THE EFFECT OF RESIDUAL FEED INTAKE ON ANGUS HEIFER GRAZING DISTRIBUTION, DIET SELECTION, AND BEHAVIOR

By

JAMES NOLAN CRAUN

Bachelor of Science in

Natural Resource Ecology and Management

Oklahoma State University

Stillwater, OK

2016

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 2018

THE EFFECT OF RESIDUAL FEED INTAKE ON ANGUS HEIFER GRAZING DISTRIBUTION, DIET SELECTION, AND BEHAVIOR

Thesis Approved:

Laura E. Goodman
Thesis Adviser

Ryan R. Reuter

Karen R. Hickman

James P. S. Neel

ACKNOWLEDGEMENTS

I would like to specifically thank my adviser Dr. Laura Goodman for her willingness to advise me and accept me as her first graduate student. In addition, I thank Dr. Ryan Reuter for teaching me about beef cattle management, Dr. Karen Hickman for providing me a firm undergraduate foundation that enabled me to achieve a master's degree, and Dr. Jim Neel and the USDA-ARS-SP Grazinglands Research Laboratory, El Reno, OK for providing me the resources needed to complete my research.

I attribute my academic success to the development and encouragement that my family has afforded me during my life.

> Sarah and Levi, you have been the source of my desire to perform and work at such a level.
>
> Dad and Mom, my work ethic and educational success are a product of your rearing and teaching.

Finally, thank you to those who have provided me assistance during my time as an undergraduate and graduate student, especially Eric Duell, John McQuaig, and Dr. Shishir Paudel

Name: JAMES NOLAN CRAUN

Date of Degree: DECEMBER, 2018

Title of Study: THE EFFECT OF RESIDUAL FEED INTAKE ON ANGUS HEIFER GRAZING DISTRIBUTION, DIET SELECTION, AND BEHAVIOR

Major Field: NATURAL RESOURCE ECOLOGY AND MANAGEMENT

Abstract: Feed represents the single largest source of input costs in the beef industry. Residual feed intake (RFI) is the difference between an animal's actual feed intake and expected intake based on body weight and growth. Selection against RFI for improved feed efficiency has been proposed to reduce feed costs. Little research has been conducted evaluating the effect of RFI on beef cattle grazing in extensive environments. This study used global positioning system (GPS) collars to collect spatial data on 38 Angus and 5 Brahman × Angus heifers with known RFI values in a 69ha pasture in the south central Great Plains. Heifers were categorized by RFI value, low-RFI (efficient), mid-RFI (average), and high-RFI (inefficient). Body weight and gain were similar among RFI group. Residual feed intake and feed conversion ratio differed among each RFI group whereas rumination times did not. No differences were observed in the plant community electivity among RFI groups; the Johnsongrass community was most preferred and the woody community was most avoided among each RFI group. Fecal samples indicate heifers selected diets higher in protein than the dominant grasses could provide, and diet selection results reveal a selection for the Cornaceae plant family. Overall, diet selection results reveal a significant difference in plant family use among two of the most abundant 10 plant families. Diet quality results indicate heifers were selecting diets with a higher protein content (>5.8%) than the average warm-season grass plant community could provide, and diets did not differ among RFI group ($P \geq 0.60$). Only small differences in diet quality or selection at the plant family level were detected among RFI group. Similarly, differences among RFI groups were not detected when behaviors (24-hour, daytime, sunset to midnight, and midnight to sunrise distance travelled, water and shade use, area explored, and slope use) were compared. On average heifers travelled in excess of 6.3km per day. Because testing for RFI is laborious and expensive, discriminant function analysis was used to identify useful variables in predicting RFI, and cross-validation was used to determine model error rate in RFI grouping. Stepwise analysis identified rumination time during RFI test as the only variable useful for predicting RFI, and model error rate was 44.19%. The culmination of these results indicate a selection against RFI for feed efficient beef cattle is unlikely to impact grazing distribution, diet quality and selection, and grazing behavior.

TABLE OF CONTENTS

Chapter ....Page

LIST OF TABLES

Table ....Page

LIST OF FIGURES

CHAPTER I

LITERATURE REVIEW OF RESIDUAL FEED INTAKE

ABSTRACT

Improvement in the beef industry has typically been approached by increasing outputs, but the rising cost of feed and land are causing a shift towards an improvement in input efficiency. The use of feed conversion ratio (FCR) has been used, but the correlation between FCR and body weight (BW) has resulted in no change in production cost efficiency. Residual feed intake (RFI) is a measure of feed efficiency that is phenotypically independent of BW and gain, i.e. average daily gain (ADG). To obtain RFI, dry matter intake (DMI) is predicted from a multiple linear regression using BW and ADG as predictor variables. The difference between the actual DMI of an animal and its predicted DMI yields the RFI. Correlation coefficients (R^2) for RFI regression models reveal the amount of variation in DMI explained by BW and ADG, with R^2 values typically greater than 60%. Feed efficient animals have negative RFI values and inefficient animals have positive RFI values. The reranking of animals as efficient or inefficient has been addressed by previous studies and it is recommended animals be tested for RFI at or near mature BW to reduce the likelihood of reranking. The selection against RFI (i.e. improved efficiency) has minimal to no impact on animal performance

and is moderately heritable. Decreased DMI from cattle with negative RFI values results in lower enteric methane emissions than cattle with positive RFI values. Selecting against RFI in beef cattle is a method to decrease DMI, maintain production, and decrease greenhouse gas emissions all while reducing input costs for producers.

INTRODUCTION

Measures of Efficiency

A multitude of efficiency measures have been developed for cattle and the selection of any one measure is dependent on the type of animal and production system at use. The incorporation of efficiency within animal production is vital for producers because feed costs are a major source of input costs for animal production systems. In the cow-calf sector of production, 60-65% of feed costs (grazed forage and supplement) are spent on maintenance (Herd et al. 2003; Arthur and Herd 2008). Establishing an efficient herd is thus an opportunity for cost savings (Meyer et al. 2008). Stocker operations and confined animal feeding operations use gross efficiency (or its inverse, feed conversion ratio [FCR]) to measure the ratio between feed input and average daily gain (Archer et al. 1999). Average daily gain (ADG) is also useful when cattle are actively growing as a measure of growth over time, but does not provide information relative to efficiency of feed use. Feed conversion ratio is the most widely used index of efficiency and selecting for FCR improves efficiency during the growth and finishing phase of beef production; however, selecting for FCR in cattle has resulted in high mature weights and maintenance requirements (Archer et al. 1999; Arthur and Herd 2008). Increases in mature body size and therefore maintenance cost subsequently negate progress made toward production cost efficiency. For cow-calf producers, maintenance efficiency is perhaps a more appropriate measure than FCR because it accounts for the mature stasis of the cow. Maintenance efficiency is the ratio of body weight to feed intake at zero body weight change (Archer et al. 1999). Cows tested for maintenance efficiency repeatedly showed consistent levels of efficiency until the animal's age approached 8-9 years (Taylor et al. 1981). This suggests selecting for efficient cows would result in savings during the cow's productive period compared to a cow whose efficiency is unknown or inefficient. Although each of these efficiency measures are well suited to particular levels of production, none are suited for all production levels (e.g. young, growing animals; mature breeding stock). One measure of feed efficiency, residual feed intake (RFI), is becoming the measure of choice among evaluators because RFI is independent of body weight (BW) and production (ADG) (Moore et al. 2009). Therefore RFI can be effectively used with all kinds, classes, and ages of livestock, though RFI reranking can occur as animals age (discussed below, Durunna et al. 2011).

Residual feed intake (also referred to as net feed intake) is the difference between an animal's actual intake and predicted intake, with the predicted intake based on the animal's BW and ADG over a specified period of time (Arthur and Herd 2008). Residual feed intake therefore represents the amount of feed intake not accounted for by BW or ADG (Dai et al. 2017). Multiple regression is used to calculate predicted intake from BW and ADG using the following equation:

$$Y = ß_0 + ß_1X_1 + ß_2X_2 + \varepsilon$$

where Y is predicted dry matter intake, $ß_0$ is the intercept, $ß_1$ and $ß_2$ are the equation coefficients, X_1 is the mid-test body weight, X_2 is the average daily gain, and ε is the residual. By using the above equation, predictive intakes for each animal being tested for RFI can be calculated. The predicted intake of the animal is then subtracted from the actual intake of the animal during the RFI test, which yields the residual of the feed intake prediction (Sainz and Paulino 2004) (Figure 1.1). A negative residual value represents feed efficiency whereas a positive residual value represents feed inefficiency. The degree of efficiency (or inefficiency) is determined by the size of the residual. Proportionally small residuals (i.e., when actual intakes are similar to predicted intakes) indicate little variation in feed efficiency whereas large residuals indicate great variation in feed efficiency relative to other animals in the test. Tested individuals are typically placed into one of three groups based on their RFI. Individuals within 0.5 standard deviation (SD) of the mean RFI value are considered the middle/average group, whereas individuals with RFI values greater than mean RFI + 0.5 SD from the mean are considered inefficient and those with RFI values less than mean RFI - 0.5 SD from the mean are efficient (Kelly et al. 2010; Durunna et al. 2011; Connor et al. 2013). Actual intakes are derived from a recommended 70 day long testing period (Archer et al. 1997; Ahlberg et al. 2018) in which a cohort of animals are acclimated to a testing facility and test diet prior to the 70 day testing period. After acclimatization, measured quantities of feed are provided to each animal ad libitum, and total intake of each animal is recorded daily. Body weights at the start and end of the testing period are averaged by animal to obtain mid-test body weights, and ADG is calculated from total weight gained and number of days during the testing period. Residual feed intake can be tested with high quality diets and actively growing animals that would have relatively high daily gains and within animal variation in body weight during the test, or it can be tested with a balanced hay diet and mature cows that exhibit small changes in daily gains and little variation in body weight. Regardless of test diet and production level of the animal, variation in actual intake versus predicted intake can be obtained and used to identify animals with different levels of efficiency. Although first reported in a study of beef cow feed efficiency (Koch et al. 1963), RFI is used in swine, poultry, salmonid, shrimp, and other animal production systems (van Eerden et al. 2004; Silverstein et al. 2005; Gilbert et al. 2007; Dai et al. 2017).

Like FCR, RFI is a heritable measure of efficiency (Crews 2005), but RFI has benefits that FCR does not. Selecting against RFI can reduce the amount of feed required for maintenance and subsequent gain. In addition, RFI is phenotypically independent of the traits used in its calculation, and therefore allows animals of differing production levels to be compared. Residual feed intake should be interpreted with caution as only animals within the same RFI test can be compared because the residual value of feed intake is subjective to the regression model results used to obtain RFI. By incorporating BW and ADG in its calculation, RFI is not subject to any latent correlations with BW or ADG that would result in increased mature size (Crews 2005). This characteristic of RFI has led some to suggest RFI represents actual variation in metabolism that determines efficiency (Brelin and Brannang 1982; Richardson et al. 2001). Unlike selecting for improved FCR which results in increased growth rates and mature cow weights (Archer et al. 1999; Arthur and Herd 2008), selection against RFI decreases the conversion ratio of feed to product and does not affect growth performance or mature cow size (Herd et al. 2003). This is important to note because as animal size increases, so does the amount of feed needed for maintenance (Archer et al. 1999; Arthur and Herd 2008).

Possibility of Advancement in Efficiency

Residual feed intake is an economically relevant trait (ERT) because it directly affects the cost associated with producing livestock (Crews 2005). This is in contrast to an indicator trait which is not directly related to a cost or income from production (e.g. calf birth weight, scrotal circumference) (Enns 2013). Accurately quantifying savings from reduced DMI in extensive grazing systems is challenging as the economic value of forage varies and residual forage can be difficult to quantify (Herd et al. 2003; Arthur and Herd 2008). Expected savings from divergent RFI selection would also be variable as the range of DMI in efficient and inefficient cattle is variable and still primarily dependent on body weight and gain. Even if an economic value is not determined, the savings of forages as drought reserves, wildlife habitat, or allowance for greater stock numbers can be realized. In the feedlot sector quantifying feed inputs and associated costs are not only easier to obtain, but integral to profitable operation. It is therefore much easier to predict potential economic savings by reduced DMI in confined feeding versus extensive grazing. To place estimated savings into perspective, in 2017 the United States feedlot industry fed 32.2 million head of cattle. Assuming a FCR of 6.5, feed costs of $\$220^{-\text{ton}}$, and 225kg of gain, a 2% increase in feed efficiency would result in a savings of $230 million (formula adopted from Herring and Bertrand 2002). A 2% improvement in efficiency is equivalent to a decrease of 0.24kg $\text{DMI}^{-\text{d}}$ for one animal unit, and is a conservative improvement relative to the 20%+ improvement in efficiency possible through multiple generations selected for low RFI (Kerley 2010).

Measuring RFI is financially and labor intensive, and the traditional 70 day testing period is short relative to the duration of production, especially for breeding stock.

This raises concern as to the possibility that individual levels of efficiency could change over the life of the animal. Archer et al. (2002) reported moderate and high correlations between RFI measured post-weaning and RFI measured two years later (phenotypic correlation: r=0.40, genetic correlation: r=0.98). Correlations between post-weaning RFI and mature RFI rank also existed in mice, although at lower levels (phenotypic correlation: r=0.29, genetic correlation: r=0.60) (Archer et al. 1998). Based on the higher correlations from genetic tests, it would seem that measuring RFI genetically would be the most appropriate route when seeking to identify long term feed efficient animals. However, Cheverud (1988) suggests that much of the dissimilarity between phenotypic and genetic correlations exists as a result of imprecise estimates of genetic correlations. The reranking of individual efficiency levels as a result of diet changes has also been examined due to the extreme variation in diet quality experienced by cattle in the traditional beef production system. When switched from a growing diet to a finishing diet, 51% of steers changed RFI group by 0.5 SD (Spearman rank correlation=0.33), whereas steers fed the same growing or finishing diet in two successive RFI tests yielded correlation coefficients of 0.44 and 0.42 between initial and subsequent testing (Durunna et al. 2011). Durunna et al. (2011) suggest RFI testing may be most useful when conducted at or near the animals mature BW. Similar results of reranking were reported in 16-21 month old Nellore (*B. indicus*) steers after two feeding periods (r=0.11-0.40) (Gomes et al. 2012). In both Durunna et al. (2011) and Gomes et al. (2012) the gain:feed (i.e. the inverse of FCR) correlations between initial testing and subsequent testing were much lower than that of RFI, furthering the argument for divergent selection of RFI for efficiency rather than FCR.

Residual Feed Intake and Cattle Performance

The degree to which RFI affects performance traits is important to understand because the increased adoption of RFI as *the* efficiency measure in the United States would likely wane if negative effects on performance occurred. Of primary concern are fertility, ADG, mature BW, FCR, and carcass and meat quality traits. Basarab et al. (2011) reported no difference in heifer age at puberty, weight at puberty, or rate at which heifers reached puberty between low-RFI (i.e. more efficient) and high-RFI (i.e. less efficient) individuals. When RFI was adjusted for subcutaneous fat thickness ($Y = ß_0 + ß_1X_1 + ß_2X_2 + ß_3X_3 + \varepsilon$ where $ß_3$ is the partial regression coefficient of standardized DMI on final ultrasound subcutaneous fat thickness), low-RFI heifers were 11 days older and 12.1kg heavier at puberty than high-RFI heifers. This was similar to the results in Shaffer et al. (2011) in which a small negative relationship between RFI and age at puberty (r=-0.16) was detected. Shaffer et al. (2011) concluded that the large variation in age at puberty of both low-RFI and high-RFI heifers could allow for the selection of low RFI and early maturation without affecting herd fertility. Breeding weight, abortion rate, and average calving date for low-RFI and high-RFI heifers were similar, however low-RFI heifers trended towards lower pregnancy rates via natural service (76.84% versus 86.32%) and calving rate compared to the high-RFI heifers (Basarab et al. 2011). Numerous studies reveal corresponding results regarding BW, ADG, and FCR between low-RFI and high-RFI cattle (Table 1.1). Briefly, differences were not observed among RFI and BW or RFI and ADG, but were observed between RFI and FCR. One exception is Richardson et al. (2001) where FCR was similar among RFI groups (Table 1.1). When RFI was adjusted for subcutaneous fat thickness, no effect on fertility traits was observed, thus Basarab et al. (2011) suggest subcutaneous fat thickness may be negatively associated with feed intake and should be considered when selecting heifers for improved feed efficiency. In addition Basarab et al. (2011) support the recommendation that RFI be adjusted for body fat measures in young growing cattle due to the change in relationships between RFI efficiency groups when RFI is adjusted for subcutaneous fat thickness compared to non-adjusted RFI. Intramuscular fat (i.e. marbling) between low-RFI and high-RFI heifers did not differ in Shaffer et al. (2011) (4.65% versus 4.72%, $P=0.64$), nor in McDonagh et al. (2001) (5.4% versus 5.3%, $P>0.10$) between low-RFI and high-RFI steers. High-RFI steers had less subcutaneous fat over the rib than low-RFI steers ($P<0.05$) and trended toward less fat over the rump as well (Mcdonagh et al. 2001). Antithetically, subcutaneous fat in low-RFI heifers was less than that in their high-RFI herdmates (Shaffer et al. 2011). Quantities of subcutaneous fat and intermuscular fat between low-RFI and high-RFI Angus steers did not differ when fat type was compared individually, but the additive effect of both fats together did differ (Richardson et al. 2001). Baker et al. (2006) attributes the inconsistency in fat deposition reported in the literature to be caused by differences in age and maturity of animals between studies, or that there remain unknown variables influencing body composition. Meat tenderness of the M. longissimus dorsi did not differ between low-RFI and high-RFI steers regardless of number of days aged (McDonagh et al. 2001). Likewise shear force, tenderness, juiciness, and flavor did not differ between steaks from low-RFI and high-RFI steers (Baker et al. 2006).

Residual Feed Intake Influence on Greenhouse Gas Emissions

Global agriculture is responsible for 10-12% of human sourced emissions of greenhouse gases (GHG) (Smith et al. 2007), and enteric methane (CH_4) production from ruminants accounts for 5% of the total GHGs (Scholtz 2013). Ruminants also produce nitrous oxide (NO_2) and carbon dioxide (CO_2) (NASEM 2016), but CH_4 is of primary concern due to its CO_2 equivalence range of 21 to 25 and also because CH_4 emissions represent an energy loss to the ruminant organism (Haque et al. 2017). Enteric methane production occurs primarily in the anaerobic rumen when H_2 and CO_2 are joined and then released via eructation (Eckard et al. 2010). A small portion of CH_4 production also occurs from the fermentation of organic matter in the feces (Herd et al. 2002). Multiple technologies and management strategies are currently being proposed and employed in agriculture to reduce CH_4 emissions from ruminant production. Eckard et al. (2010) suggested three primary methods for reducing CH_4 emissions; rumen manipulation, diet manipulation, and/or animal manipulation. Rumen manipulation methods include introduction of competitive or predatory microbes to decrease CH_4, addition of chemical inhibitors of CH_4 to the diet, and continued use of ionophores such as monensin to reduce acetate:propionate ratios (Tomkins and Hunter 2004; Eckard et al. 2010). Diet manipulation strategies include feeding higher quality forages (e.g. lower fiber and higher soluble carbohydrates), supplementing condensed tannins to the diet to reduce CH_4 production via direct toxic effects on methanogens, as well as supplementing dicarboxylic acids such as fumarate and malate which act as alternative H_2 sinks and thus restrict methanogenesis (Woodward et al. 2004; Beauchemin et al. 2008; McAllister and Newbold 2008; Grainger 2009). Although these methods offer many literature-supported avenues of CH_4 abatement (Smith et al. 2008), the authors suggest application of such technologies are often cost prohibitive, negatively affect animal performance, lack sufficient trial data, or are unlikely to be adopted due to public perception and preferences (Eckard et al. 2010). Alternatively, animal manipulation via a breeding strategy that results in decreased CH_4 emissions is a suitable option. Breeding for CH_4 abatement alone is not likely to gain much support because beef producers are not compensated for CH_4 restriction efforts (Eckard et al. 2010); however, breeding for reduced intake via RFI offers a more promising strategy as a herd with lower intake will have reduced CH_4 production and also lower grazing/feeding costs for the producer without compromising profit.

