep, HS = 11 to 12/rep, STF = 8 to 9/rep). Number of cows assigned to STF was determined based upon stockpile yield and available acreage. All remaining cows were then divided between HAY and HS.

The study was divided into two periods (Figure 3.1): from initiation to shortly before calving (period 1; year 1, d 1 to 81; year 2, d 1 to 68) and from precalving until the trial's conclusion (period 2; year 1, d 82 to 130; year 2, d 69 to 103). After the study ended, cows were treated under similar conditions and were monitored through prebreeding (year 1, d 40 post-trial; year 2, d 54 post-trial) and weaning (year 1, d 212 post-trial).

Animal and Pasture Management

All replicates were rotated through their respective treatment paddocks approximately every 1.5 to 2 weeks until calving to remove variation due to paddock. The same paddocks were used for each treatment in years 1 and 2. All cows had ad libitum access to water and mineral supplement (Table 3.1).

Hay Treatments. Tall fescue-based grass hay was fed ad libitum in round bale rings to HAY and HS treatments in previously grazed, dormant non-endophyte infected tall fescue-based paddocks (approximately 4.05 ha each). HS cows were fed supplement daily in feeders with adequate bunk space located near the bale rings. In year 1, the gestation supplement was 0.40 kg corn (DM basis), fed until the mid-point of calving (d 119). The lactation supplement during year 1 was 1.23 kg corn and 1.44 kg dried distillers grains with solubles (**DDGS**, DM basis). During year 2, the supplement for the entire study was 1.07 kg corn and 0.90 kg DDGS (DM basis).

Stockpiled Tall Fescue Treatment. Non-endophyte infected tall fescue-based paddocks (approximately 4.05 ha, 2/replicate in year 1, 1/replicate in year 2) were used to stockpile forage for this study. During early August in both years, 45 kg/ha N was applied to the paddocks used in this study, which had been previously grazed. After N application, the forage was allowed to accumulate until the trial's initiation (November 18 in year 1, December 14 in year 2).

During the study, stockpiled tall fescue was strip-grazed using electric poly-tape. A new strip was allocated about every 3.5 days (2x/week) with a goal utilization of 75 to 80% of forage available. When excessive snow or ice accumulation prevented cows from grazing stockpile, they were fed hay until conditions improved. In year 1, no hay was fed to STF cows. In year 2, however, hay was fed for 4 days after an ice storm.

Animal Performance Measurements

Timing of measurements of animal performance taken in both years is shown in Figure 3.1. At the trial's initiation, precalving, and conclusion during each year, 2-day

body weights of cows were taken, and cows were body condition scored (1 to 9 scale, 1 = emaciated, 9 = obese) by a trained technician. At this time, ultrasound measurements were also taken for back fat thickness (years 1 and 2) and rump fat thickness (year 2) using an Aloka 500V ultrasound machine (Aloka Co., Ltd., Japan). Back fat measurements were the average of 3 images taken at the 12th rib, measuring fat thickness three-quarters the length of the longissimus dorsi from the backbone end. Rump fat thickness was measured 3 times at the midpoint between the hook and pin bones, over the gluteus medius, and averaged.

Upon conclusion of the trial, cows were managed together as one group, or in multiple groups managed similarly until weaning. Post-trial performance was monitored, and prior to the initiation of the breeding season and again at weaning, cows were weighed and body condition scored. All calves were weighed at birth and weaning, and calving difficulty and loss was recorded. All weights of cows and calves were taken without removal from feed and water.

Pregnancy rates were determined for cows during both years. Cows were synchronized and artificially inseminated at a fixed-time on d 59 post-trial in year 1 and d 60 post-trial in year 2. Bulls were then turned out 13 d after AI in year 1 and 15 d later in year 2 for 50 and 48 d natural service periods, respectively. Both years therefore had 60-day breeding seasons.

Forage Measurements

Sample Collection. Round bales from the same harvest date and location were used during both periods in year 1 and period 1 of year 2. Bales were stored on a concrete

pad and covered by tarps for preservation. Hay used during period 2 of year 2 was of similar quality, but was stored uncovered in a well-drained area. Round bales were weighed and recorded as they were fed to track total hay offered. Core samples were taken for quality analysis of hay that was to be fed prior to trial initiation during years 1 and 2, and then before period 2 in year 2.

Stockpiled tall fescue was sampled monthly during year 1 to determine stockpiled forage quality, yield, and utilization. Pre- and post-grazing samples were taken before and after each section was offered to cows. Due to snow and ice accumulation during year 2, only one pre- and one post-grazing sampling occurred before and near the conclusion of the trial, respectively. Stockpiled forage was sampled using a flail-type harvester pulled behind a tractor to take 10 strips per paddock (4.9 m x 81.3 cm each, down to 2 cm). Forage obtained from each strip was weighed and subsampled in the field.

Forage Quality Analysis. After collection, hay cores and stockpiled forage subsamples were dried (55°C, until stable in forced-draft oven), ground through a Wiley Mill to 5 mm, then ground to 1 mm using a Cyclotec grinder (Model 1093, Tecator AB, Höganäs, Sweden). Once ground, forage samples were dried at 100° C for 24 hours to determine total dry matter (**DM**) and ashed at 600°C to determine inorganic matter content (AOAC, 1984). Neutral detergent fiber (**NDF**) and acid detergent fiber (**ADF**) were sequentially analyzed using an Ankom Fiber Analyzer (Model 200, Fairport, NY). Nitrogen was determined by thermoconductivity using a LECO nitrogen analyzer (model FP-428, St. Joseph, MI), and used to calculate crude protein (**CP**, N x 6.25).

Weather. Temperature and precipitation data during the experiment were collected from a weather station located on South Farm, and 30-year average data were obtained from the National Oceanic and Atmospheric Administration's National Weather Service archive of climatology and weather records for Columbia, Missouri.

Statistical Analysis

Utilization of stockpiled forage was calculated as the percent of forage DM disappearance between pre- and post-grazed sampling. Average dry matter intake (**DMI**) for STF cows was calculated from the forage DM disappearance, total acreage grazed, and days on trial. Hay offered per paddock over the trial was converted to a daily offering per head, without accounting for wastage.

The post-trial monitoring phase is not yet completed for year 2, thus no calf weaning weights, cow BW or BCS changes until weaning, or pregnancy rates are presented here for year 2. In addition, due to processing errors, ultrasound data for year 2 is not shown. Cows were removed from the dataset due to illness or if they were found to be open, aborted, lost calves, or gave birth to twins. Eight cows were removed from year 1 with 98 remaining, and 15 cows were removed from year 2 with 78 remaining.

The data were analyzed as a completely randomized design using the MIXED procedure of the SAS program (SAS version 9.1, SAS Inst. Inc., Cary, NC) with paddock as the experimental unit. All cow performance measurements with data from years 1 and 2 were analyzed as a split-plot design, with year as the main plot and treatment as the sub-plot. Rep (paddock) effects and interactions were considered random effects. Cow BW and BCS changes over trial and post-trial periods were analyzed using repeated

measures with compound symmetry covariance structure to test for differences in performance. Changes in BW and BCS over the entire trial were not analyzed using repeated measures because they were already accounted for in analysis of period 1 and 2 changes. Cow pregnancy rates were compared using chi-squared analysis of the GENMOD procedure of SAS 9.1.

RESULTS AND DISCUSSION

Hay and Stockpiled Forage Quality and Yield

Stockpiled tall fescue pasture and hay quality and STF yield are shown in Tables 3.2, 3.3, and 3.4. As expected, in both years pre-grazed STF was of higher quality than hay fed, having higher percent CP and lower concentrations of NDF and ADF. Although hay quality was similar for both years, STF was of higher quality and yield in year 1 than year 2. This difference is likely due to weather being more favorable for forage growth in year 1 (Figure 3.2). Whereas rainfall was much above the 30-year average in August, above average in September and near average for October in year 1, year 2 precipitation was well below the 30-year average in September and November, which are crucial periods for stockpile growth. The highest sampled stockpile yield was in November for year 1 and December for year 2. This was another likely effect of the lack of rainfall during November of year 2, in addition to warmer temperatures in December of that year.

Because snow and ice accumulation prevented monthly sampling of STF in year 2, year 1 provides the only profile of STF yield and quality throughout the winter to

evaluate. As expected, stockpile yield of areas sampled declined after peaking near trial initiation. It has been well-established that fall forage growth stops when temperatures drop below freezing and conditions become less favorable (Archer and Decker, 1977b; Ocumpaugh and Matches, 1977; Fribourg and Bell, 1984). Because temperatures in January were elevated, it is probable that some STF growth occurred, which may explain the increase in CP at d 61. Kallenbach et al. (2003) hypothesized that warm periods during winter cause new growth of tall fescue, while at the same time increasing decomposition of stockpiled forage. It is difficult to know the definite pattern of STF growth and deterioration in this study, however, because different areas of pre-grazed stockpile were sampled at each date.

The quality of STF observed is similar to that reported by others (Fribourg and Bell, 1984; Hedtcke et al., 2002), although yield can be much greater (Curtis, 2006). One factor that may have decreased yield is that these paddocks are non-endophyte infected. Although less problematic for cattle, non-endophyte infected tall fescue is known to be lower-yielding when stockpiled than its infected counterpart (Kallenbach et al., 2003; Curtis, 2006).

When the pre- and post-grazing quality of STF are compared, quality of residual stockpile after grazing was of lower quality from both year 1 (Tables 3.2 and 3.3) and year 2 (Table 3.4). These quality differences suggest that cows selectively grazed the higher quality portions of forage available. Cattle have been shown to select plant species and individual plant components, such as choosing to graze leaves over stems (Roth et al., 1990). This is in agreement with Hitz and Russell (1998) who demonstrated that selection also occurs as cattle graze stockpiled forage.

Stockpile Utilization and Dry Matter Intake and Hay Offered

Utilization of stockpile during years 1 and 2 are shown in Tables 3.3 and 3.4, respectively. The average STF utilization during year 1 was near the goal at 80.1%. During year 2 however, utilization averaged only 60.6%. This calculation may be in error, as spring growth may have given a falsely high residual yield. Utilization was likely lower during year 2 though, due to smaller cow numbers grazing STF and snow and ice accumulation covering portions of stockpile for much of the winter. Although grazing stockpile was prevented by ice for only four days and cattle were able to graze through snow and ice during the rest of the winter, some areas of the paddocks were more covered and thus had reduced grazing.

Average DMI of stockpile during year 1 was $10.8 \text{ kg}\cdot\text{cow}^{-1}\cdot\text{d}^{-1}$ versus $6.9 \text{ kg}\cdot\text{cow}^{-1}\cdot\text{d}^{-1}$ in year 2 (Table 3.5). Although the DMI during year 1 is very close to the predicted intake of 11.5 kg when a 1.2% BW intake of NDF (Mertens, 1987) is assumed, DMI in year 2 is much lower than its predicted intake of 11.2 kg. A small portion of this difference may be attributed to hay being fed for 4 days after an ice storm in year 1, whereas no hay was fed during year 1. Much of this discrepancy, however is likely due to inaccurate post-grazing sampling in year 2. Because no other post-grazing sampling dates were possible due to weather, it is unknown what the actual utilization and therefore DMI were, but it was most likely not as low as reported here when forage quality and cow performance are considered.

Hay offered daily per cow ($\text{kg}\cdot\text{cow}^{-1}\cdot\text{d}^{-1}$) for HAY and HS treatments is shown in Table 3.5. Because the average daily hay offering presented here does not account for hay

wasted, hay data for both treatments from year 2 are plausible when considering the expected intake of 10.1 kg. In contrast, hay offered in year 1 was much lower than expected. Although this is the only hay that was offered to both treatments in year 1, paddocks on which hay was fed that year had much more remaining residual forage at trial initiation than in year 2. In addition, milder temperatures in January and February probably caused some pasture growth that was also grazed. This forage was not sampled and cannot be accounted for, however. Paddocks used for HAY and HS treatments in year 2 were sampled pre-trial and estimated to average less than 300 kg/ha.

Average hay offered daily per cow was 34% higher for HS than HAY in year 1, and 5% less for HS than HAY in year 2. When cattle on low quality forage-based diets are fed a supplement containing high levels of starch, the concentrate begins to have a substitution effect and less forage is consumed (Chase and Hibberd, 1987; Pordomingo et al., 1991; Caton and Dhuyvetter, 1997), which is in agreement with data from year 2. Supplementation has also been found to increase intake when ruminal fermentation was limited by nutrient intake (Moore et al., 1999). It is unlikely that the 0.4 kg corn supplement fed in year 1 actually increased hay intake this dramatically, however. Because residual forage in paddocks at trial initiation is unknown, it is more probable that HAY paddocks had more residual forage than HS paddocks in year 1.

Animal Performance

Winter Trial. Body weight and BCS changes of cows in years 1 and 2 are shown in Table 3.6 and 3.7, respectively. Similar initial ages, BW, and BCS were observed among treatments in each year, although initial BCS had a significant year effect ($P =$

0.005). Cows began the trial in year 2 at approximately 0.5 lower BCS than in year 1 (4.95 vs. 5.53). Effects of year ($P = 0.02$) and treatment ($P \leq 0.10$) were observed for BW changes, and the effect of year * treatment * period was significant for both BW and BCS changes. These are thus presented for each treatment by year and period, except for BCS changes over the entire trial, as these had to be analyzed separately. Body weight changes over the trial had a year * treatment effect ($P = 0.07$), but there was no treatment * year effect for BCS change. The effect of treatment was significant ($P < 0.05$) for this measure however, and thus years were pooled. Ultrasonic back fat thickness is only presented for year 1 due to processing errors (Table 3.8). Initial back fat thicknesses were similar among treatments, and treatment ($P = 0.09$) and period ($P < 0.001$) effects were observed.

Because period 1 ended shortly before calving, BW gains were expected due to the developing fetus. In year 1, all treatments experienced similar gains in BW, BCS, and back fat. Cows in HS and STF treatments in year 2 gained weight during period 1 while HAY cows lost weight (HS and STF vs. HAY, $P < 0.05$). BCS losses were numerically less for STF and HS cows as well, although not significant. Cows in year 2 lost condition because they were not able to meet maintenance requirements in addition to those for fetal growth, and thus had to pull from body stores. This is illustrated by the much lower gains of HS and STF cows in year 2 than those observed for all treatments in year 1. In year 1, cows were able meet fetal growth demands and build body stores (STF treatment) because their nutrient intake must have met or exceeded their requirements.

A majority of the cows on trial calved during period 2 of both years (year 1: 72 of 98, year 2: 60 of 78), thus weight loss was expected on average. A decrease in BCS and

back fat due to the demands of late gestation and early lactation was also anticipated. In year 1, STF cows lost less weight than HAY or HS cows during this time ($P < 0.05$), while also losing numerically less BCS and back fat. Cows in HAY and HS treatments were similar for all 3 traits during this period, but HS had the largest numerical losses. In year 2, no differences were observed in BW change among treatments, although HS and STF had a lesser decline in BCS than HAY cows ($P < 0.05$).