To date, much research has been conducted and reveals favorable results in reducing CH_4 emissions by divergent selection for RFI. A study of 135 Angus yearlings (BW≈280kg) from two generations of divergent RFI lines resulted in low-RFI cattle producing 15% less enteric methane than their high-RFI herdmates, all while achieving similar ADG with lower DMI (Herd et al. 2002). Nkrumah et al. (2006) reported 28% less methane produced by low-RFI steers than high-RFI steers (BW≈230kg). Dry matter intake was significantly less for the low-RFI steers, but ADG remained similar between low-RFI and high-RFI steers. Both of these studies used high energy balanced diets when assessing CH_4 emissions. Because cattle, especially breeding stock, spend the majority of their life on variable quality pasture, Jones et al. (2011) measured CH_4 emissions from cows (BW≈505kg) of the same RFI lineage as those in Herd et al. (2002). Low-RFI and high-RFI cows grazing low quality pasture did not differ in CH_4 production, yet did differ in CH_4 production while grazing high quality pasture. The authors suggest the lack of difference observed on low quality pasture may be caused by the protein-limited microbes being unable to efficiently digest consumed forages (Jones et al. 2011). The reduction in DMI in low-RFI cattle is a reasonable explanation for lower methane emissions, but work from Carberry et al. (2014) suggests the differences in methanogen operational taxonomic unit abundance between low-RFI and high-RFI cattle may be responsible for the observed difference in methane production. As mitigation of GHGs continues to be of concern, improving the efficiency of beef production by selection against RFI offers great potential in GHG control and within-animal energy savings.

Conclusion

The culmination of these studies provide much support for RFI as a measure of efficiency that should be selected against in future breeding programs. As feed costs and beef prices increase and demand for suitable beef alternatives gain support, remaining cost competitive will be important for producers to stay in business. Residual feed intake should therefore be a trait sought after by producers for improved efficiency of production.

Aside from a single study (Knight 2016), the literature is lacking any research on the effect of RFI on grazing behaviors of cattle on rangeland. Herd selection based on a single trait may adversely affect behaviors expressed by cattle grazing extensive rangelands. Producers and range managers typically desire uniform distribution and forage utilization, including on uneven terrain and at distances far from water. If the selection for feed efficient cattle changes grazing behaviors, undesirable consequences may occur with respect to utilization, willingness to travel to acquire forage, overuse of water or shade sites, or avoidance of slope. Knight (2016) addressed grazing behaviors with respect to RFI in the arid American southwest, but the behaviors of RFI tested cattle in highly productive temperate environments has yet to be addressed.

TABLES

Table 1.1. Body weight (BW), average daily gain (ADG), and feed conversion ratio (FCR) of multiple breeds and classes of cattle based on RFI efficiency level (low-RFI = efficient; high-RFI = inefficient) reported in the literature.

			BW (kg)			ADG (kg)			FCR			
Breed	Sex	Sample size	Low-RFI	High-RFI	*P*	Low-RFI	High-RFI	*P*	Low-RFI	High-RFI	*P*	Source
-	Bull and heifer calves	Low-RFI: 62 High-RFI: 73	384	381	>0.05	1.44	1.40	>0.05	6.60	7.80	<0.05	1
Angus	Steers	Low-RFI: 16 High-RFI: 17	283	292	>0.10	1.00	0.97	>0.10	8.23	8.97	>0.10	2
-	Steers and Heifers	Low-RFI: 155 High-RFI: 156	277	277	0.99	1.06	1.06	0.90	8.44	10.28	<0.01	3
-	Steers	Low-RFI: 93 High-RFI: 87	327	333	0.56	1.41	1.42	0.38	6.05	7.63	<0.01	3
Continental × British	Steers	Low-RFI: 8 High-RFI: 11	426	398	0.48	1.48	1.46	0.39	6.53	7.98	0.01	4
Angus Crossbred	Steers	Low-RFI: 6 High-RFI: 6	325	330	0.72	1.40	1.51	0.13	5.00	6.85	<0.01	5
Limousin × Holstein	Heifers	Low-RFI: 21 High-RFI: 23	192	194	0.81	1.54	1.52	0.41	4.04	4.86	<0.01	6
Crossbred	Heifers	190 (total)	296	298	0.35	0.95	0.93	0.80	-	-	-	7
Holstein	Heifers and Cows	Low-RFI: 136 High-RFI: 115	604	607	>0.05	0.14	0.13	0.14	-	-	-	8

Sources: 1) Arthur et al. 2001; 2) Richardson et al. 2001; 3) Carstens and Tedeschi 2006; 4) Nkrumah et al. 2006; 5) Golden et al. 2008; 6) Kelly et al. 2010a; 7) Durunna et al. 2012; 8) Connor et al. 2013

FIGURES

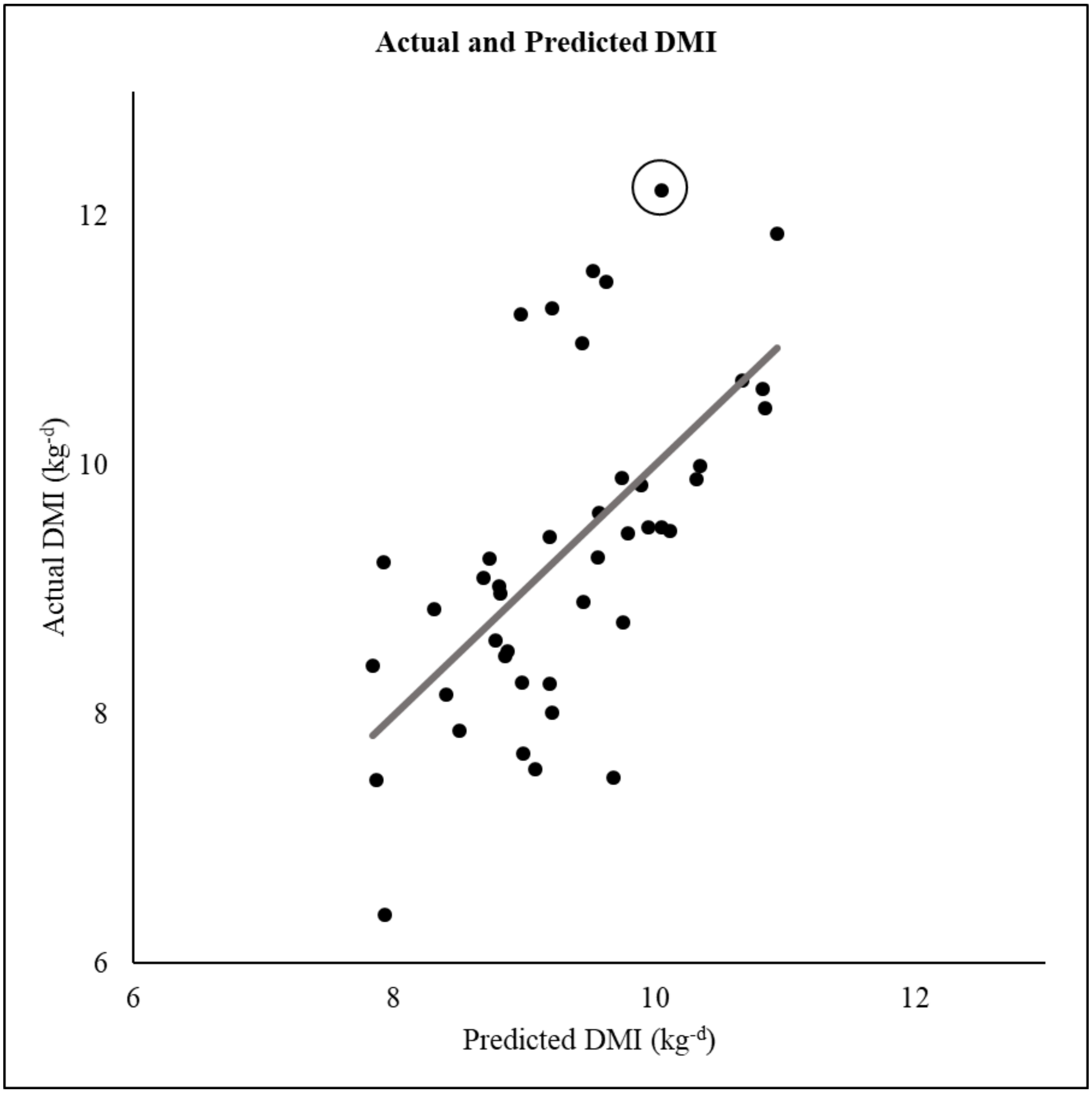

Figure 1.1. An example of predicted intakes (grey regression line) and actual intakes (black dots) of a herd of 43 heifers. The regression line shown was calculated using the following prediction equation: DMI (predicted) = -0.928 + 0.105($BW^{0.75}$) + 1.968(ADG). Residual feed intake values are obtained by subtracting the predicted DMI value from the actual DMI value. An example RFI calculation is shown for an inefficient individual (circled) that had an actual DMI of 12.2kg, a predicted DMI of 10.0kg, and therefore an RFI of 2.2kg.

CHAPTER II

THE EFFECT OF RESIDUAL FEED INTAKE ON ANGUS HEIFER PLANT COMMUNITY SELECTION, DIET QUALITY, AND DIET SELECTION

ABSTRACT

The spatial distribution of cattle on pastures is highly variable and a result of many interacting factors. As efficiency in production becomes increasingly important for livestock producers, the influence of residual feed intake (RFI) on distribution and subsequent diet selection will be important for producers seeking to reduce feed costs while considering common rangeland management principles. The distribution of 43 RFI tested beef heifers was monitored using GPS for one month late in the growing season. Two classification criteria for RFI grouping was used based on mean RFI ± 0.5SD (conservative class) and mean RFI ±1SD (extreme class). Plant community electivity rank was identical between low-RFI (efficient) and high-RFI (inefficient) heifers in each class. In addition, low-RFI heifers did not select diets that differed in percent crude protein (*P*>0.60) or digestible organic matter (*P*>0.38) from mid-RFI (average efficiency) or high-RFI heifers. Diet selection results reveal a similar composition among RFI group in regards to the amount of protein acquired from each plant family that was detected in

the feces. In the conservative class only two of ten families differed in protein abundance among RFI group (*P*<0.03) and in the extreme class only one of ten families differed in protein abundance (*P*<0.01). Selection of more efficient cattle (low-RFI) will have little to no impact on grazing distribution and diet selection.

INTRODUCTION

The distribution of cattle within an environment is highly variable and dependent on a great number of factors. Anderson (2010) described 68 factors affecting animal distribution, including herd size, animal memory, slope, body size, paddock shape, phenology, supplemental feeds, fire, and management technologies. Three broad categories of these factors include vegetation and landscape attributes, temperature regulation, and diet selection and are discussed below.

Vegetation and Landscape Attributes

Contrary to pastureland, rangelands consist of a wide variation in plant communities, topography, and water availability which affect the distribution of livestock. Ungulate grazing can cause changes in plant communities (Olff and Ritchie 1998; Knapp et al. 1999) and the role of grazing for the maintenance of communities has been documented as well (Marty 2005). While the optimum foraging theory is not particularly suited for large herbivores (Senft et al. 1987), its use in regard to foraging in communities where protein acquisition is above average is supported in the literature. Because rumen fermentation efficiency is contingent upon protein intake (NASEM 2016), cattle tend to selectively graze communities that provide or supplement their diet with required levels. In an Oregon study, cattle showed indifference or avoidance to areas of pasture that had crude protein values less than average (Ganskopp and Bohnert 2009). The same trend in selection has been shown in bison when areas of regrowth with high protein levels are available for use after fire (Allred et al. 2011).

Topography presents a unique issue to pastoralists because it cannot be changed by management. Altering the kind of livestock raised, selecting for terrain adapted breeds, or culling individuals with undesirable terrain use are common methods for increasing utilization of specific terrain types. Slope use at the animal species level is exemplified by the work of Ganskopp and Vavra (1987) in which cattle, horses, mule deer, and bighorn sheep used on average 5.8%, 11.2%, 15.7%, and 42.5% slopes, respectively. Furthermore, data for each species except bighorn sheep were skewed towards gentle topography. Tate et al. (2003) reported a negative association between percent slope and cattle fecal counts.

Lastly, water availability significantly affects forage utilization as forage use tends to decrease as distance from water increases (Pinchak et al. 1991; Bailey et al. 2001). Large quantities of forage can be found at varying distances from water, and the understanding of livestock species' willingness to travel is important for vegetation management planning (Vallentine 1990). Water availability is of little concern in the southeast and midwest U.S., but for producers in the southwest and west, water is a major consideration in production. When water availability cannot be improved, selecting water efficient cattle such as *B. indicus* breeds is a viable option.

Heat Tolerance in Cattle

Environmental stressors such as high temperature, high humidity, and high solar radiation result in elevated levels of heat stress in cattle (Silanikove 2000) causing changes in distribution to moderate body temperature. When cattle experience body temperatures outside of the thermal neutral zone, movements and willingness to seek new resources are decreased. The ability of an individual to regulate internal temperature is dependent on expressed behaviors within the individual's environment (Blackshaw and Blackshaw 1994) as well as physiological adaptations of the individual. With increased consideration for animal welfare and production efficiency, selection of cattle that are physiologically adapted to the environment in which they are used is gaining momentum (Broom 1992; McManus et al. 2009). In the United States, the use of *Bos taurus* breeds (e.g. Angus, Charolais, Hereford, Simmental) has been primarily driven by the quality of beef derived from these breeds as well as the temperate climate that resembles the regional origins of these breeds (Hammond et al. 1996; Warren et al. 2008). However, high relative humidity and ambient temperature present unique problems for producers using *B. taurus* breeds in the southeastern U.S., and water availability and ambient temperature are problematic for producers in the southwestern U.S. Thus the incorporation of Brahman (*B. indicus*) genetics in these subtropical and semi-arid regions results in greater heat tolerance, as *B. indicus* cattle originated in similar environments in India (Naik 1978). Many studies have measured heat stress in various breeds, and there is consensus that *B. indicus* breeds have greater heat tolerances than *B. taurus* breeds. Blackshaw and Blackshaw (1994) reported *B. indicus* breeds drink 60% less water than *B. taurus* breeds at 39°C and have coats that reflect more solar radiation and retain less heat. Higher rectal temperatures were observed in Angus heifers by Hammond et al. (1996), but Hammond et al. (1996) suggest that was due to differences in temperament between the traditionally docile *B. taurus* and excitable *B. indicus.* In the same study, Brahman cattle had lower respiration rates than Angus, but that may be attributed to the higher packed cell volume and erythrocyte count present in Brahman cattle. The heat tolerance adaptations that *B. indicus* breeds exhibit are thought to be responsible for the differences in grazing distribution of *B. indicus* relative to *B. taurus*. Mean distance travelled during a 24-hour period was greater for Brahman cows than Angus cows in an arid environment (Russell et al. 2012). Ganskopp and Bohnert (2006) reported daily movements of 4.4km per day by Hereford × Angus cows, while Tomkins and O'Reagain (2007) reported daily movements of 8.2km per day by Brahman cows. The lower water requirement and greater heat tolerances of *B. indicus* breeds is thought to be a major influence in the willingness of *B. indicus* breeds to travel further than *B. taurus* breeds.

Diet Selection

Diet selection by cattle is a complex process that accounts for nutritional needs, preference, previous experiences, and forage availability. Cattle typically select forages high in protein content (Bailey 1995; Ganskopp and Bohnert 2009). A selection for high protein is important for maintenance and milk production in mature cows, as well as growth for immature animals. It is important to consider individual diet selection because variation exists in nutritional needs even between closely related individuals (Provenza et al. 2003). Little evidence exists suggesting ruminants are capable of directly sensing the nutritive value of foods, providing evidence for the postingestive feedback mechanism (Provenza 1995). Postingestive feedback results in an aversion to a forage species when gastrointestinal distress follows consumption (Provenza 1995; Pfister 2000).

Methods to Alter Distribution

Persistent use of previously grazed areas has been an issue range managers have faced for many years when managing livestock on rangelands (Ganskopp and Bohnert 2006). Altering the distribution of livestock has been used to encourage use of new sites and allow previously used sites to recover. Common methods used to alter distribution of cattle are water developments, fencing, and supplementation (Bailey 2004). Porath et al. (2002) compared cow distribution between sites with multiple water sources and mineral salt and sites without multiple water sources and mineral salt. Cows with multiple water sources and salt had less predictive distribution patterns than cows without multiple water sources and salt, and it was also found that cows tended to spend afternoons in the same area where they drank. In addition, cows with access to multiple water sources and salt had greater gains, and this is thought to be caused by more uniform grazing distribution and less patch grazing. Holechek et al. (2011) recommends moving water sources if water is supplied and increasing water sources if impoundments are used to improve space use between water locations. Fencing is a suitable distribution altering method when multiple rangeland sites occur in the same grazing unit (Holechek et al. 2011). In this scenario, cattle are likely to repeatedly use one or few sites that are host to palatable forages while other sites remain unused. Managing distribution patterns caused by seasonal changes in forages is also possible when distinct differences in forage type are present (Holechek et al. 2011).

Residual Feed Intake and Grazing Distribution

Residual feed intake (RFI) is a measure of feed efficiency defined as the difference in predicted feed intake and actual feed intake of an individual with respect to body weight (BW) and average daily gain (ADG) (Chapter I, Figure 1.1). Unlike feed conversion ratio (FCR; i.e. the units of feed required to increase one unit in weight), RFI is independent of body weight and growth and the selection against RFI for decreased feed intake offers a significant cost savings for the beef industry. For example, using 2017 data, a 2% increase in feed efficiency would have saved U.S. feedlot operators a cumulative $230 million (formula adapted from Herring and Bertrand 2002). In addition, a 1% increase in feed efficiency is economically equivalent to a 3% increase in rate of gain (Shike 2012). Because feed intake costs are most realized in confined feeding operations, research regarding RFI has typically been conducted in intensive management and confined environments, and little has been done to identify the effect of RFI on grazing distribution and diet selection. The influence that RFI has on the grazing distribution behaviors of the breeding stock is an important consideration because of the number of years breeding stock spend grazing in extensive environments. It could be possible that cattle with low (feed efficient) or high (feed inefficient) RFI values favor certain plant communities or consume diets of differing quality. As a result, the variation in distribution and diet selection of cattle with different efficiency levels are rangeland management issues and need to be considered prior to herd efficiency improvement.

Across multiple livestock industries, increased production levels have been shown to have negative effects on other traits such as behavior, physiological, and immunological problems (Rauw et al. 1998). In broiler breeding hens, excessive body weight reduces fertility (Dunnington 1990) and decreases immune system performance (Miller et al. 1992). Estrus behavior in high producing Holstein cows is suppressed compared to their average producing counterparts (Harrison et al. 1989) and cows with the highest milk yields also have the highest levels of infertility (Lucy 2001). In the beef industry, selection for improved FCR resulted in animals with higher mature body weights and subsequent maintenance costs. Residual feed intake offers promise as a method to improve production by reducing inputs rather than increasing outputs, and is a trait independent of mature body weight and growth. In regard to correlated effects, breeding weight, abortion rate, and average calving date for low-RFI and high-RFI heifers was similar, however low-RFI heifers trended towards lower pregnancy rates via natural service (76.84% versus 86.32%) and calving rate compared to the high-RFI heifers (Basarab et al. 2011).

The purpose of this study was to identify differences between feed efficient (low-RFI) and feed inefficient (high-RFI) Angus and Brahman × Angus (F1) heifer plant community selection, diet quality, and diet selection. In addition, breed comparisons are made between the Angus heifers (n=38) and F1 heifers (n=5) to identify variation in distribution and diet selection caused by breed irrespective of RFI. There is currently no research on RFI and diet selection or diet quality, however the effect of RFI on grazing behavior has been documented by Knight (2016) in Arizona rangelands, and suggests low-RFI cattle may utilize irregular terrain and travel further to seek resources more than high-RFI cattle.

Results of the present research will be of value for producers selecting breeding stock based on RFI efficiency by providing foresight in the distribution and forage selection of a feed efficient herd. Diet selection responses are thought to be determined by proportions of volatile fatty acids in the rumen (Provenza 1995), which are produced by anaerobic mircoorganisms within the reticulorumen (NASEM 2016). Rumen communities have been studied in low-RFI and high-RFI cattle, and suggest bacterial communities are similar at the genus level and in diversity between low-RFI and high-RFI cattle (McCann et al. 2014; Myer et al. 2015). It is therefore hypothesized diet selection and subsequent quality will not differ between low-RFI and high-RFI heifers. Plant community use is not expected to differ among low-RFI and high-RFI heifers due to similar nutrient requirements required by heifers.