When BW, BCS, and back fat changes were combined for periods 1 and 2 and the entire trial was considered, STF cows gained weight while HAY and HS cows lost weight (STF vs. HS, $P < 0.05$; STF vs. HAY, $P < 0.10$) in year 1. In addition, HS cows lost back fat compared to gains in this measure for STF and HAY cows (HS vs. STF and HAY, $P < 0.05$). Although not statistically significant, STF gained more back fat than HAY cows and also maintained BCS versus HAY and HS cows losing BCS. In year 2, HS ($P < 0.05$) and STF ($P < 0.10$) cows lost less weight than HAY cows over the course of the trial. Cows in HS and STF treatments also lost numerically less BCS than HAY cows. When both years were pooled, STF ($P < 0.05$) and HS ($P < 0.10$) cows had lower BCS losses than HAY cows throughout the entire trial. HS losses were numerically intermediate to the other two treatments.

Body condition score and back fat changes followed BW changes closely in year 1. In year 2, STF and HS treatments switched order with BW and BCS changes, but their performance remained well above that of HAY cows. Differences observed among treatments were largely expected. Cows grazing STF performed better overall as they had access to higher quality forage, which provided them with more nutrients and allowed for greater intake due to increased digestibility. Stockpile quality and yield were better in

year 1 due to more favorable weather conditions, but were adequate in both years for wintering spring-calving cows. This is in agreement with previous findings that spring-calving cows wintered on stockpiled forage maintain adequate body weight and condition (Allen et al., 1992; Hitz and Russell, 1998; Schoonmaker et al., 2003)

The poor performance of HS cows in year 1 was unexpected and difficult to explain. The supplementation scheme of year 1 was based upon NRC requirements given in the 1984 edition and must have been too low for gestation. The lactation supplement probably had little effect upon cow performance as it was fed for only 12 d. In year 2, the newest NRC (2000) requirements were used, in which cow requirements are higher, especially for energy during gestation. Based upon performance of HS cows in year 2, it is apparent that the supplement fed more adequately met the demands of gestation and lactation, and that the HS diet overall was more comparable to STF. Despite too little supplement being fed in year 1, HS cows should not have performed worse than HAY cows, yet they lost more BW numerically and more back fat thickness ($P < 0.05$). Too little corn was fed for its starch to have been able to negatively affect fermentation to a great extent. In addition, calves from HS dams had the numerically lowest weaning weight, making it unlikely that HS cows increased milk yield due to supplementation, as has been previously reported (Forcherio et al., 1995). Differences in residual forage initially available in paddocks may be the source of this discrepancy, as it was likely of better quality than hay fed. Because HS cows consumed more hay than HAY cows in year 1, it can be assumed that they had less forage on offer in their paddocks, although this was not measured.

Other differences noted between years 1 and 2 are probably due to weather. In addition to its negative influence upon STF quality, the hot dry summer preceding year 2 also decreased forage availability and thus contributed to the poorer BCS of cows as they began the trial. The winter of year 2 was cold and wet, especially in January and February. These conditions increased the energy requirements of cows (NRC, 2000), while snow and ice also decreased stockpile accessibility and mobility of cows.

Post-trial Monitoring Phase. During the monitoring phase post-trial until prebreeding, STF cows in year 1 had numerically greater BW losses, while at the same time losing numerically less BCS than HAY and HS cows. These differences may be due to fill differences at trial conclusion. All treatments had similar weight gains before the breeding season of year 2. During this time however, HAY cows gained BCS compared to STF ($P < 0.05$) and HS ($P < 0.10$). In year 2 post-trial, cows used in this study were put on a short reproduction study which included supplementation, thus this probably explains differences observed. In year 1, HS ($P < 0.05$) and HAY ($P < 0.10$) cows then lost less weight than STF cows and HS cows lost numerically less BCS from the trial's conclusion until weaning.

Pregnancy rates from cows in year 1 are shown in Table 3.9. Cows grazing STF had the numerically highest pregnancy rates, followed by HS cows, with HAY cows having the numerically lowest. Although differences observed here were not statistically significant, this is not surprising due to the number of animals used in this experiment. Pregnancy rates observed in year 1 were as hypothesized, but do not agree with cow performance data. Performance data during the trial suggests that HS cows would have pregnancy rates more similar to HAY cows due to their BW, BCS, and back fat thickness

losses. It is possible that these losses gave HS cows a greater opportunity for compensatory gain post-trial, although this was not observed in prebreeding performance data. Because all treatments averaged a BCS of 5 or above at calving and had similar BW and BCS losses prebreeding, cows in year 1 also may have been in adequate condition for subsequent rebreeding regardless of previous dietary treatment (Morrison et al., 1999; Wettemann et al., 2003; Hess et al., 2005).

Calf Performance. Average dates of birth, birth weights, and weaning weights of calves born to cows in this study are presented in Table 3.10. Cow performance differences observed among treatments did not translate into differences in calf weights at birth or weaning. Despite STF cows gaining weight over the trial in year 1 and STF and HS cows in year 2 losing less weight, these cows gave birth to calves of similar weight to their counterparts. Although most fetal growth occurs during the last third of gestation, which occurred in this trial during both years, maternal nutrition has often been found to agree with the current study and have no effect upon birth weight during this time (Hough et al., 1990; Stalker et al., 2006; Martin et al., 2007). This is not always the case, however, as nutrient restriction has also been shown to decrease birth weight (Corah et al., 1975; Houghton et al., 1990; Redmer et al., 2004).

No differences were observed in weaning weights of calves in year 1. Similarly, Schoonmaker et al. (2003) found no difference in weaning weight of spring-born calves whose dams had been wintered on hay, limit-fed corn, or stockpiled orchardgrass. Calves of HS dams had the lowest numerical weaning weights however, which suggests that dietary treatment may have reduced the milk yield of HS dams and is supported by the treatment's lesser weight and BCS losses from trial conclusion to weaning.

Observed Management Differences

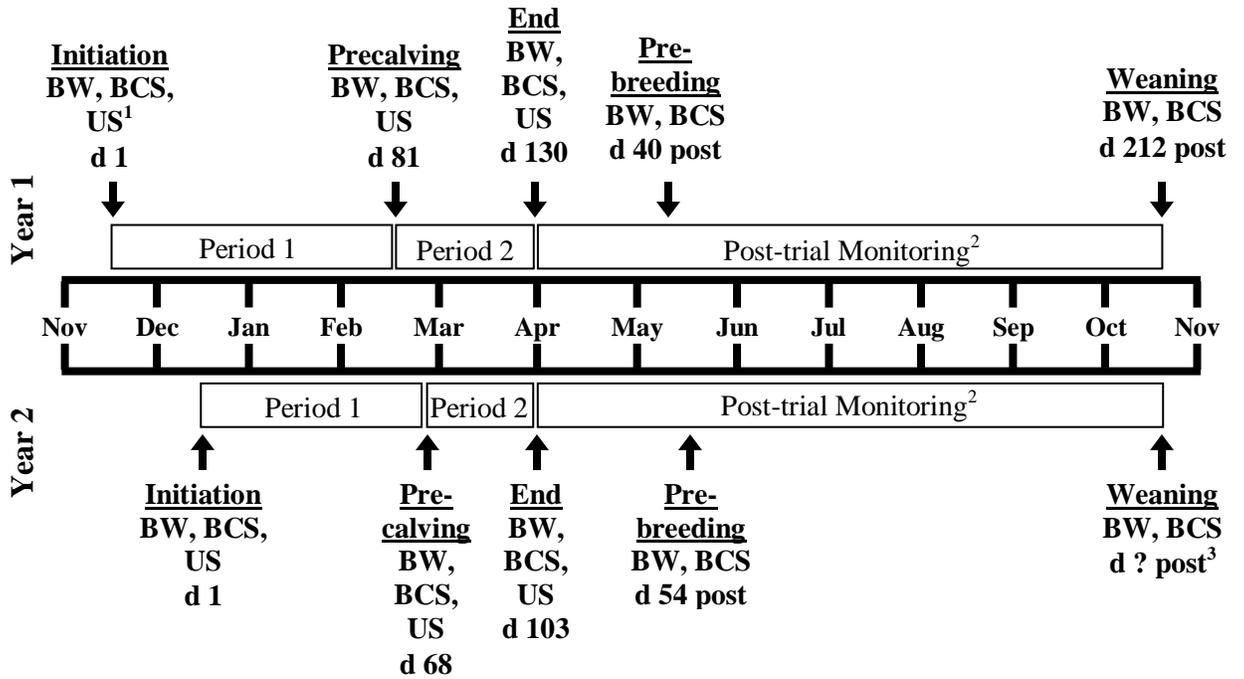
During year 2, snow and ice melt in addition to spring rainfall created very muddy conditions, especially in HAY and HS paddocks. Areas around bale ring, waterers, and feed bunks that were heavily traveled had increased mud. During the trial, 3 calves from HAY dams and 4 from HS dams died due to mud-related problems such as drowning, hypothermia, and respiratory illness, while none of these problems were seen in calves born in STF paddocks. It was observed that strip-grazing STF lessened the areas where mud could form, as cattle constantly moved to graze in a new area. Because STF replicates were over halfway through their paddocks when calving began, if a new strip did get muddy, there was plenty of previously grazed area for calves to avoid it. Although HAY and HS cows did have large paddocks, cows tended to keep calves nearby in the muddy areas around feeders and waterers.

In addition to contributing to calf loss, mud around round bale rings and feed bunks also disturbed forage stands in this area and made it less productive and more weed-filled in spring and summer. Even in winters that are dry, cattle damage the area in which hay is fed and limit its productivity, while also leaving most of the valuable nutrients from their waste concentrated in that one area. Strip-grazing stockpile was observed to reduce damage as cattle spent less time in any one area, while at the same time encouraging more equal distribution of nutrients throughout the pasture.

CONCLUSION

Results of this study indicate that stockpiled tall fescue is a viable option for wintering spring-calving beef cows. Cows grazing stockpile ended the winter trial with higher BW and BCS than cows fed hay only in both years and cows fed hay with supplement in year 1. Quality differences between mid-quality summer-baled grass hay and stockpiled forage make it necessary to supplement hay with grain to achieve similar cow performance to that observed while grazing stockpile. Differences in performance do not seem to extend past winter grazing when cows graze together during late spring and summer, and calves born to dams in this study had similar birth and weaning weights among treatments. Pregnancy rates may be improved in cows grazing stockpile due to their increased BCS at calving.

Figure 3.1. Experimental design and animal performance measurement timeline for years 1 and 2.



¹ BW = cows weighed, BCS = cows body condition scored (1 to 9 scale, 1 = emaciated, 9 = obese), US = cows ultrasounded for back fat (years 1 and 2) and rump fat (year 2)

² Cows were managed under similar condition during post-trial monitoring.

³ Weaning of calves from year 2 has not occurred yet.

Figure 3.2. Temperature and precipitation data for stockpiling and trial dates of years 1 and 2 compared to a 30-year average

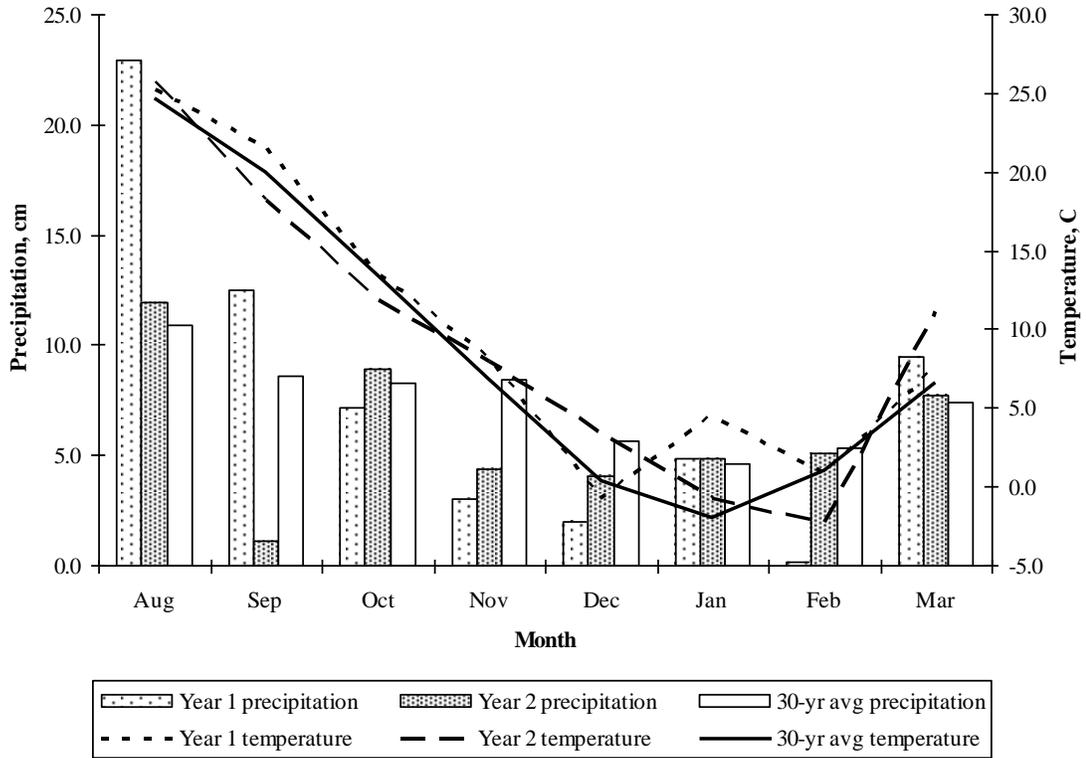


Table 3.1. Nutrient composition of mineral supplements¹ offered ad libitum in years 1 and 2

Guaranteed Analysis	Supplement 1	Supplement 2
Calcium (min), %	13.5	9.9
Calcium (max), %	16.2	11.8
Phosphorus (min), %	7.0	5.4
Sodium Chloride (min), %	18.2	15.5
Sodium Chloride (max), %	21.8	18.5
Magnesium (min), %	1.0	10.0
Potassium (min), %	0.4	0.4
Copper (min), ppm	2,500	2,500
Selenium (min), ppm	26.4	26.4
Zinc (min), ppm	4,000	10,000
Vitamin A (min), IU/kg	660,000	660,000
Vitamin D-3 (min), IU/kg	66,000	66,000
Vitamin E (min), IU/kg	440	330

¹ Supplement 1 was fed from d 1 to 118 in year 1 and from d 1 to 90 in year 2. Supplement 2, a high magnesium formulation, was fed from d 119 to 130 in year 1 and from d 91 to 103 in year 2, in preparation for grazing new spring growth.

Table 3.2. Pre-grazing stockpiled tall fescue forage yield and quality versus quality of hay fed during year 1

Variable	Stockpiled Tall Fescue Sampling Dates ¹					Avg STF ²	Hay ³
	d -44	d -2	d 29	d 61	d 96		
Yield, kg DM/ ha	3111	4075	3640	3264	2839	3454	
CP, %	15.6	14.2	12.1	13.3	12.7	13.1	7.7
NDF, %	63.6	60.2	63.6	68.5	65.6	64.5	71.6
ADF, %	34.0	33.5	34.7	36.5	35.8	35.1	40.3
Ash, %	10.7	10.7	9.4	8.8	7.8	9.2	8.2

¹ d -44 = October 4, d -2 = November 16, d 29 = December 16, d 61 = January 17, d 96 = February 21. Each sampling except d -44 was from a different area of the paddocks.

² Average STF includes pre-grazing sampling during the trial (d -2, 29, 61, and 96).