MATERIALS AND METHODS

Residual Feed Intake Classification and Grouping

The sampling protocol for this research was approved by the Grazinglands Research Laboratory in El Reno, OK (IACUC-GRL-2017-8-9). On March 2, 2017 38 Angus and 5 Angus × Brahman (F1) 1.5 year old heifers were penned for an RFI test (mid-test body weight [BW]= 348 ± 42kg, mean ± SD). Following a 10 day pen acclimatization period, heifers were provided alfalfa hay ad libitum. The quantity of hay consumed by each heifer was recorded daily. After the 70 day testing period, each heifer's average intake was regressed against her metabolic midweight (i.e. average test $BW^{0.75}$) and average daily gain (see Figure 1.1, Chapter I). The residuals from this regression are RFI and are the difference between the predicted intake (regression line) and actual intake of each heifer for their respective body weight and growth rate. Heifers with negative residuals were considered efficient because they required less feed to perform at the same level as their positive residual counterparts.

Animal Classification

Residual feed intake groups were categorized using two approaches. The first being conservative and based on the commonly used method of the mean RFI ± 0.5 SD (Kelly et al. 2010; Durunna et al. 2011; Connor et al. 2013) and the second created to contrast behavioral variation in individuals based on the mean RFI ± 1 SD. The first approach, hereafter referred to as the conservative class, includes a middle efficiency group (mid-RFI) consisting of heifers with RFI values within ± 0.5 SD of the mean RFI value; an inefficient group (high-RFI) consisting of heifers with RFI values 0.5 SD greater than the mean; and an efficient group (low-RFI) consisting of heifers with RFI values 0.5 SD less than the mean. The conservative class consisted of 12 low-RFI, 20 mid-RFI, and 11 high-RFI heifers. The second categorical approach, hereafter referred to as the extreme class, was created to contrast individuals with extreme RFI values, and also includes three RFI groups. These groups were created using the same methods as conservative class, but divided groups at ± 1 SD from the mean RFI value rather than ± 0.5 SD to create the low-, mid-, and high-RFI groups. The extreme class consisted of 5 low-RFI, 31 mid-RFI, and 7 high-RFI heifers. Heifer mid weight was calculated as the average weight during the RFI test, and is one of four weights included in analysis (Table 2.1; 3.1).

Concurrent with the RFI test, Heatime® Pro+ System units (SCR Dairy Inc., Madison, WI, USA) were used to monitor rumination times of each heifer. Rumination data were also collected in a pasture dominated by a non-native *Bromus spp.* Rumination data was collected to identify possible relationships between RFI and rumination duration.

Study Site

Research was conducted in a single 69.4ha pasture (35° 33’ N, 98° 01’ W; elevation 414m) at the United States Department of Agriculture Agricultural Research Service Grazinglands Research Laboratory 3.2km west of El Reno, OK, USA. Average annual precipitation in Canadian Co. is 85cm, with approximately 45% of precipitation occurring from March to June, and average annual temperature is 15.5°C (Oklahoma Climatological Survey). Average temperature during GPS data collection was 21.4°C. The pasture is approximately 2km north to south and 0.5km east to west (Figure 2.1). An ephemeral stream runs south to north through the middle of the pasture and enters the North Canadian River 3.5km northeast of the pasture. Aside from a stock tank in the northeast of the pasture and a small centrally located pond, a large pool formed by the stream serves as the primary water source for livestock. The pasture primarily consists of warm season grasses such as big bluestem (*Andropogon gerardii* Vitman), indiangrass (*Sorghastrum nutans* L.), little bluestem (*Schizachyrium scoparium* [Michx.] Nash), switchgrass (*Panicum virgatum* L.), and johnsongrass (*Sorghum halepense* [L.] Pers.). Dense woody vegetation such as buckbrush (*Symphoricarpos orbiculatus* [Hook.] Nutt.), pecan (*Carya illinoinensis* [Wangenh.] K Koch), roughleaf dogwood (*Cornus drummondii* C. A. Mey), and eastern cottonwood (*Populus deltoids* W. Bartram ex Marshall) are present along the east and west banks of the centrally located stream. Soils consist primarily of Port and Norge silt loams (Soil Survey Staff). Based on a 25% harvest efficiency, the pasture in this study was stocked at 14% of carrying capacity (0.49 AUM^{-ha} versus maximum sustainable rate of 3.57 AUM^{-ha}).

To monitor the spatial distribution of the heifers, I built custom Global Positioning System (GPS) collars. The GPS collar design for this study was an adaptation of the design described in Knight et al. (2018a). The Mobile Action i-gotU GT-600 (New Taipei City, Taiwan) was the GPS unit used for this study. This unit has the capacity to record 262,000 GPS points and has an average satellite acquisition time from a cold start of <35 seconds. The factory 3.7V 750mAh Li-ion battery was removed and replaced with a Tenergy 3.7V 5200mAh Li-ion battery pack (Fremont, CA) to allow for a longer deployment period without sacrificing monitoring duration (Pépin et al. 2004). The modified GPS unit was then placed in a polycarbonate enclosure (Polycase; Avon, OH) and attached to a 3.8cm × 111.8cm nylon cow collar (Valhoma Corporation; Tulsa, OK). A steel plate bent at a 90° angle was used as a counterweight and attached to the nylon collar to keep the GPS unit in its desired orientation around the heifer’s neck. To account for the 66% fix rate reported by Knight et al. (2018a), collars were set to collect location data every two minutes to achieve our overall goal of three minute interval data. These units have circular logging and motion detection settings; both of which were disabled to prevent the overriding of data and for user control of logging periods. Power saving mode was also disabled (C. Knight, personal communication) to prevent excessive battery use during on/off cycles. Spatial distribution variables measured included rank order preference for each plant community based on Ivlev’s Electivity Index, hot spot analysis (Getis-Ord Gi* statistic), plant community biomass and nutrient composition. Heifer dietary variables included crude protein, digestible organic matter, and plant family consumed (Table 2.1). At the time of GPS data collection, heifers averaged 417 ± 43kg (mean ± SD).

GPS Data Cleaning

Data from the i-GotU GPS units were downloaded using the @trip PC software provided by Mobile Action. All GPS data were then merged into a single Microsoft Excel (2017) file and edited using the methods reported by Knight et al. (2018b) to remove inaccurate data. To summarize, the first step in removing any inaccuracies in the data was an adjustment of the time recorded for each GPS fix. Because the iGotU GPS units use the Coordinated Universal Time (UTC) based in London, England, the recorded time data were 5 hours ahead of the local Central Daylight Time (CDT) in Oklahoma, USA. The Kutools for Excel add-in was used to complete this task. Next, the rate of travel between each consecutive GPS fix for each heifer was calculated and any GPS fixes that exceeded a rate of $84m^{-min}$ were removed, as well as any distances between successive GPS fixes that exceeded 168m (84m × 2 minute set sampling interval). This was based on the average $84m^{-min}$ walking rate of a cow reported by Chapinal et al. (2009). Latitude and longitude data were then converted to Universal Transverse Mercator (UTM) northing and easting values.

Vegetation Measurements

Prior to placing GPS collars on heifers, a Trimble Juno 3B GPS unit with three meter accuracy was used to delineate the boundary of the pasture. I collected plant community data only in the herbaceous communities due to the improbability that cows would graze in the dense woody vegetation near the stream. On August 10-11, 2017 I characterized and mapped six plant communities by dominant species using the >40% cover cutoff value suggested by the USDA (Table 2.5; 2.6.1; 2.6.2). These were 1) native tallgrass, 2) forb, 3) native tallgrass/forb codominant, 4) Johnsongrass, 5) annual sunflower, and 6) yellow bluestem. Hereafter, the plant communities will be referred to as 1) tallgrass, 2) forb, 3) codominant, 4) Johnsongrass, 5) sunflower, and 6) yellow bluestem, respectively. After initial identification of plant communities and construction of a digital map, I assigned random sampling points to the multiple occurring patches of each plant community in the pasture using ArcMap 10.4. At each sampling point, canopy cover was assessed using a modification of the Braun-Blanquet method (Bonham et al. 2004). Each plot sampled was $10m^2$ in area and circular in shape. Cover classes were assigned as follows: class 1, <1%; class 2, 1-5%; class 3, 6-25%; class 4, 26-50%; class 5, 51-75%; class 6, 76-95%; class 7, >95%. On September 19, herbaceous forage in each of the plant communities was clipped using a $0.09m^2$ ring. Forage sampling occurred four days after heifers entered the pasture, and sampling did not occur in any grazed patches. There had been no growing season grazing in the pasture prior to September 15. Clipped samples were oven dried at 48°C for 4 days, weighed, and then submitted to the Oklahoma State University Soil, Water and Forage Analytical Laboratory in Stillwater, OK, USA for a nutritive value analysis (Forage Analysis Procedures). Variables analyzed include crude protein and total digestible nutrients (Table 2.1).

Fecal Sampling

Fecal samples were collected by rectal grab on October 16 for diet quality and selection analyses. Unless the quantity of feces was insufficient for analysis (n=3), subsamples of feces from each heifer were sent to the Grazing Animal Nutrition Lab (GAN Lab, Temple, TX, USA) for near infrared reflectance spectroscopy (NIRS) tests to determine the quality of diet consumed. This method of predicting diet quality uses the near infrared ([NIR] 800-2500nm, 10^4 to 4×10^{14} Hz) light spectrum to project known quantities of radiation onto the sample and records the reflectance of NIR from the sample. Chemical bonds, primarily those between CH, NH, OH, CO, and CC are bent and stretched during the exposure to NIR radiation, and the degree to which these distortions occur reveal information about the sample at hand (Stuth et al. 2003). When compared with known laboratory samples used to create calibration equations, an accurate reconstruction of diet quality can be made (e.g. crude protein $R^2 \geq 0.95$; Althaus et al. 2013, Stuth et al. 2003). Subsamples from each heifer were also sent to Jonah Ventures (Boulder, CO, USA) for diet reconstruction through DNA sequencing to identify the various taxa of forages in the diet and their respective proportion of protein supplied in the diet (Bergmann et al. 2015). Plant DNA found in the feces are amplified thousands of times via polymerase chain reaction and then the sequence of nucleotides within the DNA strand are compared to a database of known plants to determine what taxa the DNA belongs to. Rather than identifying the quantity of each taxon in the diet, this method of DNA barcoding reveals the proportion of nitrogen (i.e. protein) in the diet provided by each taxon (J. Craine, personal communication). Fecal samples of adequate size for NIRS and DNA sequencing were unable to be collected for all heifers, and therefore sample sizes presented in Tables 2.9 and 2.10 regarding fecal sampling are not representative of the total number of heifers used in the study.

Statistical Analysis

Data were analyzed using SAS v9.4 2013 (SAS Institute, Cary, NC, USA). The GLM procedure was used to compare the mean values of the low-RFI, mid-RFI and high-RFI groups within each RFI class for forage analyses and diet selection, and the ADJUST=TUKEY option was used to identify differences among means of each RFI group. Significance was determined at $\alpha=0.05$. Percentage values were arcsin transformed for analysis. PROC MEANS was used to obtain summary data and PROC CORR was used for correlation analysis. I calculated Pearson correlation coefficients using PROC CORR and examined relationships: a) among and between heifer performance and grazing distribution, and b) among and between heifer grazing distribution and diet selection.

Because the differentiation of plant communities was initially a visual estimation, a non-metric multidimension scaling ordination (Oksanen et al. 2018) using the species richness and abundance data collected from each plot within each community was used to determine if the communities actually differed in composition and/or abundance. This method in combination with crude protein content of each plant community was used to validate or refute the differentiation of communities from one another.

To determine grazing preference for each plant community by RFI group, I used Ivlev's Electivity Index (Jacobs 1974) with the equation $E_i = (r_i - p_i)/(r_i + p_i)$ where r_i is the number of GPS coordinates within community i divided by the total number of GPS coordinates, and p_i is the area of each plant community (m^2) divided by the total area of the pasture (m^2). GPS coordinates for r_i were summed across all heifers in each RFI group to obtain a single E_i value for each RFI group. Table 2.1 presents a list of all variables used in analysis.

The Getis-Ord Gi* statistic was used for a hot spot analysis in ArcMap 10.4 to obtain a 20m × 20m raster of statistically significant "hot" or "cold" spots (Figure 2.3). This statistic calculates a z-score and P value for each raster cell based on spatial clustering. Thus a significance level can be assigned and for the present application, areas of use and avoidance within the pasture irrespective of plant communities can be identified.

RESULTS

GPS Performance

The GPS units in this research performed well. The fix rate averaged 91.3% which exceeded our expectations, but the battery life was not sufficient in each unit to collect 30 consecutive days of data. Future research using these units will make use of the power saving mode in attempt to increase battery life. Based on an accuracy test of 4,200 data points collected from 6 stationary GPS collars, the circular error of precision yielded a value of 4.01m, meaning 50% of data points are expected to lie within a circle with a radius of 4.01m (Sawaguchi et al. 2003).

Heifer Performance and Residual Feed Intake

Average mid-test BW of heifers irrespective of RFI class was 348 ± 42kg (mean ± SD). During the RFI test, heifers had an average dry matter intake of 9.33 ± 1.32kg, average daily gain (ADG) of 0.93 ± 0.18kg, and FCR of 10.35 ± 2.42kg (mean ± SD). Range of values were 271kg to 432 (mid-test BW), 6.39kg to 12.21kg (intake), 0.59kg to 1.25kg (ADG), 6.57 to 16.76 (FCR), and -2.19kg to 2.23kg (RFI). With regard to RFI, FCR differed significantly between the low-RFI and high-RFI in both classifications ($P<0.01$; Table 2.2; 2.3).

The linear regression model from which the feed intake residuals were derived is:

$$DMI = -0.928 + 0.105(BW^{0.75}) + 1.968(ADG)$$

where DMI is dry matter intake, $BW^{0.75}$ is metabolic body weight, and ADG is average daily gain (kg). The coefficient of determination (R^2) was 0.380 ($P<0.01$), which is much lower than that reported by Kelly et al. (2010), Basarab et al. (2011), and Durunna et al. (2012) in which R^2 for the regression of DMI on mid-test metabolic BW and ADG ranged from 0.66 to 0.80 in heifers, but was still greater than the R^2 of 0.24 reported in Lawrence et al. (2013). Expected intakes did not differ among RFI groups in either the conservative (P=0.79) or extreme classes (P=0.77), however, actual intakes did differ (conservative classification: P<0.01; extreme classification P<0.01); Table 2.2; 2.3).

Frame score (see Dolezal and Coe for score determination) did not differ among RFI group in either RFI class (Table 2.2; 2.3), but did differ between Angus and F1 heifers (4.78±0.15 versus 5.94±0.24 [mean±SE], respectively; P<0.01) (Table 2.4). The amount of time spent ruminating during the RFI test differed between the low-RFI and mid-RFI groups in the conservative class (478.67 minutes versus 523.85 minutes; P=0.04), but did not differ in the extreme class (P>0.98) or among breed (P>0.18). Time spent ruminating in the *Bromus spp.* dominated pasture did not differ among RFI groups in either RFI classificicication nor among breeds (conservative class: P>0.14; extreme class: P>0.87; breed: P>0.74).

Residual feed intake was not correlated with mid-test BW (r=0.00; P>0.99) nor ADG (r=0.00; P>0.99) (see Figure 2.2; Table 2.11), but was correlated with FCR (r=0.50; P<0.01). Feed conversion ratio was positively correlated with mid-test BW (r=0.45; P<0.01) and negatively correlated with ADG (r=-0.75; P<0.01) (Table 2.11).

Plant Communities

The non-metric multidimension scaling ordination results suggested combining the forb and sunflower communities due to similarities in species richness and abundance. Furthermore, crude protein levels were similar among the two communities (Table 2.5). Because of the extreme physiognomy differences between the two communities (Kenoyer 1929), it was deemed most suitable for the present scope of research to differentiate between the two, albeit primarily because of plant height, structure, and near monoculture composition. Forage biomass values in each plant community were very high relative to other tallgrass prairie sites (Briggs and Knapp 1995) due to the fertile Port series soil found at the research site. Port soils are very deep, well drained, have little run off and occur in narrow flood plains in Oklahoma (USDA 2004). Aside from the forb community, all other communities averaged in excess of 10,000kg^{-ha} (Table 2.5). Forage analysis results revealed the forb community had the highest average protein content at 8.19% and the yellow bluestem community had the lowest average at 4.65%. Total digestible nutrients (TDN) did not differ among communities ($P>0.05$) (Table 2.5). Cumulative species richness across all samples in each community ranged from 4 in the yellow bluestem community to 42 in the forb community. Likewise, the yellow bluestem community had the lowest Shannon-Wiener index of 0.17 and the forb community had the highest index of 2.47 (Table 2.5). Fifteen species composed the top five species across all six plant communities (Table 6.1; 6.2).

Plant Community Use

Results indicate preference for easily accessed areas that also coincide with grass dominated communities (Figure 2.3). Areas that did not have any recorded GPS coordinates are not included in the hot spot analysis. Furthermore, the majority of the area on the west side of the stream was sampled by heifers but ultimately avoided in preference of the greater forage availability and ease of water access on the east side of the stream (Figure 2.3). This analysis provides insight into the grazing preference of the entire herd and was not calculated with respect to RFI.

Ivlev's Electivity Index was used to rank preferential use of each plant community as well as the woody dominated areas that were not sampled using the aforementioned techniques in Materials and Methods. Woody areas were included in this analysis because of their importance in providing shade for thermoregulation. Because preference indices are most appropriately interpreted by rank order, only the rank of each plant community is presented (Table 2.7; 2.8) (Lechowicz 1982). Preferences were similar among groups within each RFI classification, as well as among breed. The Johnsongrass community was most preferred typically followed by the tallgrass community, while the forb, codominant, and woody plant communities were avoided (Table 2.7; 2.8). Correlations of performance measures and plant community electivity indicated a moderate positive relationship between BW and selection for the yellow bluestem community ($r=0.43$; $P<0.01$), which was the strongest correlation between any performance variable and distribution variable (Table 2.12).

Diet Quality and Selection

The diet quality of each RFI group within each classification did not differ ($P>0.38$) (Table 2.9). Little numeric differences were observed among RFI groups in either RFI class in regards to percent protein and digestible organic matter (DOM). Likewise, no differences were observed between the diets of Angus and F1 heifers (Table

2.10), except a trend for F1 heifers to select diets higher in DOM (*P*=0.07). A moderate positive correlation between selection for the sunflower community and dietary crude protein was detected (r=0.49; *P*<0.01) (Table 2.13).

A total of 137 plant families were detected in the feces, 76 of which are vascular flora found in Oklahoma. The remaining 61 families are non-vascular plants such as mosses or are likely pollen contaminants from other regions that were detected. The 10 families that provided the greatest amount of protein to each heifer's diet were compared and in order of abundance are Cornaceae (dogwoods), Poaceae (grasses), Fabaceae (peas), Anacardiaceae (sumacs), Aulacomniaceae (mosses), Polygalaceae (milkworts), Pinaceae (pines), Brassicaceae (mustards), Asteraceae (asters/composites), and Rosaceae (roses). Families 11 through 137 provided a cumulative 17.43% of protein in the diet. When proportion of family use was compared among RFI groups among conservatively classed heifers, no differences occurred except in the Brassicaceae (*P*=0.03) and Asteraceae (*P*=0.03) families. Low-RFI heifers had a greater proportion of protein in their diet supplied by the Brassicaceae family than mid-RFI heifers, and high-RFI heifers had a greater proportion of protein in their diet supplied by the Asteraceae family than mid-RFI heifers (see Figure 2.4). Among heifers in the extreme classification, only the Brassicaceae family differed (*P*<0.01) among RFI group, where low-RFI heifers selected Brassicaceae more than mid-RFI and high-RFI heifers (Figure 2.5). No differences in diet selection were found between Angus and F1 heifers (Figure 2.6).

DISCUSSION

GPS Performance

The 91.3% fix rate recorded by the GPS units was much greater than expected, and may be a result of using the i-gotU GT-600 rather than the i-gotUGT-120 used by Knight (2018a). When compared to the commercially available LOTEK® 3300, the Knight GPS units did not differ ($\alpha=0.05$) when calculating distance traveled, or average, maximum, and minimum values for elevation, distance from water, or slope. A significant difference between Knight units and LOTEK® units occurred between the fix rate (i.e. actual GPS coordinates recorded ÷ scheduled GPS coordinates) ($P<0.01$). The use of this GPS collar design proved to be effective for the needs of this research as the low cost allowed for sampling of each RFI tested heifer.