³ Hay was sampled pre-trial and kept under tarp for preservation.

Table 3.3. Post-grazing stockpiled tall fescue forage yield, quality, and utilization rates during year 1

Variable	Stockpiled Tall Fescue Sampling Dates ¹			
	d 29	d 61	d 96	d 131
Yield, kg DM/ha	974	781	341	635
CP, %	11.9	11.6	11.7	12.0
NDF, %	68.4	73.5	69.4	79.3
ADF, %	37.9	41.2	39.4	41.7
Ash, %	8.7	11.9	8.6	12.7
Utilization ² , %	75.7	78.7	89.1	77.0

¹ d 29 = December 16, d 61 = January 17, d 96 = February 21, d 131 = March 28

² Utilization calculated as the percent of forage consumed using the pre- and post-sampling forage yield data for each period.

Table 3.4. Pre- and post-grazing stockpiled tall fescue forage yield, quality, and utilization versus quality of hay fed during year 2

Variable	Stockpiled Tall Fescue Sampling Dates ¹			Hay 1 ²	Hay 2 ³
	d -40	d 2	d 89		
Yield, kg DM/ha	2068	2691	1013		
CP, %	11.3	11.8	7.4	7.7	8.2
NDF, %	56.5	67.2	71.3	74.2	74.2
ADF, %	29.7	36.2	42.8	42.9	46.7
Ash, %	8.2	8.5	13.0	9.4	8.9
Utilization ⁶ , %			60.6		

¹ d -40 = November 3, d 2 = December 15, d 89 = March 12. Day 2 was the only pre-grazing sampling due to snow and ice cover. Day 89 was the only post-grazing sampling due to snow and ice cover.

² Hay 1 was fed during Period 1 and sampled prior to trial initiation. This was kept under tarp for preservation.

³ Hay 2 was fed during Period 2 and sampled just prior to beginning of use. This was stored outside without cover.

⁴ Utilization calculated as the percent of forage consumed using the pre- and post-sampling forage yield data for each period.

Table 3.5. Hay offered to hay, hay plus supplement (HS), and stockpiled tall fescue (STF) treatments and estimated stockpile dry matter intake of STF during years 1 and 2

Variable	Hay	HS	STF
YEAR 1			
Hay Offered ¹ , kg•cow ⁻¹ •d ⁻¹	3.8	5.1	--
Stockpile DMI ² , kg•cow ⁻¹ •d ⁻¹	--	--	10.8
YEAR 2			
Hay Offered, kg•cow ⁻¹ •d ⁻¹	12.4	11.8	0.7
Stockpile DMI, kg•cow ⁻¹ •d ⁻¹	--	--	6.9

¹ Hay offered daily per cow does not account for hay wastage.

² Stockpile DMI was calculated using stockpile yield, area grazed, and utilization.

Table 3.6. Body weight change of cows wintered on hay, hay plus supplement (HS), or stockpiled tall fescue (STF) during years 1 and 2

Variable ¹	Hay	HS	STF
YEAR 1			
Initial Age, yr	6.1 ± 0.6	6.1 ± 0.6	6.1 ± 0.5
Initial BW, kg	615.2 ± 11.3	610.5 ± 11.5	633.2 ± 9.1
Grazing Trial BW Changes			
Period 1 ² , kg	53.7 ± 6.4	43.9 ± 6.5	57.1 ± 5.5
Period 2 ³ , kg	-59.0 ± 6.4 ^b	-61.2 ± 6.5 ^b	-35.7 ± 5.5 ^a
Entire ⁴ , kg	-5.5 ± 9.8 ^{abd}	-17.4 ± 9.9 ^{bcd}	21.4 ± 8.7 ^{ac}
Post-trial BW Changes			
Pre-breeding ⁵ , kg	-14.1 ± 6.4	-12.6 ± 6.5	-25.7 ± 5.5
Weaning ⁶ , kg	-29.5 ± 12.2 ^{abc}	-23.7 ± 12.2 ^{acd}	-59.8 ± 10.6 ^{bd}
YEAR 2			
Initial Age, yr	6.0 ± 0.6	6.5 ± 0.6	6.6 ± 0.7
Initial BW, kg	630.4 ± 11.5	627.6 ± 11.3	615.5 ± 12.4
Grazing Trial BW Changes			
Period 1, kg	-10.0 ± 6.6 ^b	21.2 ± 6.6 ^a	12.9 ± 7.0 ^a
Period 2, kg	-76.3 ± 6.6	-70.6 ± 6.6	-67.8 ± 7.0
Entire, kg	-86.6 ± 9.9 ^{bd}	-49.8 ± 9.8 ^{acd}	-54.8 ± 10.4 ^{abc}
Post-trial BW Changes			
Pre-breeding, kg	8.9 ± 6.6	6.7 ± 6.4	17.6 ± 7.0

^{a,b} Means within a row lacking a common superscript differ ($P \leq 0.05$).

^{c,d} Means within a row lacking a common superscript differ ($P \leq 0.10$).

¹ All data presented as least square mean ± standard error, due to heterogeneous variance of SE.

² Period 1 was from trial initiation to shortly before calving (year 1: d 1 to 81, year 2: d 1 to 68).

³ Period 2 was from shortly before calving to trial conclusion (year 1: d 81 to 130, year 2: d 68 to 103).

⁴ Periods 1 and 2 were combined for body weight change over the entire trial.

⁵ BW changes post-trial to pre-breeding were measured from the trial's conclusion to just prior to the breeding season (year 1: 40 d post-trial, year 2: 54 d post-trial).

⁶ BW changes post-trial to weaning were measured from the trial's conclusion until weaning (year 1: 212 d post-trial).

Table 3.7. Body condition score change of cows wintered on hay, hay plus supplement (HS), or stockpiled tall fescue (STF) during years 1 and 2

Variable ¹	Hay	HS	STF
YEAR 1			
Initial BCS ²	5.54 ± 0.13	5.39 ± 0.13	5.66 ± 0.10
Grazing Trial BCS Changes			
Period 1 ³	0.02 ± 0.11	0.07 ± 0.11	0.23 ± 0.09
Period 2 ⁴	-0.29 ± 0.11	-0.37 ± 0.11	-0.22 ± 0.09
Entire ⁵	-0.27 ± 0.15	-0.30 ± 0.15	0.01 ± 0.13
Post-trial BCS Changes			
Pre-breeding ⁶	-0.29 ± 0.11	-0.30 ± 0.11	-0.15 ± 0.09
Weaning ⁷	-0.42 ± 0.14	-0.31 ± 0.14	-0.40 ± 0.12
YEAR 2			
Initial BCS	4.91 ± 0.13	4.93 ± 0.13	5.02 ± 0.14
Grazing Trial BCS Changes			
Period 1	-0.31 ± 0.11	-0.16 ± 0.11	-0.09 ± 0.12
Period 2	-0.57 ± 0.11 ^b	-0.14 ± 0.11 ^a	-0.13 ± 0.12 ^a
Entire	-0.88 ± 0.15	-0.30 ± 0.15	-0.21 ± 0.16
Post-trial BW Changes			
Pre-breeding	0.22 ± 0.11 ^{ac}	-0.09 ± 0.11 ^{abd}	-0.35 ± 0.12 ^{bcd}
Combined Years⁸			
BCS Change, Entire Trial	-0.58 ± 0.11 ^{bd}	-0.30 ± 0.11 ^{abc}	-0.10 ± 0.10 ^{acd}

^{a,b} Means within a row lacking a common superscript differ ($P \leq 0.05$).

^{c,d} Means within a row lacking a common superscript differ ($P \leq 0.10$).

¹ All data presented as least square mean ± standard error, due to heterogeneous variance of SE.

² BCS evaluated on 1 to 9 scale (1 = emaciated, 9 = obese)

³ Period 1 was from trial initiation to shortly before calving (year 1: d 1 to 81, year 2: d 1 to 68).