Heifer Performance and Residual Feed Intake

As expected, mid-test BW and ADG were similar (mid-test BW: $P>0.76$; ADG: $P>0.44$) among RFI groups in each RFI class. A review of the literature reveals this consistency, and the lower FCR of low-RFI heifers in each RFI class is also consistent with the literature (Arthur et al. 2001; Richardson et al. 2001; Carstens and Tedeschi 2006; Golden et al. 2008). The lower FCR of low-RFI heifers compared to high-RFI heifers should be expected as FCR is derived from DMI and ADG, and the similarity in ADG among the RFI groups leaves variation in FCR to be affected by variation in DMI.

The consistency of frame score among RFI groups suggests RFI is not influenced by frame score, which is consistent with the potential mechanisms by which RFI works (i.e. protein turnover, ion pumping, proton leakage, digestion, heat increment of feeding) as outlined in Herd et al. (2004). Likewise, the larger frames of the F1 heifers compared to purebred Angus heifers was expected with the results mirroring those reported in Arango et al.'s (2002) comparison of breed heights, weights, and body condition scores.

The rumination activity of a ruminant is typically considered an indicator of health and well being (Paudyal et al. 2018). Rumination activity is dependent upon many factors, such as dry matter intake, particle size, and feed quality, and affects rumen health by altering saliva production (NASEM 2016). In the present study, heifers in the conservative class low-RFI group had lower rumination times during the RFI test (P=0.04) compared to high-RFI heifers, but did not differ in the extreme class (P=0.98; Table 2.2; 2.3). Rumination time while grazing on *Bromus spp.* pasture did not differ among RFI group in either classification (conservative class: P=0.14; extreme class: P=0.87; Table 2.2; 2.3). Despite digestion being proposed as having a minor part (14%) in RFI variation among individuals (Herd et al. 2004), the variation in forage quality within a pasture may have a greater effect on ruminating behaviors of cattle despite wide variation in RFI (Table 2.2, 2.3).

Grazing Distribution

The distribution patterns expressed by heifers in this research is a composition of many factors. Perhaps the most important factor determining distribution was the light stocking rate of 0.49 $\text{AUM}^{\text{-ha}}$ versus maximum sustainable (assuming 25% harvest efficiency) rate of 3.57 $\text{AUM}^{\text{-ha}}$, which meant heifers did not have to travel far or traverse the entire pasture to acquire adequate forage to meet daily needs. Thus the light stocking rate is likely responsible for the avoidance of the west half of the pasture (Figure 2.3) where forages were not easily accessible. Also of interest is the indifference of the area around the centrally located pond as indicated by the hot spot analysis in Figure 2.3.

Although water is an attractant for livestock (Ganskopp 2001), areas indicated as hot spots in the present study all had water sources within close proximity. The only exception is the hot spot in the east central portion of the pasture. Although the pond would have been the closest water source to heifers in this area, there is no easy path of direct travel to the pond. The presence of a flat two-track road along the east fenceline may therefore have been a preferred travel route to the stock tank as a water source despite the stock tank being farther away than the pond.

Rank order preference of the Ivlev Electivity Index for each plant community suggest cattle prefer spending time in grass dominated sites (Table 2.7; 2.8). Aside from the sunflower community that had minor preference, communities with a major forb and woody plant component were avoided. Although this seems to contradict the diet quality results that indicate cattle select diets of higher quality (i.e. protein content) than grass dominated sites allow, it is most probable that the heifers in this study were spending most of their time grazing in grass dominated sites. By spending only a limited time in forb and woody plant communities, the Ivlev results make it appear that heifers were avoiding those sites. In reality, heifers may have only selected those sites for short duration trips for the sole purpose of protein acquisition.

Diet Quality and Selection

Grass dominated sites in the southern Great Plains typically decrease in quality as they mature (Holechek 2011). At the time of sampling (mid September), the tallgrass plant community had 5.0% protein on average. When fecal samples were collected, heifers weighed on average 435kg and were in their first trimester of pregnancy. For continued growth and maturity, it is recommended that heifers at this stage receive at least 8.5% protein in their diet (Lalman and Richards). The level of protein intake observed by the heifers in this study suggest the heifers are selecting high protein forbs and/or browse (Figure 2.4; 2.5; 2.6). Of the plant communities sampled, only communities with a significant forb or browse component could provide protein quantities high enough to mitigate the low levels of grass dominated sites. It is not surprising then that Cornaceae, Fabaceae, Brassicaceae, Polygalaceae, Asteraceae, and Rosaceae provided 53.9% of protein within the heifer's diets. When diet quality results (Table 2.9; 2.10) are paired with the diet selection results (Figure 2.4; 2.5; 2.6) heifers were likely consuming protein dense Cornaceae and forb species at levels high enough to augment an otherwise low protein diet. Despite not sampling the woody vegetation near the stream, it is most likely heifers were selecting roughleaf dogwood (*Cornus drummondii* [C. A. Mey.]) from this area. Although roughleaf dogwood was detected in the codominant, forb, and Johnsongrass communities, its abundance within these communities is not great enough to presume heifers were encountering it often enough to provide the levels of protein reported (Table 2.9; 2.10). Wei et al. (2019) reported Angus heifers fed a grain diet with red osier dogwood (ROD; *Cornus sericea*) had greater protein and fiber digestibility than heifers fed the same diet without ROD. In addition, Wei et al. (2019) suggest ROD has the ability to improve immune system status and antioxidant activity. Because the distribution of protein intake in the Cornaceae family was non-normal, it is expected that a few heifers consumed extremely high quantities of roughleaf dogwood. In light of Wei et al. (2019), heifers that consumed high quanities of dogwood may have been self-medicating.

Ruminants are known to selectively graze areas with high protein concentrations and these results further support the idea that cattle are capable of sensing the nutritional value of forages via postingestive feedback (Bailey 1995; Provenza 1995). Furthermore, Atwood et al. (2001) reported calves provided free-choice rations selected diets that met their nutritional needs, despite no two calves selecting the same quantities of each ingredient. Atwood et al. (2001) concluded animals can more efficiently meet their own nutritional needs when offered free-choice. The results from the present study reflect Atwood et al. (2001); within each of the 10 plant families reported (Figure 2.4; 2.5; 2.6), the standard deviation of the quantity of protein provided by each family was high, indicating individuals were selecting families at vastly different levels (Note: error bars in Figure 2.4; 2.5; 2.6 are standard error not standard deviation). When compared with the diet quality of each RFI group (Table 2.9), results indicate very similar diets overall (percent crude protein: $P>0.60$; percent digestible organic matter: $P>0.38$), meaning heifers were capable of selecting diets of similar quality despite being composed of different ingredients (i.e. plant families).

The diet selection results reveal a surprising trend in the use of multiple plant families. Rather than heifers consuming similar quantities of each plant family, the non-normal distribution of protein acquisition suggests that within each family many heifers consumed small quantities of that family, but a few individuals consumed very high quantities of that family. It is remarkable then that average dietary protein levels were so similar considering the wide variation in plant family use for protein acquisition. From a livestock production point of view, these results indicate a diversity of available forages will be utilized by cattle and will ultimately provide cattle with nutrients that a grass dominated site could not. Past research indicates the spatial behavior of cattle has the potential to influence diet selection, nutrient uptake, and efficiency of forage utilization (Senft et al. 1983). Based on the recorded GPS locations for heifers in this study, it is appropriate to state that heifers sampled the entire pasture. Thus their spatial distribution after sampling available resources suggests the hot spots indicated in Figure 3 were areas in which nutrient uptake and forage utilization could be maximized. Also, the influence of social structure could be the most prevalent source of distribution and subsequent diet selection patterns compared to RFI. Because the social behavior of cattle may be as important as environmental influences on cattle dispersion (Senft et al. 1983), the small sub-groups made of 4-8 individuals observed could have had a greater influence on any one individual's distribution than the effect of RFI alone.

It is important to consider the influence of sampling time with respect to forage and diet quality. Forages were clipped for analysis at the beginning of the research period to obtain biomass values prior to grazing. Subsamples of the clipped herbage was then submitted for nutrient analysis and therefore represent the quality of the forages during the middle of September. Fecal samples from which the diet quality data were derived were collected 30 days later in October and are indicative only of the diet consumed between three and five days prior. Because forage quality decreases as plants senesce, it is expected that the nutritional quality of the plant communities at the time of fecal sampling was even lower than the values obtained from September samples.

Conclusion

A primary challenge faced by range managers is successfully achieving land management objectives while considering complex and dynamic cattle behaviors

(Launchbaugh and Howery 2005). This study supports the strong body of literature that cattle selectively graze areas that have abundant, nutritious forage, and where cattle have easy access to water. Although cattle behaviors are indeed dynamic, cattle can also be very consistent in exhibiting these behaviors. The grazing distribution of the heifers in this study reveals patterns of use and avoidance of multiple areas within the pasture. The repeated use of certain areas deemed hot spots is consistent with previous research in which cattle selectively graze areas repeatedly and make use of more nutritious regrowth (Ganskopp and Bohnert 2006). Based on diet quality and selection results, heifers in this study were selecting forages based on nutrient profile and were not limited to only grass intake. These results provide support for range management and livestock production strategies that allow for a diverse plant community and do not restrict grazing by aggressively rotating, therefore allowing individuals to select the most nutritious diet. In doing so, individual animal production is improved (Ash and Smith 1996) and the overall health of the rangeland system is maintained through a diversity of plants and dependent wildlife. These results indicate RFI determined in a drylot environment has little to no effect on grazing distribution, diet quality, or diet selection of beef heifers.

TABLES

Table 2.1. List of performance and grazing distribution variables measured on 38 Angus and 5 Brahman × Angus (F1) heifers in a 69.4ha pasture near El Reno, OK.

Category	No.	Variable	Units	Formula
GPS performance	1	Fix rate	%	((collected GPS fixes) ÷ (scheduled GPS fixes))*100
	2	Elevation records	m	
Heifer performance	1	Birth weight	kg	
	2	205-d wean weight	kg	
	3	Mid-test BW (Apr. 2017)	kg	
	4	BW (Oct. 2018)	kg	
	5	Average daily gain	kg^{-d}	(end BW - start BW) ÷ no. of days
	6	Residual feed intake	kg^{-d}	Regression residuals: DMI = -0.928 + 0.105(BW0.75) + 1.968(ADG)
	7	Feed conversion ratio	ratio	Actual intake ÷ ADG
	8	Body condition score (post calving)		Scale 1-9; 1=emaciated, 9=obese
	9	Frame score		see Dolezal and Coe
	10	Calving date	Julian day	
	11	Rumination time (RFI test)	min^{-d}	Average for each heifer
	12	Rumination time (pasture)	min^{-d}	Average for each heifer
Distribution	1	Hot spot analysis		Optimized hot spot analysis, ArcMap10.4
	2	Rank order selection	Rank of Ivlev's electivity index	$E_i=(r_i-P_i)/(r_i+P_i)$
Plant community	3	Biomass	kg^{-ha}	Average for each plant community
	4	Crude protein	%	Average for each plant community
	5	Total digestible nutrients	%	Average for each plant community
	6	Species richness		Sum for each plant community
	7	Shannon-Wiener diversity index		$\mathrm{H}' = -\sum_{i=1}^{s} p_i \ln p_i$
Diet quality	8	Crude protein	%	Average for each RFI group
	9	Digestible organic matter	%	Average for each RFI group
Diet selection	10	Plant family	%	Top 10 families presented

Table 2.2. Means of performance and efficiency variables of beef heifers classified in RFI groups. Group membership of heifers were determined using the mean RFI ± 0.5SD for the conservative class.

	RFI Classification: Conservative[1]						
Measurement[2]	Low-RFI	SE	Mid-RFI	SE	High-RFI	SE	*P*
Birth weight, spring 2016 (kg)	38.10	2.07	34.16	1.62	36.58	3.43	0.43
205-day adj. weaning weight (kg)	190.29	10.90	206.16	7.03	185.15	16.47	0.32
RFI Mid-test BW, Apr. 2017 (kg)	345.08	11.68	352.96	9.51	342.94	13.84	0.79
BW, Oct. 2017 (kg)	441.16	11.87	441.81	9.80	423.13	15.47	0.51
Actual intake, RFI test (kg^{-d})	8.18^{a}	0.26	9.35^{b}	0.19	10.57^{c}	0.41	<0.01
Expected intake, RFI test (kg^{-d})	9.62	0.25	9.79	0.20	9.58	0.29	0.79
Average daily gain, RFI test (kg^{-d})	0.92	0.05	0.97	0.04	0.88	0.06	0.44
Residual feed intake (kg^{-d})	-1.07^{a}	0.15	-0.14^{b}	0.06	1.43^{c}	0.21	<0.01
Feed conversion ratio, RFI test	9.31^{a}	0.72	9.91^{a}	0.39	12.29^{b}	0.74	<0.01
Rumination time, RFI test (min^{-d})	478.67^{a}	13.25	523.85^{b}	11.26	506.09^{ab}	10.89	0.04
Rumination time, pasture (min^{-d})	486.67	10.67	515.15	10.24	500.64	7.02	0.14
Frame score, RFI test	4.84	0.36	5.09	0.13	4.69	0.34	0.50
Body condition score, post calving	6.09	0.09	6.04	0.09	6.00	0.00	0.78

[1] Sample size: Low-RFI=12; Mid-RFI=20; High-RFI=11

[2] Least squares means with different letter superscripts differ ($P < 0.05$)

Table 2.3. Means of performance and efficiency variables of beef heifers classified in RFI groups. Group membership of heifers were determined using the mean RFI ± 1SD for the extreme class.

	RFI Classification: Extreme[2]						
Variable[1]	Low-RFI	SE	Mid-RFI	SE	High-RFI	SE	*P*
Birth weight, spring 2016 (kg)	35.74	3.32	35.09	1.33	39.47	4.91	0.47
205-day adj. weaning weight (kg)	176.36	8.78	199.95	7.44	194.72	17.29	0.48
RFI Mid-test BW, Apr. 2017 (kg)	335.39	14.28	350.66	8.02	346.42	14.94	0.76
BW, Oct. 2017 (kg)	416.95	11.66	443.66	8.38	420.88	16.11	0.28
Actual intake, RFI test (kg^{-d})	7.43^{a}	0.27	9.23^{b}	0.17	11.13^{c}	0.35	<0.01
Expected intake, RFI test (kg^{-d})	9.43	0.30	9.74	0.17	9.65	0.32	0.77
Average daily gain, RFI test (kg^{-d})	0.87	0.09	0.95	0.03	0.91	0.07	0.60
Residual feed intake (kg^{-d})	-1.55^{a}	0.17	-0.17^{b}	0.08	1.88^{c}	0.13	<0.01
Feed conversion ratio, RFI test	8.82^{a}	0.78	10.06^{a}	0.38	12.73^{b}	1.06	0.01
Rumination time, RFI test (min^{-d})	502.60	27.83	507.35	8.82	506.71	16.80	0.98
Rumination time, pasture (min^{-d})	500.40	13.21	505.42	7.90	497.14	10.38	0.87
Frame score, RFI test	4.48	0.08	4.99	0.18	4.89	0.37	0.54
Body condition score, post calving	6.00	0.00	6.06	0.06	6.00	0.00	0.87

[1] Least squares means with different letter superscripts differ ($P < 0.05$)

[2] Sample size: Low-RFI=5; Mid-RFI=31; High-RFI=7

Table 2.4. Means of performance and efficiency variables of Angus and Brahman × Angus (F1) heifers.

	Breed[2]				
Variable[1]	Angus	SE	F1	SE	*P*
Birth weight, spring 2016 (kg)	33.92^{a}	0.99	50.71^{b}	4.20	<0.01
205-day adj. weaning weight (kg)	197.60	6.53	186.88	19.51	0.58
RFI Mid-test BW, Apr. 2017 (kg)	349.77	7.11	336.21	11.13	0.51
BW, Oct. 2017 (kg)	433.32	7.40	463.67	12.55	0.16
Actual intake, RFI test (kg^{-d})	9.34	0.22	9.25	0.52	0.88
Expected intake, RFI test (kg^{-d})	9.72	0.15	9.44	0.24	0.52
Average daily gain, RFI test (kg^{-d})	0.92	0.03	1.00	0.06	0.36
Residual feed intake (kg^{-d})	0.00	0.17	-0.01	0.58	0.98
Feed conversion ratio, RFI test	10.49	0.41	9.25	0.25	0.29
Rumination time, RFI test (min^{-d})	510.34	7.95	479.00	18.09	0.18
Rumination time, pasture (min^{-d})	502.74	6.70	509.20	12.76	0.74
Frame score, RFI test	4.78^{a}	0.15	5.94^{b}	0.24	<0.01
Body condition score, post calving	6.05	0.05	6.00	0.00	0.75

[1] Least squares means within the same row with different superscripts differ (*P* <0.05)

[2] Sample size: Angus=38; F1=5

Table 2.5. Descriptors for the six herbaceous plant communities found in a native rangeland pasture near El Reno, OK. The wooded plant community (27.89ha) was not measured and therefore is not included. Water accounted for an area of 2.55ha.

Plant Community	Sample size	Area (ha)	Biomass (kg^{-ha})		Crude Protein (%)		TDN (%)		Species Richness	Shannon-Wiener Diversity Index
			Mean	SE	Mean	SE	Mean	SE		
Tallgrass	19	20.31	10,423.90	1,160.21	5.04^{c}	0.21	52.42	1.55	35	1.63
Codominant	20	1.80	10,610.71	1,119.28	5.56^{bc}	0.28	52.59	0.58	37	2.39
Forb	15	7.33	9,112.51	1,516.33	8.19^{a}	0.39	54.46	1.12	42	2.47
Sunflower	15	6.63	14,989.50	2,302.87	7.28^{ab}	0.68	53.66	1.57	8	0.39
Johnsongrass	16	2.86	12,837.47	1,379.01	5.55^{bc}	0.35	52.24	0.68	22	0.83
Yellow bluestem	5	0.02	15,280.92	1,780.63	4.65^{c}	0.48	53.57	0.30	4	0.17

Significant differences ($P < 0.05$) within columns are indicated by different letters

Table 2.6.1. The top five most abundant species in each plant community and the cumulative proportion of abundance within each community that the five species compose. Palatability ranking is based on cattle preference listed by source. See next page for remaining section of the table.

	% Abundance by Plant Community							
Species	Tallgrass	Codominant	Forb	Johnsongrass	Sunflower	Yellow bluestem	Palatability[1]	Source[2]
Big bluestem (*Andropogon gerardii*)	55.48	18.58	20.18	8.17		3.43	1	1
Little bluestem (*Schizachyrium scoparium*)	14.80					0.10	2	1
Tall dropseed (*Sporobolus compositus*)	10.20						3	1
Switchgrass (*Panicum virgatum*)	4.69			2.48			1	1
Indiangrass (*Sorghastrum nutans*)	3.85	12.71				0.10	1	1
American germander (*Teucrium canadense*)		16.64	19.41				4	1
Ironweed (*Vernonia baldwinii*)		12.27					5	2
White sage (*Artemesia ludoviciana*)		12.24					4	2

--Continued on next page--

Table 2.6.2. The top five most abundant species in each plant community and the cumulative proportion of abundance within each community that the five species compose. Palatability ranking is based on cattle preference listed by source. See previous page for previous section of the table.

--Continued from previous page--

	% Abundance by Plant Community							
Species	Tallgrass	Codominant	Forb	Johnsongrass	Sunflower	Yellow bluestem	Palatability[1]	Source[2]
Maximillian sunflower (*Helianthus maximiliani*)			13.49				4	2
Annual sunflower (*Helianthus annuus*)			11.16	3.11	91.10		3	2
Canada goldenrod (*Solidago canadensis*)			7.53	1.16	0.31		3	1
Johnsongrass (*Sorghum halepense*)				81.24	6.41		1	2
Virginia wildrye (*Elymus virginicus*)					1.06		1	1
Giant ragweed (*Ambrosia trifida*)					0.61		4	2
Yellow bluestem (*Bothriochloa ischaemum*)						96.37	1	1
Cumulative %	89.02	72.44	71.76	96.17	99.49	100.00		

[1] Legend: 1) Preferred; 2) Good; 3) Fair; 4) Poor; 5) Avoided

[2] Source: 1) Natural Resources Conservation Service Plant Fact Sheet; 2) Tyrl et al. 2008

Table 2.7. The rank order according to Ivlev’s electivity index, *E*, of each plant community selected by heifers in two RFI classes and three groups. Plant communities are ordered by average preference and color coded for ease of comparison. High rank values indicate preference whereas low rank values indicate avoidance. Avoidance (*E*<0) was first detected in the forb community for each RFI class and group.

	Conservative Classification			Extreme Classification			
Plant Community	Low-RFI	Mid-RFI	High-RFI	Low-RFI	Mid-RFI	High-RFI	Legend
Johnsongrass	1	1	1	1	1	1	1: Preferred
Tallgrass	2	3	2	2	2	2	2
Yellow bluestem	4	2	4	4	3	3	3
Sunflower	3	4	3	3	4	4	4
Forb	5	5	5	5	5	5	5
Codominant	6	6	6	6	6	6	6
Woody	7	7	7	7	7	7	7: Avoided

Table 2.8. The rank order according to Ivlev's electivity index, *E*, of each plant community selected by Angus and Brahman × Angus (F1) heifers. Plant communities are listed in same order as Table 2.7 and are color coded for ease of comparison. High rank values indicate preference whereas low rank values indicate avoidance. Avoidance ($E<0$) was first detected in the forb community for each breed.

	Breed		
Plant Community	Angus	F1	Legend
Johnsongrass	1	1	1: Preferred
Tallgrass	2	2	2
Yellow bluestem	4	3	3
Sunflower	3	4	4
Forb	5	5	5
Codominant	6	6	6
Woody	7	7	7: Avoided

Table 2.9. Mean diet quality of beef heifers by RFI classification and group.

		Low-RFI		Mid-RFI		High-RFI		
Quality[1]	RFI Class[2,3]	Mean	SE	Mean	SE	Mean	SE	*P*
% Protein	Conservative Class	6.26	0.26	6.24	0.24	6.23	0.23	>0.99
	Extreme Class	5.84	0.49	6.32	0.17	6.15	0.32	0.60
% DOM	Conservative Class	56.48	0.88	57.00	0.24	57.49	0.26	0.38
	Extreme Class	56.88	0.12	56.98	0.34	57.06	0.22	0.99

[1] Least squares means within rows with different letter superscripts differ ($P<0.05$)

[2] Sample size: Class 1, Low-RFI=11; Mid-RFI=19; High-RFI=10

[3] Sample size: Class 2, Low-RFI=4; Mid-RFI=30; High-RFI=6

Table 2.10. Mean diet quality of Angus and Brahman × Angus (F1) heifers.

	Angus[2]		F1		
Quality[1]	Mean	SE	Mean	SE	*P*
% Protein	6.27	0.16	6.06	0.68	0.66
% DOM	57.16	0.12	55.75	4.39	0.07

[1] Least squares means within rows with different letter superscripts differ (*P* <0.05)

[2] Sample size: Angus=35; F1=5

Table 2.11. Pearson correlation coefficients for all pair-wise associations among performance variables measured on 38 Angus and 5 Brahman × Angus (F1) heifers.

	Mid-test BW	Intake	ADG	FCR	Rumination time (RFI test)	Rumination time (pasture)	Frame score	Calving date	Heifer 205-d wean wt.
RFI	0.00	0.79†	0.00	0.50†	0.14	0.06	0.02	-0.04	0.02
Mid-test BW (Apr. 2017)		0.56†	-0.09	0.45†	0.04	0.12	0.53†	0.06	0.75†
Intake			0.22	0.45†	0.19	0.23	0.34*	-0.08	0.45†
ADG				-0.75†	0.23	0.41†	0.05	-0.32	0.00
FCR					-0.06	-0.21	0.15	0.27	0.28
Rumination time (RFI test)						0.75†	0.14	-0.09	0.15
Rumination time (pasture)							0.28	-0.13	0.14
Frame score								0.19	0.65†
Calving date									0.08

† indicates significance at $P < 0.01$

* indicates significance at $P < 0.05$

P values were not adjusted for multiple comparisons, therefore statistical significance must be interpreted with caution

Table 2.12. Pearson correlation coefficients for all pair-wise associations among performance and distribution and diet selection variables measured on 38 Angus and 5 Brahman × Angus (F1) heifers.

		Distribution and Diet Selection								
		Plant Community Electivity								
		Tallgrass	Forb	Codominant	Sunflower	Johnsongrass	Yellow bluestem	Wooded	Dietary CP	Dietary DOM
Performance	RFI	0.02	-0.14	0.01	-0.13	0.09	0.09	0.05	-0.06	0.16
	BW (Oct. 2017)	0.22	-0.06	-0.09	-0.16	-0.16	0.43†	0.00	-0.08	-0.34*
	Intake	0.23	-0.11	-0.03	-0.27	-0.11	0.35*	-0.03	-0.15	-0.04
	ADG	-0.10	0.13	0.02	0.07	0.05	0.21	0.05	-0.04	-0.14
	FCR	0.24	-0.19	-0.04	-0.25	-0.12	0.01	-0.04	-0.03	0.08
	Rumination time (RFI test)	0.00	-0.08	0.01	-0.22	0.06	0.00	0.16	-0.21	-0.07
	Rumination time (pasture)	-0.14	0.03	-0.07	-0.03	0.10	0.07	0.24	-0.22	-0.28
	Frame score	0.05	-0.01	0.08	-0.18	-0.08	0.39*	0.17	-0.21	-0.24
	Calving date	-0.27	-0.39*	-0.29	-0.02	0.30	-0.22	0.38*	-0.18	-0.25
	Heifer 205-day wean wt.	0.13	0.04	0.08	-0.23	-0.18	0.40*	0.05	-0.09	-0.24

† indicates significance at *P* <0.01

* indicates significance at *P* <0.05

P values were not adjusted for multiple comparisons, therefore statistical significance must be interpreted with caution

Table 2.13. Pearson correlation coefficients for all pair-wise associations among distribution variables measured on 38 Angus and 5 Brahman × Angus heifers (F1).

		Plant Community Electivity							
		Forb	Codominant	Sunflower	Johnsongrass	Yellow bluestem	Wooded	Dietary CP	Dietary DOM
Plant Community Electivity	Tallgrass	-0.26	0.31*	$-0.48^{\dagger}$	$-0.67^{\dagger}$	0.06	$-0.74^{\dagger}$	-0.20	-0.17
	Forb		$0.48^{\dagger}$	0.16	-0.34*	-0.19	0.06	0.12	0.01
	Codominant			-0.20	$-0.48^{\dagger}$	-0.28	-0.35*	-0.21	-0.06
	Sunflower				0.11	-0.15	0.30	$0.49^{\dagger}$	0.19
	Johnsongrass					0.24	0.34*	0.05	0.12
	Yellow bluestem						-0.02	0.15	0.10
	Wooded							0.06	0.05
	Dietary CP								0.38*

† indicates significance at $P < 0.01$

* indicates significance at $P < 0.05$

P values were not adjusted for multiple comparisons, therefore statistical significance must be interpreted with caution

FIGURES

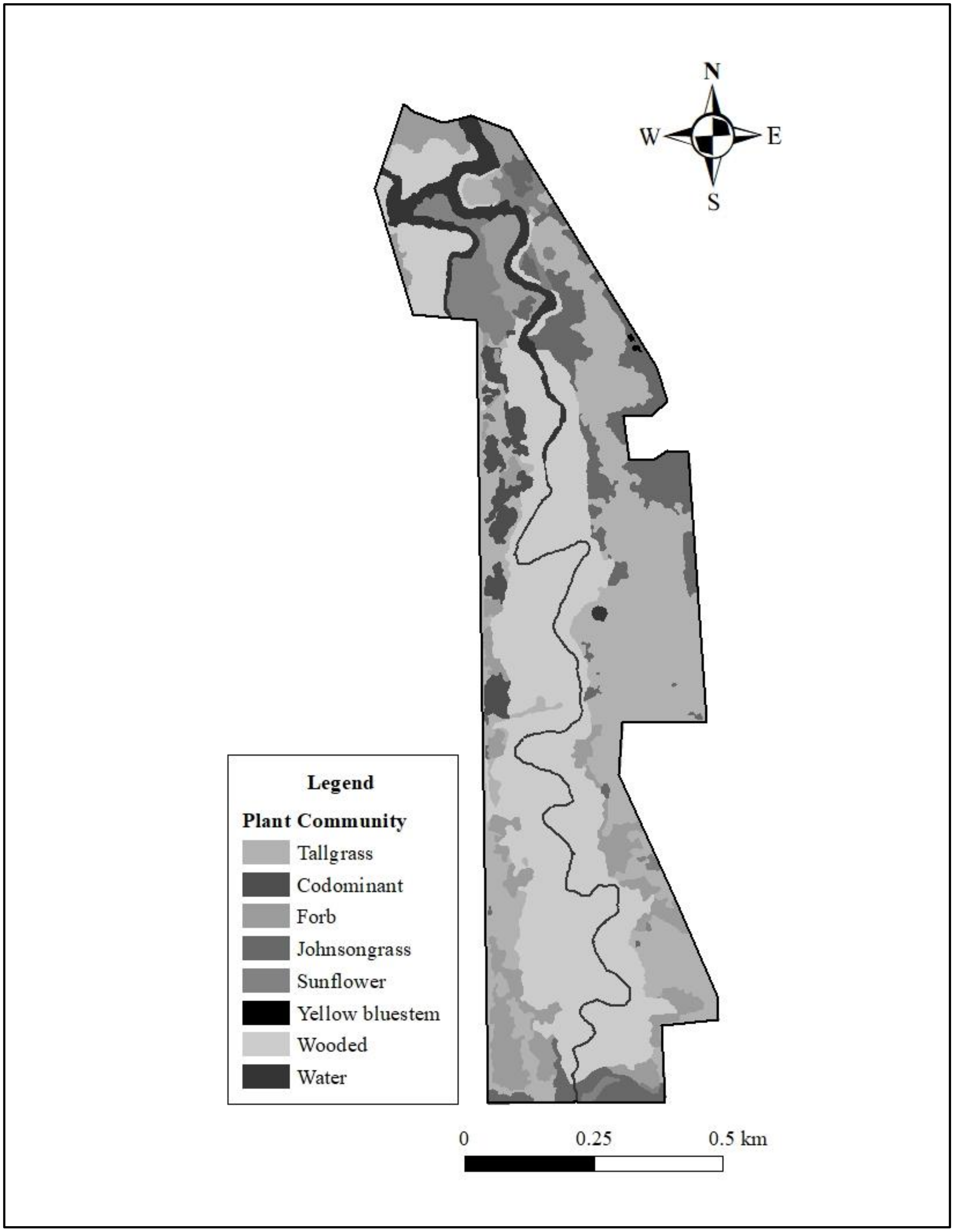

Figure 2.1. Map of study site showing various plant communities and water sources. Due to scale, the water tank 0.35km northeast of the pond is not visible. Total area is 69.4ha.

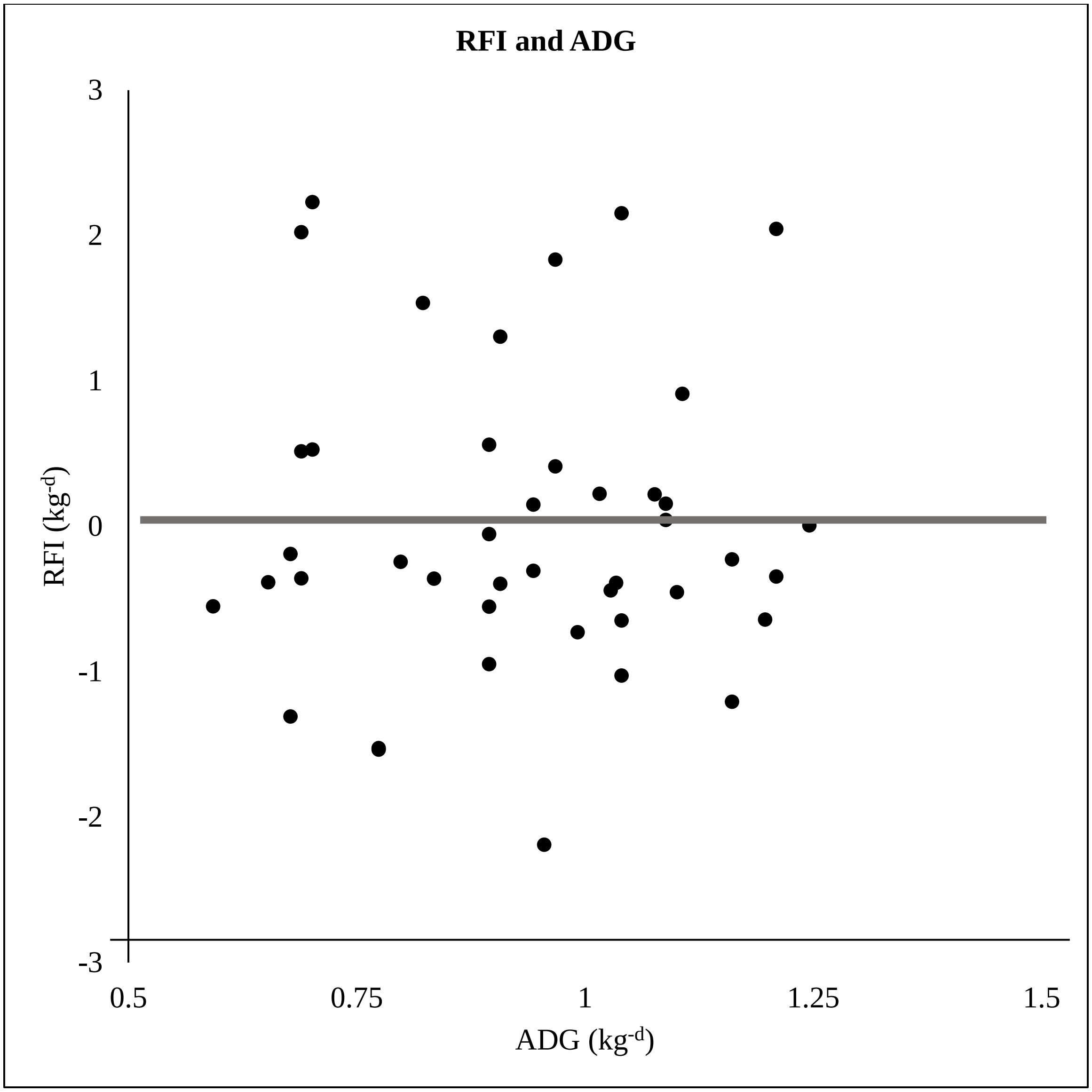

Figure 2.2. Residual feed intake and average daily gain of 43 beef heifers during RFI testing period. The lack of correlation (r=0.00) between RFI and ADG is evident in the figure above. A grey reference line is drawn at 0kg RFI. For additional performance correlations, see Table 2.11.

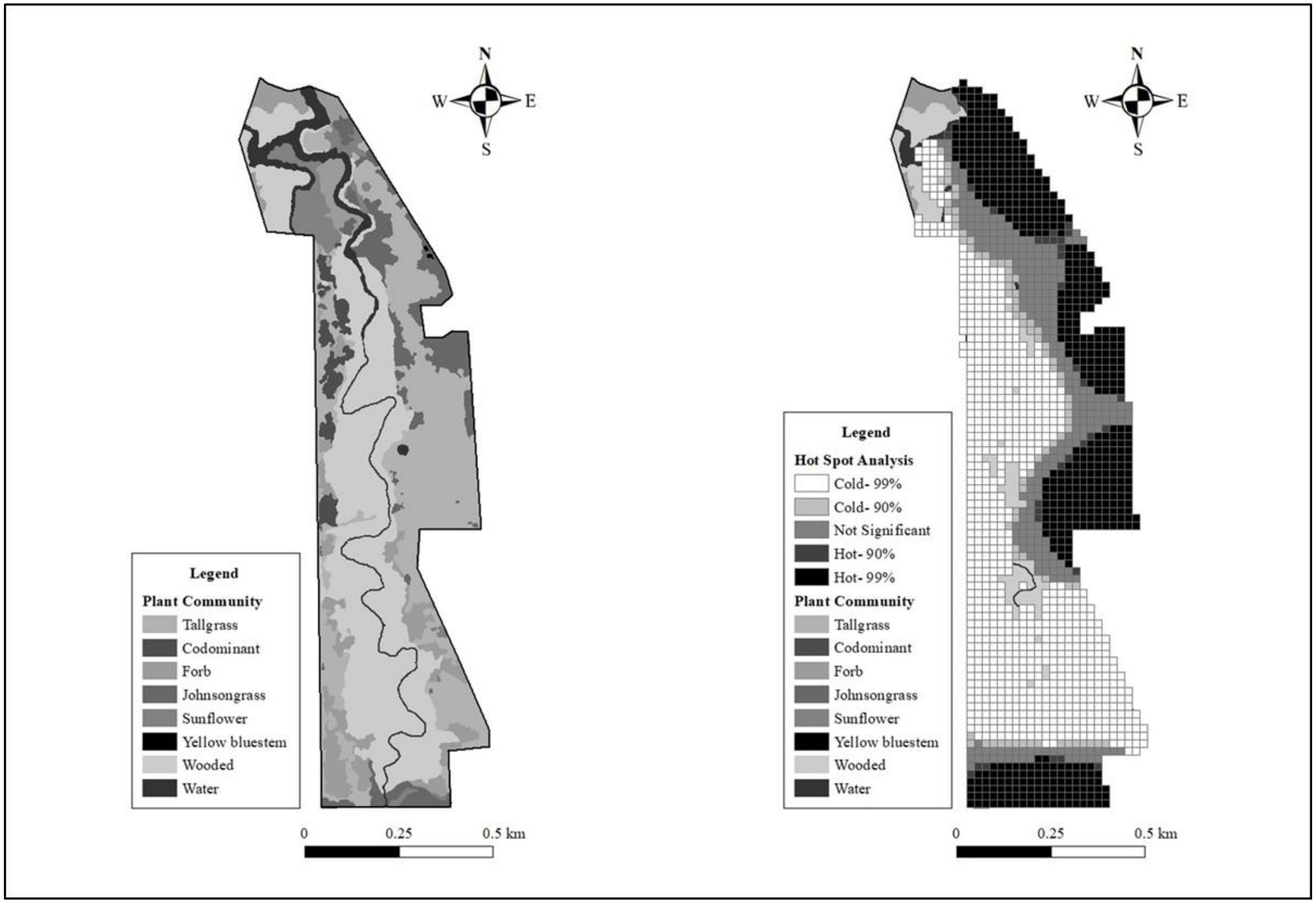

Figure 2.3. An Optimized Hot Spot Analysis (Getis-Ord Gi*) raster overlayed on the plant communities presented in Figure 2.1. Hot spots are represented by black cells whereas cold spot cells are represented by white cells. Grey cells are areas where there was neither selection nor avoidance, and areas without cell color had no GPS data. Cell size is 20m × 20m.