⁴ Period 2 was from shortly before calving to trial conclusion (year 1: d 81 to 130, year 2: d 68 to 103).

⁵ Periods 1 and 2 were combined for BCS change over the entire trial.

⁶ BCS changes post-trial to pre-breeding were measured from the trial's conclusion to just prior to the breeding season (year 1: 40 d post-trial, year 2: 54 d post-trial).

⁷ BCS changes post-trial to weaning were measured from the trial's conclusion until weaning (year 1: 212 d post-trial).

⁸ Although there were no effects of Trt x Year for BCS change over the entire trial, the effect of Trt was significant ($P < 0.05$), and thus is presented here.

Table 3.8. Back fat thickness change of cows wintered on hay, hay plus supplement (HS), or stockpiled tall fescue (STF) during year 1

Variable	Hay	HS	STF
Initial Back Fat, cm	0.76	0.91	0.84
Grazing Trial Back Fat Changes			
Period 1 ¹ , cm	0.28	0.20	0.30
Period 2 ² , cm	-0.18	-0.20	-0.10
Entire ³ , cm	0.10 ^a	-0.03 ^b	0.20 ^a
Standard Error	0.05	0.05	0.03

^{a,b} Means within a row lacking a common superscript differ ($P \leq 0.05$).

¹ Period 1 was from trial initiation to shortly before calving (year 1: d 1 to 81, year 2: d 1 to 68).

² Period 2 was from shortly before calving to trial conclusion (year 1: d 81 to 130, year 2: d 68 to 103).

³ Periods 1 and 2 were combined for body weight change over the entire trial.

Table 3.9. Pregnancy rates of cows wintered on hay, hay plus supplement (HS), or stockpiled tall fescue (STF) during year 1

Variable	Hay	HS	STF	<i>P</i> -value
Pregnancy Rate, %	82.1	85.2	88.4	0.46

Table 3.10. Average date of birth, birth weight, and weaning weight of calves born to dams wintered on hay, hay plus supplement (HS), or stockpiled tall fescue (STF) during years 1 and 2

Variable ¹	Hay	HS	STF
YEAR 1			
Avg Date of Birth, Julian Date	75 ± 4	74 ± 4	75 ± 4
Birth Wt, kg	43.0 ± 1.2	40.7 ± 1.2	41.5 ± 1.0
Weaning Wt ² , kg	263.8 ± 6.3	252.4 ± 6.3	261.0 ± 4.9
YEAR 2			
Avg Date of Birth, Julian Date	68 ± 4	69 ± 4	71 ± 4
Birth Wt, kg	39.3 ± 1.2	40.4 ± 1.2	40.1 ± 1.3

¹ All data presented as least square mean ± standard error, due to heterogeneous variance of SE.

² Actual weaning weights, taken 212 d post-trial

LITERATURE CITED

- Adams, D. C., R. T. Clark, S. A. Coady, J. B. Lamb, and M. K. Nielsen. 1994. Extended grazing systems for improving economic returns from Nebraska sandhills cow/calf operations. *J. Range Manag.* 47: 258-263.
- Allen, V. G., J. P. Fontenot, D. R. Notter, and R. C. Hammes, Jr. 1992. Forage systems for beef production from conception to slaughter: I. Cow-calf production. *J. Anim. Sci.* 70: 576-587.
- AOAC. 1984. Official Methods of Analysis. 14th ed. Offic. Anal. Chem., Washington, D.C.
- Archer, J. A., A. Reverter, R. M. Herd, D. J. Johnston, and P. F. Arthur. 2002. Genetic variation in feed intake and efficiency of mature beef cows and relationships with postweaning measurements. 7th World Congress on Genetics Applied to Livestock Production, Montpellier, France. 31: 221-224.
- Archer, J. A., E. C. Richardson, R. M. Herd, and P. F. Arthur. 1999. Potential for selection to improve efficiency of feed use in beef cattle: A review. *Aust. J. Agric. Res.* 50: 147-161.
- Archer, K. A., and A. M. Decker. 1977a. Autumn-accumulated tall fescue and orchardgrass. II. Effects of leaf death on fiber components and quality parameters. *Agron. J.* 69: 605-609.
- Archer, K. A., and A. M. Decker. 1977b. Autumn-accumulated tall fescue and orchardgrass: I. Growth and quality as influenced by nitrogen and soil temperature. *Agron. J.* 69: 601-605.
- Arthur, P. F., J. A. Archer, and R. M. Herd. 2004. Feed intake and efficiency in beef cattle: Overview of recent Australian research and challenges for the future. *Aust. J. Exp. Agric.* 44: 361-369.
- Arthur, P. F., J. A. Archer, R. M. Herd, and G. J. Melville. 2001a. Response to selection for net feed intake in beef cattle. *Proc. Assoc. Advmt. Anim. Breed. Genet.* 14: 135-138.
- Arthur, P. F., J. A. Archer, R. M. Herd, E. C. Richardson, S. C. Exton, C. Oswin, K. C. P. Dibley, and D. A. Burton. 1999. Relationship between postweaning growth, net feed intake and cow performance. *Proc. Assoc. Advmt. Anim. Breed. Genet.* 13: 484-487.
- Arthur, P. F., J. A. Archer, D. J. Johnson, R. M. Herd, E. C. Richardson, and P. F. Parnell. 2001b. Genetic and phenotypic variance and covariance components for

- feed intake, feed efficiency, and other postweaning traits in Angus cattle. *J. Anim. Sci.* 79: 2805-2811.
- Arthur, P. F., and R. M. Herd. 2005. Efficiency of feed utilisation by livestock - Implications and benefits of genetic improvement. *Can. J. Anim. Sci.* 85: 281-290.
- Arthur, P. F., R. M. Herd, J. F. Wilkins, and J. A. Archer. 2005. Maternal productivity of Angus cows divergently selected for post-weaning residual feed intake. *Aust. J. Exp. Agric.* 45: 985-993.
- Arthur, P. F., G. Renand, and D. Krauss. 2001c. Genetic and phenotypic relationships among different measures of growth and feed efficiency in young Charolais bulls. *Livest. Prod. Sci.* 68: 131-139.
- Bagley, C. P., J. P. Fontenot, R. E. Blaser, and K. E. Webb, Jr. 1983. Nutritional Value and Voluntary Intake of Tall Fescue (*Festuca Arundinacea* Schreb.) Fed to Sheep. *J. Anim. Sci.* 57: 1383-1391.
- Barnes, R. F., C. J. Nelson, M. Collins, and K. J. Moore. 2003. *Forages: An Introduction to Grassland Agriculture*. 6th ed. Iowa State Press, Ames, Iowa.
- Basarab, J. A., M. A. Price, J. L. Aalhus, E. K. Okine, W. M. Snelling, and K. L. Lyle. 2003. Residual feed intake and body composition in young growing cattle. *Can. J. Anim. Sci.* 83: 189-204.
- Castro Bulle, F. C. P., P. V. Paulino, A. C. Sanches, and R. D. Sainz. 2007. Growth, carcass quality, and protein and energy metabolism in beef cattle with different growth potentials and residual feed intakes. *J. Anim. Sci.* 85: 928-936.
- Caton, J. S., and D. V. Dhuyvetter. 1997. Influence of energy supplementation on grazing ruminants: requirements and responses. *J. Anim. Sci.* 75: 533-542.
- Channon, A. F., J. B. Rowe, and R. M. Herd. 2004. Genetic variation in starch digestion in feedlot cattle and its association with residual feed intake. *Aust. J. Exp. Agric.* 44: 469-474.
- Chase, C. C., Jr., and C. A. Hibberd. 1987. Utilization of low-quality native grass hay by beef cows fed increasing quantities of corn grain. *J. Anim. Sci.* 65: 557-566.
- Corah, L. R., T. G. Dunn, and C. C. Kaltenbach. 1975. Influence of Prepartum Nutrition on the Reproductive Performance of Beef Females and the Performance of Their Progeny. *J. Anim. Sci.* 41: 819-824.
- Crews, D. H. 2006. The genetics of feed efficiency in beef cattle. *Beef Improvement Federation Proc.*, Choctaw, MS. 28-37.

- Curtis, L. E. 2006. Impact of grazing stockpiled tall fescue on lactating beef cows. M.S. Thesis. University of Columbia, Columbia.
- Curtis, L. E., and R. L. Kallenbach. In press. Endophyte infection level of tall fescue stockpiled for winter grazing does not alter the gain of calves nursing lactating beef cows. *J. Anim. Sci.*
- D'Souza, G. E., E. W. Maxwell, W. B. Bryan, and E. C. Prigge. 1990. Economic impacts of extended grazing systems. *Amer. J. Alt. Agric.* 5: 120-125.
- Dove, H., and R. W. Mayes. 1996. Plant Wax Components: A New Approach to Estimating Intake and Diet Composition in Herbivores. *J. Nutr.* 126: 13-26.
- Forcherio, J. C., G. E. Catlett, J. A. Paterson, M. S. Kerley, and M. R. Ellersieck. 1995. Supplemental protein and energy for beef cows consuming endophyte-infected tall fescue. *J. Anim. Sci.* 73: 3427-3436.
- Fribourg, H. A., and K. W. Bell. 1984. Yield and composition of tall fescue stockpiled for different periods. *Agron. J.* 76: 929-934.
- Gerrish, J. R., P. R. Peterson, C. A. Roberts, and J. R. Brown. 1994. Nitrogen fertilization of stockpiled tall fescue in the midwestern USA. *J. Prod. Agric.* 7: 98-104.
- Hall, M. H., P. J. Levan, E. H. Cash, H. W. Harpster, and S. L. Fales. 1998. Fall-grazing management effects on production and persistence of tall fescue, perennial ryegrass, and prairie grass. *J. Prod. Agric.* 11: 487-491.
- Hedtcke, J. L., D. J. Undersander, M. D. Casler, and D. K. Combs. 2002. Quality of forage stockpiled in Wisconsin. *J. Range Manag.* 55: 33-42.
- Hennessy, D. W., and P. F. Arthur. 2004. The effect of preweaning growth restriction on the feed intake and efficiency of cattle on a grain-based diet before slaughter. *Aust. J. Exp. Agric.* 44: 483-488.
- Herd, R. M., J. A. Archer, and P. F. Arthur. 2003. Reducing the cost of beef production through genetic improvement in residual feed intake: Opportunity and challenges to application. *J. Anim. Sci.* 81 (E. Suppl.): E9-E17.
- Herd, R. M., and S. C. Bishop. 2000. Genetic variation in residual feed intake and its association with other production traits in British Hereford cattle. *Livest. Prod. Sci.* 63: 111-119.
- Herd, R. M., R. S. Hegarty, R. W. Dicker, J. A. Archer, and P. F. Arthur. 2002. Selection for residual feed intake improves feed conversion in steers on pasture. *Anim. Prod. Aust.* 24: 85-88.

- Herd, R. M., V. H. Oddy, and E. C. Richardson. 2004. Biological basis for variation in residual feed intake in beef cattle. 1. Review of potential mechanisms. *Aust. J. Exp. Agric.* 44: 423-430.
- Herd, R. M., E. C. Richardson, R. S. Hegarty, R. Woodgate, J. A. Archer, and P. F. Arthur. 1998. Pasture intake by high versus low net feed efficient Angus cows. *Anim. Prod. Aust.* 22: 137-140.
- Hess, B. W., S. L. Lake, E. J. Scholljegerdes, T. R. Weston, V. Nayigihugu, J. D. C. Molle, and G. E. Moss. 2005. Nutritional controls of beef cow reproduction. *J. Anim. Sci.* 83 (E. Suppl.): E90-E106.
- Hitz, A. C., and J. R. Russell. 1998. Potential of stockpiled perennial forages in winter grazing systems for pregnant beef cows. *J. Anim. Sci.* 76: 404-415.
- Hough, R. L., F. D. McCarthy, H. D. Kent, D. E. Eversole, and M. L. Wahlberg. 1990. Influence of nutritional restriction during late gestation on production measures and passive immunity in beef cattle. *J. Anim. Sci.* 68: 2622-2627.
- Houghton, P. L., R. P. Lemenager, L. A. Horstman, K. S. Hendrix, and G. E. Moss. 1990. Effects of body composition, pre- and postpartum energy level and early weaning on reproductive performance of beef cows and preweaning calf gain. *J. Anim. Sci.* 68: 1438-1446.
- Hughes, T. E., and W. S. Pitchford. 2004. How does pregnancy and lactation affect efficiency of female mice divergently selected for post-weaning net feed intake? *Aust. J. Exp. Agric.* 44: 501-506.
- Janovick, N. A., J. R. Russell, D. R. Strohbehn, and D. G. Morrical. 2004. Productivity and hay requirements of beef cattle in a Midwestern year-round grazing system. *J. Anim. Sci.* 82: 2503-2515.
- Jenkins, T. G., C. L. Ferrell, and A. J. Roberts. 2000. Lactation and calf weight traits of mature crossbred cows fed varying daily levels of metabolizable energy. *J. Anim. Sci.* 78: 7-14.
- Johnson, D. E., C. L. Ferrell, and T. G. Jenkins. 2003. The history of energetic efficiency research: Where have we been and where are we going? *J. Anim. Sci.* 81 (E. Suppl. 1): E27-E38.
- Kallenbach, R. L., G. J. Bishop-Hurley, M. D. Massie, G. E. Rottinghaus, and C. P. West. 2003. Herbage mass, nutritive value, and ergovaline concentration of stockpiled tall fescue. *Crop Sci.* 43: 1001-1005.
- Kennedy, B. W., J. H. van der Werf, and T. H. Meuwissen. 1993. Genetic and statistical properties of residual feed intake. *J. Anim. Sci.* 71: 3239-3250.

- Koch, R. M., L. A. Swiger, D. Chambers, and K. E. Gregory. 1963. Efficiency of feed use in beef cattle. *J. Anim. Sci.* 22: 486-494.
- Kolath, W. H., M. S. Kerley, J. W. Golden, and D. H. Keisler. 2006. The relationship between mitochondrial function and residual feed intake in Angus steers. *J. Anim. Sci.* 84: 861-865.
- Lawrence, J. D., and D. R. Strohbehm. 1999. Understanding and managing costs in beef cow-calf herds. National Cattlemen's Beef Association Convention, Charlotte, North Carolina.
- Lippke, H. 2002. Estimation of forage intake by ruminants on pasture. *Crop Sci.* 42: 869-872.
- Martin, J. L., K. A. Vonnahme, D. C. Adams, G. P. Lardy, and R. N. Funston. 2007. Effects of dam nutrition on growth and reproductive performance of heifer calves. *J. Anim. Sci.* 85: 841-847.
- Mertens, D. R. 1987. Predicting intake and digestibility using mathematical models of ruminal function. *J. Anim. Sci.* 64: 1548-.
- Miller, A. J., D. B. Faulkner, R. K. Knipe, D. R. Strohbehm, D. F. Parrett, and L. L. Berger. 2001. Critical control points for profitability in the cow-calf enterprise. *Prof. Anim. Sci.* 17: 295-302.
- Moore, J. E., M. H. Brant, W. E. Kunkle, and D. I. Hopkins. 1999. Effects of supplementation on voluntary forage intake, diet digestibility, and animal performance. *J. Anim. Sci.* 77 (Suppl 2): 122-135.
- Morrison, D. G., J. C. Spitzer, and J. L. Perkins. 1999. Influence of prepartum body condition score change on reproduction in multiparous beef cows calving in moderate body condition. *J. Anim. Sci.* 77: 1048-1054.
- Ngwerume, F., and I. L. Mao. 1992. Estimation of Residual Energy Intake for Lactating Cows Using an Animal Model. *J. Dairy Sci.* 75: 2283-2287.
- Nkrumah, J. D., J. A. Basarab, M. A. Price, E. K. Okine, A. Ammoura, S. Guercio, C. Hansen, C. Li, B. Benkel, B. Murdoch, and S. S. Moore. 2004. Different measures of energetic efficiency and their phenotypic relationships with growth, feed intake, and ultrasound and carcass merit in hybrid cattle. *J. Anim. Sci.* 82: 2451-2459.
- Nkrumah, J. D., J. A. Basarab, Z. Wang, C. Li, M. A. Price, E. K. Okine, D. H. Crews, and S. S. Moore. In press. Genetic and phenotypic relationships of feed intake and different measures of feed efficiency with growth and carcass merit of beef cattle. *J. Anim. Sci.*