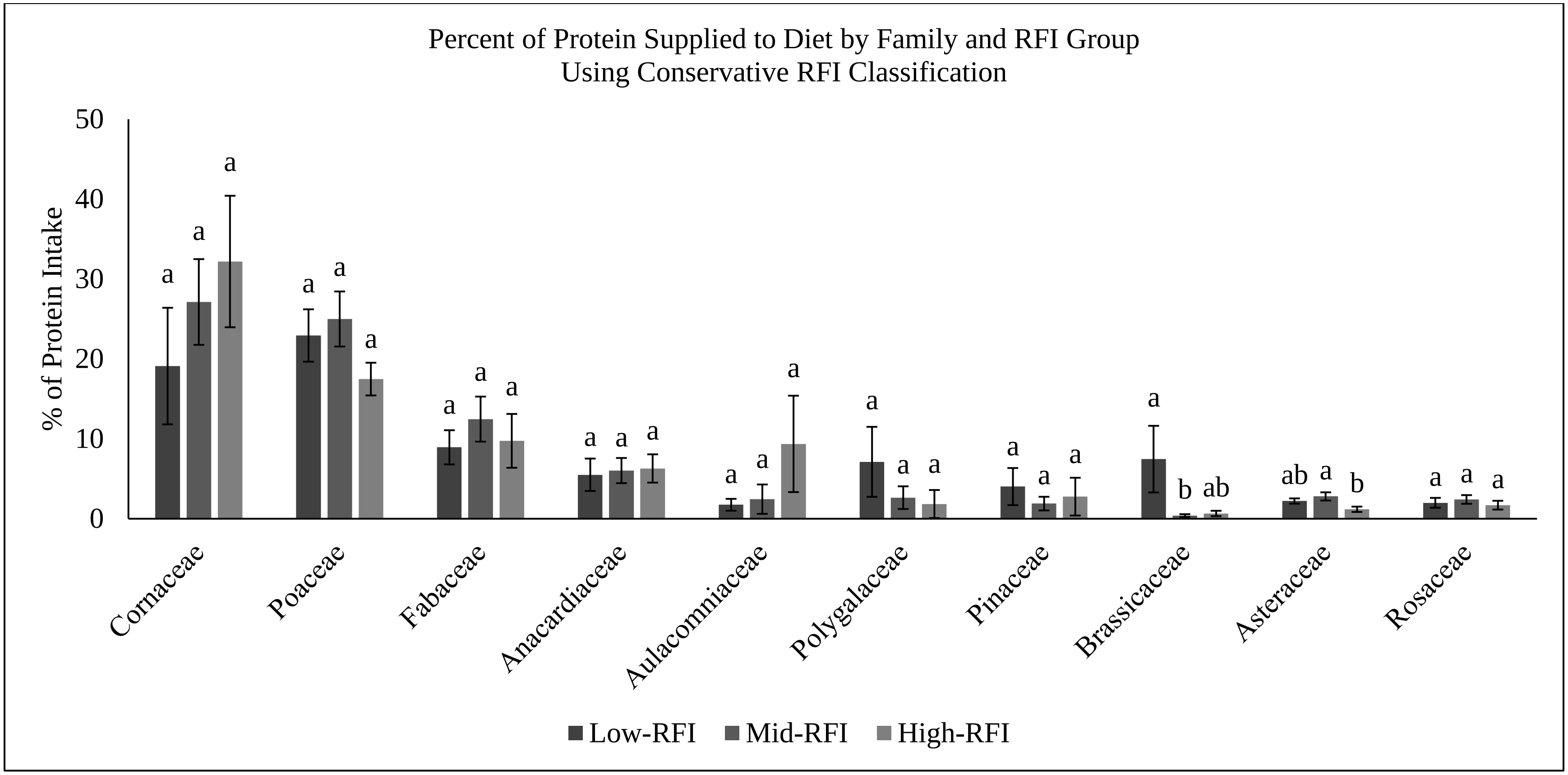

Figure 2.4. The average proportion of protein supplied to the heifer's diets by the ten most selected plant families for each RFI group in the conservative class. Percentage values of each plant family should not be interpreted as the amount of biomass afforded to the diet by each family. Error bars represent standard error. Bars with different letters within the same family are significantly different (*P*<0.05).

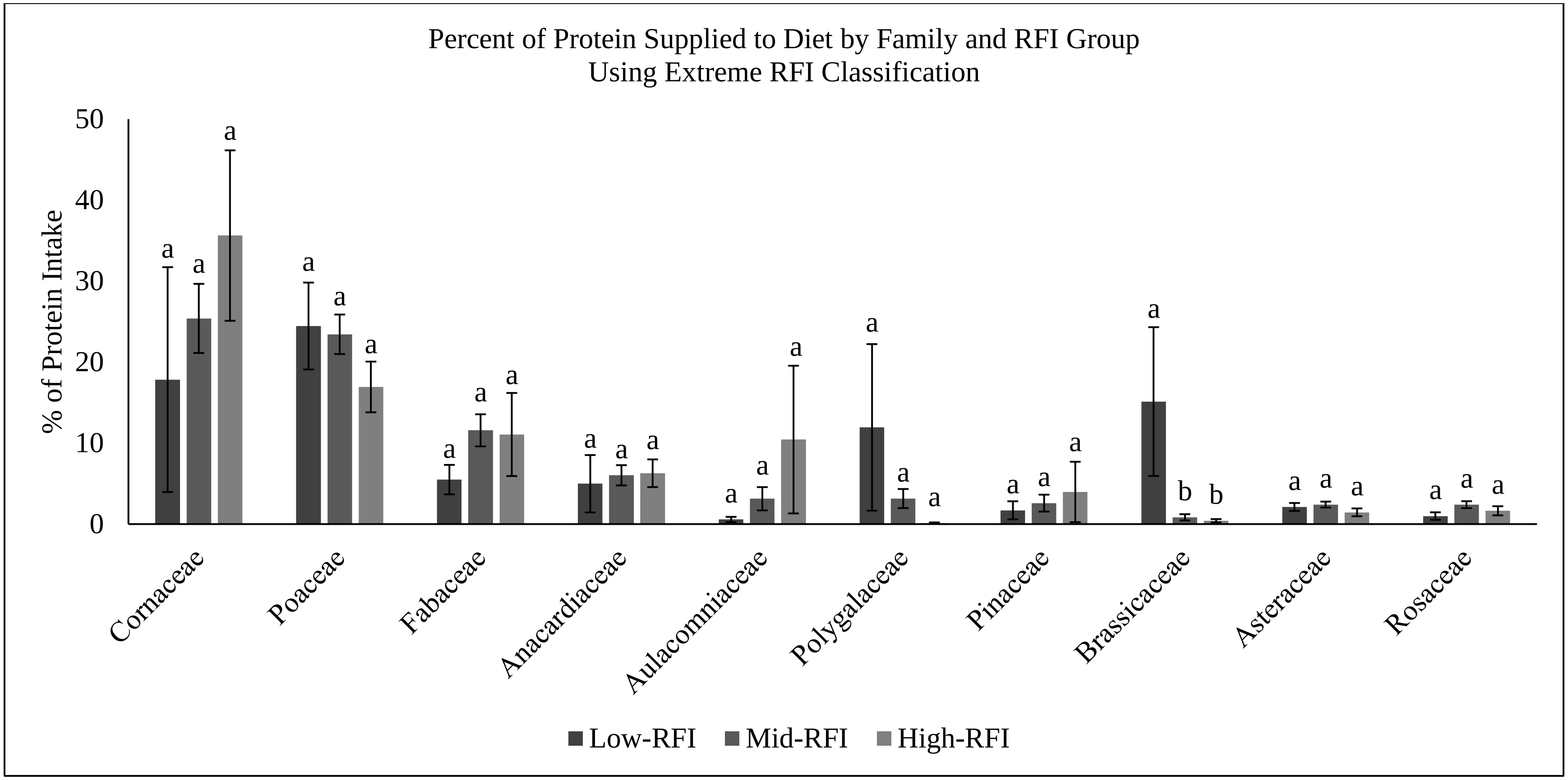

Figure 2.5. The average proportion of protein supplied to the heifer's diets by the ten most selected plant families for each RFI group in the extreme class. Percentage values of each plant family should not be interpreted as the amount of biomass afforded to the diet by each family. Error bars represent standard error. Bars with different letters within the same family are significantly different (*P*<0.05).

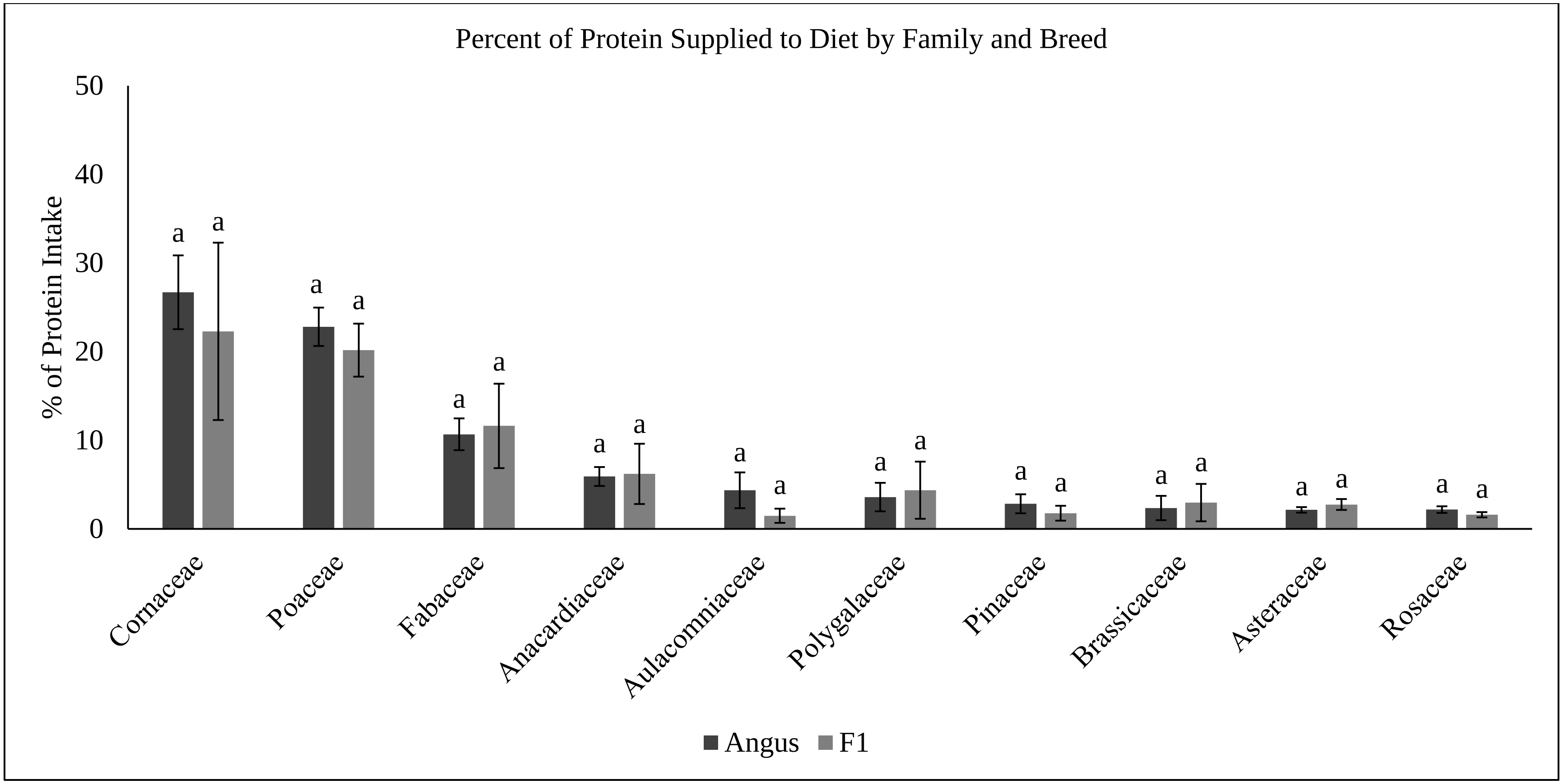

Figure 2.6. The average proportion of protein supplied to the heifer's diets by the ten most selected plant families for each breed. Percentage values of each plant family should not be interpreted as the amount of biomass afforded to the diet by each family. Error bars represent standard error. Bars with different letters within the same family are significantly different (*P*<0.05).

CHAPTER III

THE EFFECT OF RESIDUAL FEED INTAKE ON ANGUS HEIFER GRAZING DISTRIBUTION AND BEHAVIOR

ABSTRACT

While the beef cattle industry historically used performance traits as selection criteria for bull and replacement cow selection, now feed efficiency, specifically residual feed intake, is increasingly important. The selection against residual feed intake (RFI), i.e. for greater feed efficiency, has decreased dry matter intake without affecting mature body weight or gain, all while improving feed conversion ratio. Currently, behaviors influenced by RFI have been measured in confined environments. Our objective is to identify the relationships between RFI and grazing distribution variables in an extensive management environment. Thirty-eight Angus and five Brahman × Angus heifers were tracked for 30 days with GPS units. Two classification criteria for RFI grouping was used based on mean RFI ± 0.5SD (conservative class) and mean RFI ±1SD (extreme class). Body weight and average daily gain did not differ among heifers grouped as low-RFI (efficient), mid-RFI (average efficiency), or high-RFI (inefficient) ($P>0.05$). In the conservative RFI class, spatial search pattern and only one of four distance travelled measures differed among RFI groups (spatial search pattern: $P=0.01$; midnight to sunrise distance travelled: *P*=0.04), but area explored, shade use, water use, and slope use were similar among RFI group (*P*>0.05). Behavior differences were not observed among heifers in the extreme RFI class. Within RFI group, low-RFI heifers tended to have greater variability within each distribution and behavior measure. Among performance, behavior, and distribution, significant but weak correlations were observed. Breed differences were observed in distance travelled measures and area explored but were not observed among other variables. Discriminant function analysis results indicate neither performance nor behaviors are capable of placing heifers into RFI groups based on conservative or extreme RFI classification criteria. These results indicate RFI determined in a drylot environment has little to no impact on cattle behavior when grazing rangeland.

INTRODUCTION

Residual Feed Intake and Cattle Performance

Historically, performance in beef cattle has primarily focused on increasing production output traits with little emphasis on input traits such as the quantity of feed required for production (Arthur et al. 1996). Increased feed costs have caused producers to now value input efficiency as much as output characteristics. Feed conversion ratio (FCR) is a common performance/efficiency measure that was selected against to decrease feed:gain. Although improvements were made in FCR, the strong genetic correlation of FCR with growth rate (Brelin and Branang 1982) resulted in larger cattle with greater maintenance costs. The higher cost of maintenance caused by increased mature cow size may negate improvement in total feed and cost efficiency.

Residual feed intake (also referred to as net feed intake) is the difference between an animal’s actual intake and predicted intake, with the predicted intake based on the animal’s body weight and weight gain over a specified period of time (Arthur and Herd 2008). Residual feed intake therefore represents the amount of feed intake not accounted for by body weight or production (Dai et al. 2017). While the entirety of the mechanisms by which residual feed intake (RFI) works remain unknown (Nkrumah et al. 2006), research assessing the effects of RFI on various performance measures at multiple production levels continually suggests RFI is a sound candidate for improving feed efficiency while maintaining desired performance and production levels. The effect of RFI on body weight (BW), average daily gain (ADG), and FCR is consistent within the literature in that BW and ADG are not correlated with RFI whereas FCR is correlated with RFI. The inclusion of BW and ADG within the DMI regression model used to obtain RFI values makes RFI phenotypically independent of BW and ADG.

Cattle Behavior

Quantifying cattle behaviors is not difficult intrinsically, but the complexity of discerning the influence of any single factor on herd behavior proves challenging as many factors often act simultaneously (Senft et al. 1983). Management changes from the application of behavioral characteristics should therefore be used judiciously because of the immense variability among individual animals, breeds, site environments, and managerial style. Research providing information regarding behavior is still of value because it allows managers to select animals or manipulate animal behavior that best suits their circumstance. Further confounding the application of behavioral based management are the behavioral predispositions, physiological systems, and physical attributes that influence decisions regarding foraging, drinking, and resting/ruminating (Launchbaugh and Howery 2005). Two methods for quantifying behaviors exist; direct observation by human observer(s), and sensor based data collection via pedometer or GPS. Observer based studies provide the observer with an acute awareness of individual animal behavior, but are ultimately laborious and subjective (Walker et al. 1985). The continual improvement and reduced cost of technology has enabled behavioral researchers to replace human observers with senesor based data collection. Not only has this advancement removed the subjective error in observer based data collection, but the ability to continuously collect data over long periods of time on multiple animals provides greater insight into intra- and inter-animal behavior variation.

Behavioral studies of cattle with respect to RFI have primarily described differences in bunk feeding behaviors. Kelly et al. (2010a) reported eating rate was positively associated with DMI, and DMI was greatest in high-RFI and least in low-RFI heifers. Furthermore, high-RFI heifers had more feeding events per day than low-RFI heifers. Kelly et al. (2010b) also reported a positive relationship between feeding events and DMI. Number of eating bouts was greater for high-RFI steers than low-RFI steers, but eating rate was similar among RFI groups (Golden et al. 2008), which is somewhat contrasted by Bingham et al. (2009) in which high-RFI heifers consumed feed at a greater rate than low-RFI heifers. Level of intake varied more by high-RFI steers than low-RFI steers during periods of the day when feed intake was highest (Golden et al. 2008). In an individual pen environment, proportion of time spent standing, lying, or active did not differ between low-RFI and high-RFI divergently selected heifers (Lawrence et al. 2011; Halfa et al. 2013). These results provide managers in intensive feeding environments valuable information regarding the feeding behavior of low- and high-RFI cattle because behavior is a valuable indicator of health and well-being in cattle (Robert et al. 2009). However, in an extensive grazing environment the previously discussed measures are of minimal value. Lawrence et al. (2012) and Manafiazar et al. (2015) both measured forage intake of RFI tested cattle via the alkane method. Grazed DMI was similar between low-RFI and high-RFI Simmental and Simmental × Holstein-Friesian heifers (Lawrence et al. 2012), but Manafizer et al. (2015) reported lower grazed DMI in low-RFI Continental and British crossbred heifers than in their high-RFI herdmates. Both studies measured intake of pastures dominated by a single C_3 grass species.

The heritability of RFI means selection for feed efficient cattle is possible for producers seeking to reduce feed costs (Crews 2005). Selection would be most useful in breeding stock, particularly sires, but the effects of RFI on cattle behavior would be most realized in the cow herd due to the relative number of cows grazing on range compared to bulls. Energy expenditure in cattle affects weight gains (NASEM 2016), thus the study of movements and patterns of terrain use are common behavior variables measured as these affect energy use (Osuji 1974). In addition, a grazier’s desire for even distribution at the pasture scale often results in the use of attractants to alter behavior to encourage cattle to travel farther or use terrain otherwise avoided. Because selection for efficient cattle could influence behavior, studies comparing cattle of varying RFI efficiencies will provide information for producers selecting on the merit of RFI.

To date, there appears to be a gap in the existing body of literature regarding RFI and its relationship with cattle grazing behavior in rangeland environments. The work by Knight (2015; 2016) in the desert southwest is the only work available regarding RFI and grazing distribution. Currently, it is unknown whether greater efficiency allows animals to use their environment differently in sub-tropic or temperate regions. Two potential outcomes seem likely: the first, that efficient animals would use less of the pasture because they do not need to consume as much food to maintain their weight; and the second, that efficiency allows low-RFI animals to explore more of their pasture because their bodies do not require as much forage for maintenance. Selecting against high RFI could influence behavior which could have direct implications for range managers (Launchbaugh and Howery 2005). Thus the purpose of the present work is to use GPS to identify variation in expressed behavior of RFI-tested pregnant heifers grazing on Oklahoma rangeland. In addition, breed comparisons are made between Angus and Brahman × Angus F1 heifers to identify variation in distribution and diet selection caused by breed. Based on Knight's (2015; 2016) results, it is hypothesized heifers of varying RFI will not differ in behavior. Regarding breed, F1 heifers are expected to travel farther and explore greater areas than Angus heifers due to higher heat tolerances in the F1 heifers (Blackshaw and Blackshaw 1994).

MATERIALS AND METHODS

Study Site

Research was conducted in a single 69.4ha pasture (35° 33' N, 98° 01' W; elevation 414m) at the United States Department of Agriculture Agricultural Research Service Grazinglands Research Laboratory 3.2km west of El Reno, OK, USA. Average annual precipitation in Canadian Co. is 85cm, with approximately 45% of precipitation occurring from March to June, and average annual temperature is 15.5°C (Oklahoma

Climatological Survey). Average temperature during GPS data collection was 21.4°C. The pasture is approximately 2km north to south and 0.5km east to west (see Figure 3.1). An ephemeral stream runs south to north through the middle of the pasture and enters the North Canadian River 3.5km northeast of the pasture. Aside from a stock tank in the northeast of the pasture and a small centrally located pond, a large pool formed by the stream serves as the primary water source for livestock. The pasture primarily consists of warm season decreasers such as big bluestem (*Andropogon gerardii* Vitman), indiangrass (*Sorghastrum nutans* L.), little bluestem (*Schizachyrium scoparium* [Michx.] Nash), switchgrass (*Panicum virgatum* L.), and johnsongrass (*Sorghum halepense* [L.] Pers.). Dense woody vegetation such as buckbrush (*Symphoricarpos orbiculatus* [Hook.] Nutt.), pecan (*Carya illinoinensis* [Wangenh.] K Koch), roughleaf dogwood (*Cornus drummondii* C. A. Mey), and eastern cottonwood (*Populus deltoids* W. Bartram ex Marshall) are present along the east and west banks of the centrally located stream. Soils consist primarily of Port and Norge silt loams (Soil Survey Staff). The stocking rate was 0.49 AUM^{-ha}, which is 14% of sustainable rate of 3.57 AUM^{-ha}, assuming a 25% harvest efficiency (Redfearn and Bidwell).

GPS Design and Data Cleaning

To monitor the spatial distribution of the heifers, I built custom Global Positioning System (GPS) collars. The GPS collar design for this study was an adaptation of the Knight design described in Knight et al. (2018a). The Mobile Action i-gotU GT-600 (New Taipei City, Taiwan) was the GPS unit used for this study. This unit has the capacity to record 262,000 GPS points and has an average satellite acquisition time from a cold start of <35 seconds. The factory 3.7V 750mAh Li-ion battery was removed and replaced with a Tenergy 3.7V 5200mAh Li-ion battery pack (Fremont, CA) to allow for a longer deployment period without sacrificing monitoring duration (Pépin et al. 2004). The modified GPS unit was then placed in a polycarbonate enclosure (Polycase; Avon, OH) and attached to a 3.8cm × 111.8cm nylon cow collar (Valhoma Corporation; Tulsa, OK). A steel plate bent at a 90° angle was used as a counterweight and attached to the nylon collar to keep the GPS unit in its desired orientation around the heifer's neck. To account for the 66% fix rate reported by Knight et al. (2018a), collars were set to collect data every two minutes to achieve our overall goal of a three minute interval data collection. These units have circular logging and motion detection settings; both of which were disabled to prevent the overriding of data and for user control of logging periods. Power saving mode was also disabled per recommendation by Dr. Colt Knight (personal communication) to prevent excessive battery use during on/off cycles. Forty-three heifers were fitted with the GPS units and at the time of GPS data collection heifers averaged 417 ± 43kg (mean ± SD).

Data from the i-GotU GPS units were downloaded using the @trip PC software provided by Mobile Action. All GPS data were then merged into a single Microsoft Excel (2017) file and edited using the methods reported by Knight et al. (2018b) to remove inaccurate data. To summarize, the first step in removing any inaccuracies in the data was an adjustment of the time recorded for each GPS fix. Because the iGotU GPS units use the Coordinated Universal Time (UTC) based in London, England, the recorded time data were 5 hours ahead of the local Central Daylight Time (CDT) in Oklahoma, USA. The Kutools for Excel add-in was used to complete this task. Next, the rate of travel between each consecutive GPS fix for each heifer was calculated and any GPS fixes that exceeded a rate of 84m^{-min} were removed, as well as any distances between successive GPS fixes that exceeded 168m. This was based on the 84m^{-min} walking rate of a cow (84m × 2 minute set sampling interval) reported by Chapinal et al. (2009). Data were then sorted by elevation and any data with extreme values not found within our pasture (>1,000m; <0m) were removed. Latitude and longitude data were then converted to Universal Transverse Mercator (UTM) northing and easting values. Northing/easting data were then analyzed using Java to calculate distance travelled values for each heifer at four time scales (Sawalhah et al. 2014). Java output and edited GPS data from Excel was then imported into SAS 9.4 for further editing and analysis. Data collected on the first and last day of our collection period were removed to eliminate behaviors influenced by herding activities. Some GPS unit batteries expired prior to October 15, and therefore the data from the final day of collection were removed from the dataset. Each subsequent date for each heifer will be referred to as a “heifer-day”. A heifer-day is a complete 24-hour period in which GPS data were successfully recorded. Because some GPS unit batteries expired prior to 15 October, the cumulative number of heifer-days (1,051) did not equal the predicted 1,334. Furthermore, a minimum 3 minute sampling interval was desired and therefore any heifer-days with fewer than 480 GPS fixes were removed from the dataset which further reduced the number of heifer-days.

Results from the Java output and RFI data were then merged with the northing/easting GPS dataset to form a single table containing heifer, date, time, northing, easting, distance travelled values, RFI values, and the variables calculated with ArcMap 10.4, i.e. water and shade use, area explored, spatial search pattern, and slope use. The spatial search pattern (Wesley et al. 2012) by each heifer was calculated as the 24-hour distance travelled divided by the area explored in square meters. This method assumes each heifer's occupied influential space at any given time is 1m^2, which is approximately the size of a feeding station for a mature bovine (a feeding station is defined as the area available to an herbivore for foraging without moving their forefeet [Goddard 1968, Bailey et al. 1996]). Thus the spatial search pattern is (distance travelled [m^2] ÷ area explored [m^2]), which can be expressed as a percentage to determine how much of the total area explored was actually searched by the heifer.

Statistical Analysis

Data were analyzed using SAS v9.4 2013 (SAS Institute, Cary, NC, USA) (Table 3.1). PROC REG was used to determine RFI values. The GLM procedure was used to compare the mean values of the low-RFI, mid-RFI and high-RFI groups for each variable within each RFI class and the ADJUST=TUKEY option was used to identify differences among means of each RFI group. Percentage values were arcsin transformed for analysis. PROC MEANS was used to obtain summary data, and PROC CORR was used to identify correlations between behavioral variables. Because RFI is cost and labor intensive to measure, the ability to predict RFI group based on easily acquired values would be useful for beef producers. To do so, stepwise discriminant function analysis was used to identify the least set of performance and grazing behavior variables to discriminate heifers into the three distinct RFI groups in both RFI classes. I used RFI value to group heifers, therefore it was excluded as a predictor. In addition, closely related variables such as multiple body weight variables were omitted. Then the STEPDISC and DISCRIM procedures in SAS v9.4 with the *priors proportional* and *pool=test* options were used to test the homogeneity of the within group covariance matrices. The SAS 9.4 default alpha level of 0.15 was used for each variable to be to entered and be retained in the stepwise procedure. Groups were determined to be different using the Wilks' Lambda statistic from the MANOVA F test ($P \leq 0.15$). When groups differed, the *crossvalidation* option in PROC DISCRIM was used to calculate the error rate of the discriminant function.

RESULTS

GPS Performance

A total of 1,051 heifer-days were collected across 43 heifers. The GPS fix rate (successful GPS data fixes ÷ scheduled GPS data fixes) across all heifers averaged 91.3% (647 ± 40.50 successful fixes; mean ± SD) and did not differ among RFI groups in conservatively classed heifers (*P*=0.81) or among breed (*P*=0.34), but did differ among RFI group in the extreme class (*P*=0.01). Because the observed fix rate was far superior to the predicted 66% reported in Knight et al. (2018), the average time between GPS point fixes was 2.2 minutes rather than the expected 3 minutes.

Distance Travelled

The temperature during the GPS data collection period of this study ranged from 0.5° to 33.3°C (mean = 21.9°C), and precipitation totaled 19.6cm.

In this study, daily movements averaged in excess of 6.3km (Table 3.2; 3.3; 3.4). No significant differences occurred between any of the distance travelled variables (24-hour, daytime, sunset to midnight, midnight to sunrise) except for in the conservatively classed heifers where the midnight to sunrise distance variable for the high-RFI group was farther than the low-RFI (*P*=0.04) (Table 3.2).

Water Use

The distance from water at which cattle are considered ‘at water’ is determined somewhat arbitrarily by the researcher (Ganskopp 2001). In Ganskopp (2001), a distance of 250m was determined as at water, and this was in an arid environment where water is expected to be a major influence in distribution of grazing livestock. In this study, the high forage productivity and abundance of water were expected to have less of an influence on distribution. Furthermore, the narrow shape of the pasture meant cattle were never far from accessible water. The farthest possible location from water was 0.37km. Still, the assessment of water use has implications for production and management, therefore the “at water” buffers were set at 50m and 100m from available water sources. Because not all water in the creek was available for use, only sections of the creek where water was present and kernel density indicated use were included in analysis. The 50m and 100m water buffers comprise of 20.7% and 42.1% of the pasture area, respectively. Irrespective of RFI and breed, heifers spent 32.2 ± 0.6% and 55.0 ± 0.6% (mean ± SE) of their time within 50m and 100m of available water sources, respectively. No differences were detected in either RFI class among RFI groups for mean distance to water or time spent at water at either buffer distance (Table 3.2; 3.3). Likewise, no differences were observed among breed for water usage (Table 3.4). A strong negative correlation was observed between distance to water and time at water (50m buffer: r=-0.78; *P*<0.01; 100m buffer: r=-0.88; *P*<0.01; Table 3.6).

Shade Use

Only the woody vegetation in the study site was tall enough to provide shade, therefore the use of shade was determined by GPS points within the woody plant community. To account for shadow movement throughout the day, a 2m buffer was added to all woody vegetation shapefiles. No difference occurred among RFI groups in either RFI class (*P*>0.95; Tables 3.2; 3.3) or among breeds (*P*=0.65; Table 3.4).

Area Explored

As expected, the area explored (ha^{-d}) decreased as heifers became familiar with the site. In the conservative class, area explored by low-, mid-, and high-RFI heifers decreased at a rate of -0.96ha, -0.75ha, and -0.60ha per day (*P*<0.01 for all groups). Similarly, the extreme class yielded predicted decreases of -1.23ha, -0.70ha, and -0.77ha per day for the low-, mid-, and high-RFI groups (*P*<0.01 for all groups). The area explored by each RFI group within both RFI classes ranged from 24.53 to 27.55ha (Table 3.2; 3.3) but did not differ (conservative class: *P*=0.22; extreme class: *P*=0.30). Numerically, the low-RFI heifers had the greatest area explored among RFI groups in both classes. Between breeds, a trend (*P*≤0.10) was observed for area explored, as the Angus heifers averaged of 25.92ha and F1 heifers averaged 28.69ha (*P*=0.08) (Table 3.4).

Spatial Search Pattern

In conservatively classed heifers, the spatial search pattern ranged from 3.07% by the low-RFI group to 3.56% by the high-RFI group (*P*=0.01) (Table 3.2). Spatial search pattern by extreme classed heifers ranged from 3.17% to 3.53% and did not differ (*P*=0.27) (Table 3.3). The tendency of low-RFI heifers exhibiting lowest spatial search pattern and high-RFI heifers exhibiting the greatest spatial search pattern was consistent among RFI classes. There was no difference among breeds in spatial search pattern (*P*=0.79) (Table 3.4).

Slope Use

Little variation in slope existed in the study site as most of the area was less than 5% slope. Among conservatively classed heifers, average slope used by the low- and mid-RFI group was 3.82%, and the high group averaged 3.81% (P=0.98) (Table 3.2). Slope used by the RFI groups within the extreme class did not differ either (P=0.66) (Table 3.3). Between breeds, Angus heifers used an average slope of 3.82% and F1 heifers used an average of 3.84% (P=0.74; Table 3.4).

Discriminant Function Analysis

When performance variables and behavior variables were included in the discriminant analysis, only time spent ruminating during the RFI test proved to be a useful predictor in grouping heifers based on the conservative mean ± 0.5SD RFI classification. Crossvalidation results yielded an overall error rate of 44.19%, indicating based on these data RFI group can be correctly predicted from rumination time 55.81% of the time (Table 3.8; 3.9.1; 3.9.2) No behavior variables were identified as predictors. These results are further supported by the lack of any correlation between RFI and behavior (Table 3.5).

DISCUSSION

Distance Travelled

The results from the present study compare well to Knight (2016) which measured distance travelled by low-RFI and high-RFI cows (~6.3km and 5.8km travelled daily, respectively) with similar GPS units, suggesting that if error is causing an overestimation of distance travelled the error is consistent between Knight (2016) and the present study. Though the difference was not significant, Knight (2016) reported high-RFI cows typically travelled shorter distances than low-RFI cows. Likewise the present study did not observe significant differences in distance travelled among RFI group, but did have the opposite trend where low-RFI heifers had numerically lower daily movements than high-RFI heifers. Knight (2016) created two equal sized RFI groups based on positive and negative residual values which may have had an effect on the level of significance in results, however, creating three RFI groups in the present study did not necessitate significance in statistical tests. Herd et al. (2004) suggested that activity, primarily walking but also eating and ruminating accounted for 5.1% of the increased feed intake in high-RFI cattle in relation to low-RFI cattle. Based on pedometer count and an assumed stride length of 1m, Richardson et al. (2000) reported high-RFI bulls averaged 6% more steps than low-RFI bulls. Using the same assumption for stride length, the results from the present study reveal high-RFI heifers took 2.6% more strides than low-RFI heifers, but contrary to Richardson et al. (2000) this difference was not significant. Additional research quantifying the variation in feed intake explained by activity via GPS data collection would be of interest in light of the results from Knight (2016) and the present work. It is possible that herding instincts influenced behavior of individuals to a greater extent than the possible effect of RFI alone (Stephenson and Bailey 2017). Only weak correlations were detected between distance travelled and plant community preferences (Table 3.7).

At >3× the north to south length of the 69ha study site, the 6.4km travelled by Angus heifers and 7.3km travelled by F1 heifers in this study are remarkably similar to the daily travels of Angus and Brangus cows reported in Russell et al. (2012). In that study, Angus cows averaged 6.5km daily and Brangus cows averaged 7.4km daily. Russel et al. (2012) did not report a significant difference among the two breeds, however the difference between Angus and F1 heifers in the present study was significant (*P*<0.01; Table 3.4). When Angus and Brangus distances were compared to the 10.3km travelled by Brahman cows, Russell et al. (2012) reported a significant difference, suggesting crossbreeding significantly affects daily movements. Walker and Heitschmidt (1989) measured 24-hour distances travelled by Angus × Hereford cows in a semi-arid 248ha pasture and concluded cows travelled 5.8km per day. When paired with results from Russell et al. (2012) and Walker and Heitschmidt (1989), the results from the present study further indicate consistency in the daily movements of Angus cattle and Brahman × Angus crossbreeds. In addition, it should be noted that the size of pastures in Russell et al. (2012) exceeded 1,400 ha whereas the pasture in the present study was only 69ha, suggesting there may be a physiological limit regarding movement for Angus and Angus crossbreeds that is irrespective of area available for grazing. It is possible that the distance travelled results are higher than reality because stationary GPS error (circular error of precision: 4.01m) was not accounted for in the calculation. The implementation of high accuracy GPS units and calculation of distance measurements only when cattle are active should provide a more precise estimate (Russell et al. 2012).

Water and Shade Use

Heat production in cattle is affected by dry matter intake (Reynolds et al. 1991), so it was somewhat expected that high-RFI cattle would spend more time at water and in shade than their lower intake herdmates. Lack of differences may be attributed to the greater influence of solar radiation and ambient temperature on the cattle since all cattle had very dark coats. A trend ($P<0.10$) was reported in Knight (2016) when distance travelled from water was compared between low-RFI and high-RFI cattle, with high-RFI cows being more likely to travel further from water. Significance in distance travelled was not observed in this study presumably due to the small pasture size and abundance of water. Wesley et al. (2012) reported mean distances from water in excess of 0.8km by Angus crossbred cows in in an arid 146ha pasture. The 0.8km mean distance in Wesley et al. (2012) far exceeds the maximum possible distance from water in the present study, indicating the importance of pasture size when attempting to quantify distances animals are willing to travel.

It was expected that there would be a difference among breeds in water and shade use because of the increased susceptibility of Angus cattle to heat stress compared to Brahman influenced animals (Blackshaw and Blackshaw 1994). In Forbes et al. (1998), shade use by Angus heifers was greater than Brahman × Angus crossbred heifers, but time spent at water did not differ. In addition Forbes et al. (1998), defined time at water was defined as actual drinking time, so the comparison with results in the present study should be made with caution since time at water was defined as time spent within a specified buffer.

Area Explored and Spatial Search Pattern

The area explored by heifers in the present work was numerically much less than the 54.8ha explored by non-pregnant non-lactating cows in Black Rubio et al. (2008), but was comparable as a ratio with pasture size (37.5% of 146ha in Black Rubio et al. 2008 versus 37.9% of 69ha in present study). Black Rubio et al. (2008) also reported an area explored of 30.4ha (20.8% of pasture) by pregnant or lactating cows, which was much less than their non-pregnant non-lactating herdmates (54.8ha). Heifers in this study were pregnant, albeit only two months. The walking of fence lines in new pastures may be influencing the area explored calculation, as the literature is fairly consistent about daily distance travelled irrespective of pasture size. If cattle are consistent in their travel distances, but make long distance movements along linear paths with several directional changes, minimum convex polygon calculations will produce large areas explored with relatively small spatial search patterns. This behavior has been observed by the author and others, and is consistent with heifer movements during the first days in the pasture for this study. The consistency within research regarding travel distance by cattle suggests a strong instinct to move while grazing, perhaps in search of the most palatable diet.

It is probable that the lower spatial search pattern observed for the low-RFI heifers relative to the mid- and high-RFI heifers in the conservative class is caused by the compounding trend seen in the distance travelled and area explored results. Though neither of these measures differed among RFI groups, the numerically lower 24-hour distance travelled and numerically higher area explored resulted in a significant effect among conservatively classed heifers for spatial search pattern. Because the area explored was based on minimum convex polygons, and because the pasture is a concave polygon, areas outside of the fenceline were included in area explored calculations (see Figure 3.2). Although this error was present for every individual, it could be possible that some individuals used areas susceptible to area explored errors at a greater proportion than other individuals.

The greater travel distances and area explored by F1 heifers may be attributed to the higher heat tolerances of the Brahman influenced F1 heifers. Blackshaw and Blackshaw (1994) reported water intake of *B. indicus* cattle is less than that of *B. taurus* cattle, and this difference may have permitted the F1 heifers to travel greater distances from water while grazing, thus also increasing area explored by F1 heifers. It is thought that the lack of difference among breeds in the spatial search pattern is a result of the increase in both distance and area explored by F1 heifers. If one breed were to consistently exhibit greater path sinuosity without increasing area explored, it could be expected that spatial search pattern would increase as a result of increased distance travelled despite unchanged area explored. Russell et al. (2012) examined the sinuosity of Angus, Brangus, and Brahman cows and found similar sinuosity among breed in the first year of study but observed a greater degree of sinuosity in Brahman cows in summer of the second year. It is most probable then that the similarity among breeds in spatial search pattern is a result of consistency in directional movement and area explored, as the ratio of distance travelled to area explored remained similar.

Slope Use

The small amount of variation in slope within the pasture made it difficult to assess potential differences among RFI groups and respective slope use. This was compounded by the preferential use of grass dominated plant communities that occurred within the site in areas where slopes were typically less than 5% (Chapter II). Areas of slope >10% occurred near the stream, which also coincided with woody vegetation dense enough to limit any use. However, the lack of difference in slope use by RFI group is similar to that in Knight (Knight 2016) in which differences between low-RFI and high-RFI cattle were absent, despite wide variation in pasture slope.

It is sometimes necessary to consider the variation in measurements rather than just the averages being compared to obtain a greater understanding of the phenomena at hand. The low-RFI group had the greatest standard deviation among behavioral variables 58% and 66% of the time, in the conservative and extreme classes, respectively (Table 3.10; 3.11). This was specifically observed in each of the distance travelled measures and the area explored, suggesting there may be greater variability in behavioral expression by low-RFI cattle. Angus heifers (n=38) exhibited greater standard deviation than F1 heifers (n=5) in 83.3% of behavior variables (Table 3.12).

Discriminant Function Analysis

Results from the discriminant analysis reveal behaviors are not useful in predicting RFI group using the conservative classification, as evidenced by the 44.19% cross validation error rate. It would be improbable that any set of predictors could group individuals correctly 100% of the time, however, the inability to identify any high-RFI heifers and the 58.33% success in correctly grouping low-RFI heifers suggests use of the derived model would be spurious. The lack of any predictor being identified from the extreme classification grouping further suggests that RFI has little to no effect on behaviors. Wesley et al. (2012) used similar methodology to identify behaviors that could be used to predict behavior types based on a suite of 14 behavioral, physiological, and performance predictors. In that study, spatial search pattern, mean distance from water, and time spent at water were identified as useful predictors. Although not useful in RFI grouping, behaviors do appear to be relevant to other classification criteria.

Future Research

This study sought to identify differences in performance and behavior of heifers that vary in RFI. It is difficult for any one study to answer every question that may be of interest to the scientific community, and the present study added to the results of previous work related to RFI and animal performance. The contribution of grazing behavior as affected by RFI is relatively new to the literature. Lack of differences observed among RFI groups related to grazing behavior compares well with Richardson et al. (2000), Herd et al. (2004), Herd and Arthur (2009) who report estimates of physical activity account for only 10%, 5%, and 9% of variation in RFI, respectively. According to Herd et al. (2004), processes such as protein turnover, ion pumping, proton leakage, and digestion account for 81% of the variation in RFI in beef cattle. As RFI becomes increasingly adopted as a desirable efficiency selection trait, beef producers in extensive and heterogeneous environments will benefit from the behavioral information provided by this work. The results of this research provide information about cattle behavior in a narrow scope of time. Longer duration of data collection and repetition across multiple years would strengthen the validity of the results obtained. In addition, the incorporation of high performance GPS collars could further the amount of information obtained from future GPS studies. Although the use of expensive GPS collars could provide more data (e.g. temperature data and head orientation), the cost associated with such technologies is often prohibitive to the incorporation of large sample sizes, which was a strength of the present study. The rangeland environment in the present study was extremely productive in forage production and had minimal variation in topography. Although most of the beef cattle production in the United States occurs in the Great Plains and mid-western states where abundant rainfall permits high stock densities, further studies in the arid western states where topography, water distribution, and cold weather are major obstacles for producers would be of value. As resources continue to be spent on the improvement of efficiency in cattle, information regarding the influence of selection against RFI will be important for producers balancing the management of rangelands and cattle behavior.