- Nkrumah, J. D., E. K. Okine, G. W. Mathison, K. Schmid, C. Li, J. A. Basarab, M. A. Price, Z. Wang, and S. S. Moore. 2006. Relationships of feedlot feed efficiency, performance, and feeding behavior with metabolic rate, methane production, and energy partitioning in beef cattle. *J. Anim. Sci.* 84: 145-153.
- NRC. 1984. *Nutrient Requirements of Beef Cattle*. 6th ed. National Academy Press, Washington, DC.
- NRC. 1987. *Predicting Feed Intake of Food-Producing Animals*. National Academy Press, Washington, DC.
- NRC. 2000. *Nutrient Requirements of Beef Cattle*. 7th ed. National Academy Press, Washington, DC.
- Ocuppaugh, W. R., and A. G. Matches. 1977. Autumn-winter yield and quality of tall fescue. *Agron. J.* 69: 639-643.
- Paterson, J. A., J. C. Forcherio, B. Larson, M. Samford, and M. S. Kerley. 1995. The effects of fescue toxicosis on beef cattle productivity. *J. Anim. Sci.* 73: 889-898.
- Pitchford, W. S. 2004. Genetic improvement of feed efficiency of beef cattle: what lessons can be learnt from other species? *Aust. J. Exp. Agric.* 44: 371-382.
- Poore, M. H., G. A. Benson, M. E. Scott, and J. T. Green. 2000. Production and use of stockpiled fescue to reduce beef cattle production costs. *Proc. Amer. Soc. of Anim. Sci.*
- Pordomingo, A. J., J. D. Wallace, A. S. Freeman, and M. L. Galyean. 1991. Supplemental corn grain for steers grazing native rangeland during summer. *J. Anim. Sci.* 69: 1678-1687.
- Redmer, D. A., J. M. Wallace, and L. P. Reynolds. 2004. Effect of nutrient intake during pregnancy on fetal and placental growth and vascular development. *Domestic Animal Endocrinology* 27: 199-217.
- Richardson, E. C., R. M. Herd, J. A. Archer, R. T. Woodgate, and P. F. Arthur. 1998. Steers bred for improved net feed efficiency eat less for the same feedlot performance. *Anim. Prod. Aust.* 22: 213-216.
- Richardson, E. C., R. M. Herd, V. H. Oddy, J. M. Thompson, J. A. Archer, and P. F. Arthur. 2001. Body composition and implications for heat production of Angus steer progeny of parents selected for and against residual feed intake. *J. Anim. Sci.* 41: 1065-1072.
- Riesterer, J. L., M. D. Casler, D. J. Undersander, and D. K. Combs. 2000a. Seasonal yield distribution of cool-season grasses following winter defoliation. *Agron. J.* 92: 974-980.

- Riesterer, J. L., D. J. Undersander, M. D. Casler, and D. K. Combs. 2000b. Forage yield of stockpiled perennial grasses in the Upper Midwest USA. *Agron. J.* 92: 740-747.
- Roth, L. D., F. M. Rouquette, Jr., and W. C. Ellis. 1990. Effects of Herbage Allowance on Herbage and Dietary Attributes of Coastal Bermudagrass. *J. Anim. Sci.* 68: 193-205.
- Schoonmaker, J. P., S. C. Loerch, J. E. Rossi, and M. L. Borger. 2003. Stockpiled forage or limit-fed corn as alternatives to hay for gestating and lactating beef cows. *J. Anim. Sci.* 81: 1099-1105.
- Shuey, S. A., C. P. Birkelo, and D. M. Marshall. 1993. The relationship of the maintenance energy requirement to heifer production efficiency. *J. Anim. Sci.* 71: 2253-2259.
- Spitzer, J. C., D. G. Morrison, R. P. Wettemann, and L. C. Faulkner. 1995. Reproductive responses and calf birth and weaning weights as affected by body condition at parturition and postpartum weight gain in primiparous beef cows. *J. Anim. Sci.* 73: 1251-1257.
- Stalker, L. A., D. C. Adams, T. J. Klopfenstein, D. M. Feuz, and R. N. Funston. 2006. Effects of pre- and postpartum nutrition on reproduction in spring calving cows and calf feedlot performance. *J. Anim. Sci.* 84: 2582-2589.
- Taylor, T. H., and W. C. Templeton, Jr. 1976. Stockpiling Kentucky bluegrass and tall fescue forage for winter pasturage. *Agron. J.* 68: 235-239.
- Tucker, C. A., R. E. Morrow, J. R. Gerrish, C. J. Nelson, G. B. Garner, V. E. Jacobs, W. G. Hires, J. J. Shinkle, and J. R. Forwood. 1989. Forage Systems of beef cattle: Effect of winter supplementation and forage system on reproductive performance of cows. *J. Prod. Agric.* 2: 217-221.
- USDA-ERS. 2005. Commodity costs and returns, Cow-calf data. <http://www.ers.usda.gov/Data/CostsAndReturns/testpick.htm> Accessed June 6, 2007.
- Waller, J. C., J. C. Forcherio, H. A. Fribourg, M. C. Smith, and R. J. Carlisle. 1988. Performance of fall-calving cows and their calves grazing fescue-based forage systems. *J. Prod. Agric.* 1: 338-342.
- Wettemann, R. P., C. A. Lents, N. H. Ciccioli, F. J. White, and I. Rubio. 2003. Nutritional- and suckling-mediated anovulation in beef cows. *J. Anim. Sci.* 81(E. Suppl. 2): E48-E59.

VITA

Allison Meyer was born on January 7, 1983 to Alan and Kathy Meyer and grew up in Greensburg, Indiana. Allison has always been active in the beef industry, beginning with involvement in her family's purebred Shorthorn operation and continuing with leadership roles in junior organizations such as the American Junior Shorthorn Association and Indiana Junior Beef Cattle Association. In May 2005, Allison graduated with a B.S. in Animal Science from Michigan State University, where she was a member of the Livestock Judging Team. At MSU, Allison's interest in research was sparked by her advisor, Dr. David Hawkins, and further developed while completing an undergraduate research project in Dr. Gretchen Hill's trace mineral nutrition lab. Allison received her M.S. in Animal Science from the University of Missouri in August 2007 for her cow-calf nutrition research under Dr. Monty Kerley. During her time in Columbia, Allison enjoyed serving as a teaching assistant in undergraduate courses and taking part in the Miller Reproductive Management Internship in addition to her research at the farm. Upon receiving her M.S., Allison began pursuit of a Ph.D. at North Dakota State University in ruminant nutrition with an emphasis on its interaction with