TABLES

Table 3.1. List of grazing behavior variables measured on 38 Angus and 5 Brahman × Angus (F1) heifers in a 69.4ha native rangeland pasture near El Reno, OK. Some analyses presented in this chapter include performance variables that can be found in Table 2.1 of Chapter II.

Category	No.	Variable	Units	Formula
GPS performance	1	Fix rate	%	(collected GPS fixes) ÷ (scheduled GPS fixes)
	2	Elevation records	m	
Behavior		Distances travelled	$m \cdot day^{-1}$	Cumulative distance between successive GPS coordinates for each time period
	1	24-hour		
	2	Daytime		
	3	Sunset to midnight		
	4	Midnight to sunrise		
	5	Distance to water (mean)		Near tool, ArcMap 10.4
	6, 7	Time at water (50m and 100m buffers)	% of time	No. of GPS coordinates within specified buffer of water ÷ total no. of GPS coordinates per day
	8	Area explored	ha	Minimum convex hull, ArcMap 10.4
	9	Spatial search pattern	% of area explored	(24-hour distance travelled) ÷ (area explored)
	10	Shade used	% of time	No. of GPS coordinates in shade ÷ total no. of GPS coordinates per day
	11	Slope used	%	USGS DEM; extract values to point, ArcMap 10.4

Table 3.2. The behaviors expressed by each RFI group in the conservative class are summarized. Significant differences among RFI groups occurred in the midnight to sunrise distance travelled variable, as well as the spatial search pattern.

	RFI Classification: Conservative[2]						
Variable[1]	Low-RFI	SE	Mid-RFI	SE	High-RFI	SE	*P*
No. of GPS fixes, 720 scheduled	657.03	2.42	657.01	1.84	658.86	2.38	0.81
Distance travelled (m)							
24-hour distance	6402.08	132.67	6546.28	88.56	6569.99	111.78	0.53
Daytime	4142.45	93.17	4189.99	67.15	4153.73	83.36	0.90
Sunset to midnight	1145.87	31.26	1169.72	22.43	1196.55	30.91	0.49
Midnight to sunrise	1113.75^{a}	35.33	1186.57^{ab}	22.79	1219.40^{b}	27.12	0.04
Water use							
Distance to water (mean, m)	100.76	2.13	99.59	1.69	100.73	2.35	0.88
Time at water, 50m buffer (%)	32.29	0.98	31.90	0.85	32.48	1.10	0.88
Time at water, 100m buffer (%)	54.99	1.15	55.07	0.99	54.84	1.26	0.99
Area explored (ha)	27.55	1.05	26.19	0.80	25.04	0.98	0.22
Spatial search pattern (%)	3.07^{a}	0.11	3.48^{b}	0.14	3.56^{b}	0.15	0.01
Shade use (%)	13.48	0.01	13.58	0.01	13.83	0.01	0.95
Slope use (%)	3.82	0.05	3.82	0.04	3.81	0.05	0.98

[1] Least squares means with different letter superscripts differ ($P<0.05$)

[2] Sample size: Low-RFI=309 days across 12 heifers; Mid-RFI=464 days across 20 heifers; High-RFI=278 days across 11 heifers

Table 3.3. The behaviors expressed by each RFI group in the extreme class are summarized. Significant differences among RFI groups occurred only in the fix rate measurement. Unlike conservatively grouped heifers (Table 3.2), no differences were observed among behavioral variables.

	RFI Classification: Extreme[2]						
Variable[1]	Low-RFI	SE	Mid-RFI	SE	High-RFI	SE	*P*
No. of GPS fixes, 720 scheduled	649.10^{a}	3.95	657.44^{ab}	1.49	663.06^{b}	2.70	0.01
Distance travelled (m)							
24-hour distance	6363.19	217.43	6568.41	72.37	6380.91	145.78	0.36
Daytime	4149.72	154.19	4195.58	53.47	4065.81	107.77	0.56
Sunset to midnight	1112.81	50.15	1185.66	18.54	1145.35	37.24	0.27
Midnight to sunrise	1100.66	54.28	1187.17	19.25	1169.74	34.47	0.24
Water use							
Distance to water (mean, m)	97.93	3.04	100.06	1.40	102.40	2.75	0.57
Time at water, 50m buffer (%)	31.87	1.58	32.36	0.67	31.64	1.27	0.88
Time at water, 100m buffer (%)	55.63	1.83	55.28	0.78	53.46	1.48	0.52
Area explored (ha)	26.93	1.70	26.64	0.64	24.53	1.24	0.30
Spatial search pattern (%)	3.17	0.22	3.38	0.10	3.53	0.16	0.27
Shade use (%)	13.82	0.01	13.62	0.00	13.46	0.01	0.99
Slope use (%)	3.88	0.07	3.81	0.03	3.82	0.06	0.66

[1] Least squares means with different letter superscripts differ ($P<0.05$)

[2] Sample size: Low-RFI=122 days across 5 heifers; Mid-RFI=736 days across 31 heifers; High-RFI=193 days across 7 heifers

Table 3.4. The behaviors expressed by each breed (Angus and Brahman × Angus [F1]) are summarized. Significant differences among breeds occurred in all distance travelled measurements and revealed a trend ($P<0.10$) in the area explored measure where F1 heifers travelled farther and explored greater areas.

	Breed[2]				
Variable[1]	Angus	SE	F1	SE	*P*
No. of GPS fixes, 720 scheduled	657.97	1.37	654.42	2.83	0.34
Distance travelled (m)					
24-hour distance	6392.81^{a}	66.92	7286.53^{b}	163.01	<0.01
Daytime	4106.37^{a}	49.08	4563.74^{b}	125.94	<0.01
Sunset to midnight	1150.43^{a}	17.08	1297.96^{b}	39.47	<0.01
Midnight to sunrise	1136.00^{a}	17.15	1424.83^{b}	42.35	<0.01
Water use					
Distance to water (mean, m)	100.27	1.24	100.01	3.17	0.94
Time at water, 50m buffer (%)	31.97	0.59	33.46	1.53	0.370
Time at water, 100m buffer (%)	54.92	0.70	55.42	1.71	0.81
Area explored (ha)	25.92	0.57	28.69	1.58	0.08
Spatial search pattern (%)	3.39	0.09	3.34	0.15	0.79
Shade use (%)	13.56	0.00	13.95	0.01	0.65
Slope use (%)	3.82	0.03	3.84	0.07	0.74

[1] Least squares means with different letter superscripts differ ($P<0.05$)

[2] Sample size: Angus=913 days across 38 heifers; F1=138 days across 5 heifers

Table 3.5. Pearson correlation coefficients between performance and behaviors are presented. Despite some significant correlations, all correlations were weak (r<0.30) indicating behaviors are not likely to be influenced by performance, which is further supported by mean comparisons among RFI groups presented in Tables 3.2 and 3.3.

		Behavior										
		Distance Travelled										
		24-hour	Daytime	Sunset to midnight	Midnight to sunrise	Distance to water (mean)	Time at water (50m buffer)	Time at water (100m buffer)	Area explored	Spatial search pattern	Shade used	Slope used
Performance	RFI	0.03	0.01	0.03	0.06*	0.01	0.02	0.00	-0.04	0.05	0.02	-0.01
	BW (Oct. 2017)	-0.05	-0.04	-0.04	-0.06	0.05	-0.03	-0.03	0.03	-0.02	-0.01	0.04
	Intake	-0.05	-0.05	-0.04	-0.04	0.05	-0.03	-0.03	-0.03	0.02	-0.01	0.01
	ADG	0.13†	0.10†	0.09†	0.13†	0.00	0.04	0.01	0.05	0.03	0.00	-0.02
	FCR	-0.16†	-0.12†	-0.12†	-0.16†	0.05	-0.06	-0.03	-0.05	-0.03	0.00	0.03
	Rumination time (RFI test)	0.08†	0.07*	0.03	0.07*	0.02	-0.01	-0.01	0.03	0.07*	0.04	0.00
	Rumination time (pasture)	0.21†	0.16†	0.14†	0.24†	-0.01	0.04	0.03	0.08†	0.09†	0.05	0.00
	Frame score	0.06*	0.05	0.05	0.05	0.06	-0.02	-0.03	0.05	0.02	0.03	0.02
	Calving date	-0.04	0.00	-0.07*	-0.09†	-0.03	0.00	0.02	0.01	-0.03	0.07*	0.05
	Heifer 205-day wean wt.	-0.09†	-0.06*	-0.05	-0.10†	0.07*	-0.06	-0.05	-0.01	0.00	0.00	0.01

† indicates significance at *P* <0.01

* indicates significance at *P* <0.05

P values were not adjusted for multiple comparisons, therefore statistical significance must be interpreted with caution

Table 3.6. Pearson correlation coefficients among behavior variables. As expected, distance travelled variables were positively correlated with each other, as well as an expected strong negative correlation between distance to water and time spent at water.

			Distance Travelled									
			Daytime	Sunset to midnight	Midnight to sunrise	Distance to water (mean)	Time at water (50m buffer)	Time at water (100m buffer)	Area explored	Spatial search pattern	Shade used	Slope used
Behavior	Distance Travelled	24-hour	0.92†	0.67†	0.59†	-0.32†	0.40†	0.39†	0.61†	-0.08*	0.04	-0.05
		Daytime		0.43†	0.32†	-0.36†	0.41†	0.40†	0.65†	-0.14†	0.06	0.01
		Sunset to midnight			0.41†	-0.14†	0.24†	0.24†	0.31†	-0.01	-0.06	-0.07*
		Midnight to sunrise				-0.07*	0.17†	0.14†	0.19†	0.12†	0.04	-0.16†
		Distance to water (mean)					-0.78†	-0.88†	-0.11†	-0.08*	-0.05	-0.17†
		Time at water (50m buffer)						0.81†	0.28†	-0.08†	0.09†	-0.04
		Time at water (100m buffer)							0.26†	0.02	0.05	0.11†
		Area explored								-0.53†	0.07*	-0.16†
		Spatial search pattern									-0.07*	0.02
		Shade used										-0.24†

† indicates significance at $P < 0.01$

* indicates significance at $P < 0.05$

P values were not adjusted for multiple comparisons, therefore statistical significance must be interpreted with caution

Table 3.7. Pearson correlation coefficients between behaviors and distribution variables. All correlations were weak (r<0.30) indicating plant community selection and diet quality are not likely to be influenced by behavior, which is further supported by mean comparisons among RFI groups presented in Tables 3.2 and 3.3 as well as the Ivlev electivity rank order results shown in Table 2.6 of Chapter II.

			Distribution and Diet Selection								
			Plant Community Electivity								
			Tallgrass	Forb	Codominant	Sunflower	Johnsongrass	Yellow bluestem	Wooded	Dietary CP	Dietary DOM
Behavior	Distance Travelled	24-hour	-0.26†	0.09†	-0.08†	0.15†	0.17†	0.10†	0.20†	0.03	-0.08*
		Daytime	-0.20†	0.06	-0.07*	0.09†	0.13†	0.06	0.17†	0.01	-0.06
		Sunset to midnight	-0.20†	0.09†	-0.03	0.12†	0.13†	0.08†	0.14†	0.03	-0.04
		Midnight to sunrise	-0.24†	0.10†	-0.08†	0.18†	0.16†	0.13†	0.16†	0.06	-0.09†
		Distance to water (mean)	0.07*	0.13†	0.16†	-0.11†	-0.12†	-0.03	-0.05	-0.03	-0.02
		Time at water (50m buffer)	-0.13†	-0.05	-0.13†	0.14†	0.13†	0.03	0.09†	0.03	0.01
		Time at water (100m buffer)	-0.11†	-0.07*	-0.14†	0.11†	0.12†	0.03	0.08*	0.02	0.02
		Area explored	-0.11†	0.08*	-0.02	0.03	0.03	0.00	0.12†	0.00	-0.03
		Spatial search pattern	-0.04	0.00	-0.03	0.00	0.05	0.08*	0.04	0.02	-0.01
		Shade used	-0.13†	0.01	-0.02	0.03	0.06	-0.01	0.18†	0.00	0.01
		Slope used	0.08†	-0.10†	-0.06*	-0.06*	0.01	0.03	-0.05	-0.03	-0.05

† indicates significance at *P* <0.01

* indicates significance at *P* <0.05

P values were not adjusted for multiple comparisons, therefore statistical significance must be interpreted with caution

Table 3.8. Discriminant function analysis results and means of all heifer performance and behavior variables that were used as predictors in the stepwise procedure. A priori group membership of heifers in the low, mid, and high-RFI groups were determined using mean RFI value ± 0.5SD.

RFI Classification: Conservative[1]									
			Mean ± SE			Partial R-Square	Wilks' Lambda	F-value	P [3]
No.		Response Variable[2]	Low-RFI	Mid-RFI	High-RFI				
1	Performance	Birth weight, spring 2016 (kg)	38.1 ± 2.1	34.2 ± 1.6	36.6 ± 3.4				
2		205-day adj. weaning weight (kg)	419.5 ± 24.0	454.5 ± 15.5	408.2 ± 36.3				
3		RFI Mid-test BW, Apr. 2017 (kg)	345.1 ± 11.7	353.0 ± 9.5	342.9 ± 13.8				
4		BW, Oct. 2017 (kg)	441.2 ± 11.9	441.8 ± 9.8	423.1 ± 15.5				
5		**Rumination time, RFI test (min^{-d})**	**478.7 ± 13.3**	**523.9 ± 11.3**	**506.1 ± 10.9**	**0.15**	**0.85**	**3.63**	**0.04**
6		Rumination time, pasture (min^{-d})	486.7 ± 10.7	515.2 ± 10.2	500.6 ± 7.0				
7		Frame score, RFI test	4.8 ± 0.4	5.1 ± 0.1	4.7 ± 0.3				
	Behavior	Distance travelled (m)							
8		24-hour distance	6402.1 ± 132.7	6546.3 ± 88.6	6570.0 ± 111.8				
9		Daytime	4142.5 ± 93.2	4190.0 ± 67.2	4153.7 ± 83.4				
10		Sunset to midnight	1145.9 ± 31.3	1169.7 ± 22.4	1196.6 ± 30.9				
11		Midnight to sunrise	1113.8 ± 35.3	1186.6 ± 22.8	1219.4 ± 27.1				
		Water use							
12		Distance to water (mean, m)	100.8 ± 2.1	99.6 ± 1.7	100.7 ± 2.4				
13		Time at water, 50m buffer (%)	32.3 ± 1.0	31.9 ± 0.9	32.5 ± 1.1				
14		Time at water, 100m buffer (%)	55.0 ± 1.2	55.1 ± 1.0	54.8 ± 1.3				
15		Area explored (ha)	27.6 ± 1.1	26.2 ± 0.8	25.0 ± 1.0				
16		Spatial search pattern (%)	3.1 ± 0.1	3.5 ± 0.1	3.6 ± 0.2				
17		Shade use (%)	13.5 ± 0.0	13.6 ± 0.0	13.8 ± 0.0				
18		Slope use (%)	3.8 ± 0.1	3.8 ± 0.0	3.8 ± 0.1				

[1] Sample size: Low-RFI=12; Mid-RFI=20; High-RFI=11

[2] Bold type identify response variables that were selected in pairwise procedure

[3] Significance level to enter and stay: 0.15

Table 3.9.1. Cross-validation classification results from performance and behavior variables presented in Table 3.8. Cells highlighted in grey are the percentage of correct placement by RFI group. For example, low-RFI heifers were correctly grouped as low-RFI by the model 58.33% of the time. Likewise, low-RFI heifers were incorrectly grouped as mid-RFI 41.67% of the time.

Number of Observations and Percent Classified into Conservative RFI Class				
From	Low-RFI	Mid-RFI	High-RFI	Total
Low-RFI	7	5	0	12
	58.33%	41.67%	0.00%	100.00%
Mid-RFI	3	17	0	20
	15.00%	85.00%	0.00%	100.00%
High-RFI	3	8	0	11
	27.27%	72.73%	0.00%	100.00%

Table 3.9.2. Error count estimates from cross-validation classification results (Table 3.9.1). Priors indicate the proportion of observations made up of the respective RFI group. Based on the discriminant function analysis variables listed in Table 3.8, it can be expected that the model would incorrectly group heifers into the actual RFI group based on the conservative RFI classification criteria 44.19% of the time.

Error Count Estimates for Conservative RFI Class				
	Low-RFI	Mid-RFI	High-RFI	Total
Rate	41.67%	15.00%	100.00%	44.19%
Priors	27.91%	46.51%	25.58%	100.00%

Table 3.10. The standard deviations of each RFI group in the conservative class are presented. The low-RFI group had the largest standard deviation of the RFI groups in 50% of behavior variables.

	RFI Classification: Conservative[2]		
Variable[1]	Low-RFI	Mid-RFI	High-RFI
Fix rate, 720 scheduled	**42.60**	39.60	39.71
Distance travelled (m)			
24-hour distance	**2332.14**	1907.58	1863.68
Daytime	**1637.83**	1446.39	1389.88
Sunset to midnight	**549.55**	483.12	515.45
Midnight to sunrise	**621.13**	490.91	452.18
Water use			
Distance to water (mean, m)	37.50	36.44	**39.10**
Time at water (50m buffer, %)	17.20	**18.19**	18.17
Time at water (100m buffer, %)	20.21	**21.33**	21.05
Area explored (ha)	**18.51**	17.27	16.36
Spatial search pattern (%)	2.00	**2.96**	2.51
Shade use (%)	0.11	0.11	**0.12**
Slope use (%)	**0.82**	**0.82**	0.77

[1] Bold face type indicates RFI group with largest standard deviation

[2] Sample size: Low-RFI=309 days across 12 heifers; Mid-RFI=464 days across 20 heifers; High-RFI=278 days across 11 heifers

Table 3.11. The standard deviations of each RFI group in the extreme class are presented. The low-RFI group had the largest standard deviation of the RFI groups in 75% of behavior variables.

	RFI Classification: Extreme[2]		
Variable[1]	Low-RFI	Mid-RFI	High-RFI
Fix rate, 720 scheduled	**43.60**	40.54	37.47
Distance travelled (m)			
24-hour distance	**2401.54**	1963.48	2025.18
Daytime	**1703.08**	1450.51	1497.25
Sunset to midnight	**553.88**	502.86	517.30
Midnight to sunrise	**599.51**	522.30	478.90
Water use			
Distance to water (mean, m)	33.61	37.85	**38.23**
Time at water (50m buffer, %)	17.33	**18.06**	17.64
Time at water (100m buffer, %)	20.18	**21.14**	20.54
Area explored (ha)	**18.82**	17.22	17.23
Spatial search pattern (%)	2.38	**2.74**	2.16
Shade use (%)	**0.12**	0.11	0.11
Slope use (%)	**0.82**	0.81	0.79

[1] Bold face type indicates RFI group with largest standard deviation

[2] Sample size: Low-RFI=122 days across 5 heifers; Mid-RFI=736 days across 31 heifers; High-RFI=193 days across 7 heifers

Table 3.12. The standard deviations of each breed (Angus and Brahman × Angus [F1] are presented. Angus heifers had larger standard deviations than F1 heifers in 83% of behavior variables.

Variable[1]	Breed[2]	
	Angus	F1
Fix rate, 720 scheduled	**41.48**	33.29
Distance travelled (m)		
24-hour distance	**2022.13**	1914.94
Daytime	**1482.90**	1479.43
Sunset to midnight	**516.19**	163.63
Midnight to sunrise	**518.22**	497.45
Water use		
Distance to water (mean, m)	**37.48**	37.29
Time at water (50m buffer, %)	17.86	**18.02**
Time at water (100m buffer, %)	**21.04**	20.12
Area explored (ha)	17.22	**18.58**
Spatial search pattern (%)	**2.71**	1.71
Shade use (%)	**0.11**	**0.11**
Slope use (%)	**0.81**	0.79

[1] Bold face type indicates breed with largest standard deviation

[2] Sample size: Angus=913 days across 38 heifers; F1=138 days across 5 heifers

FIGURES

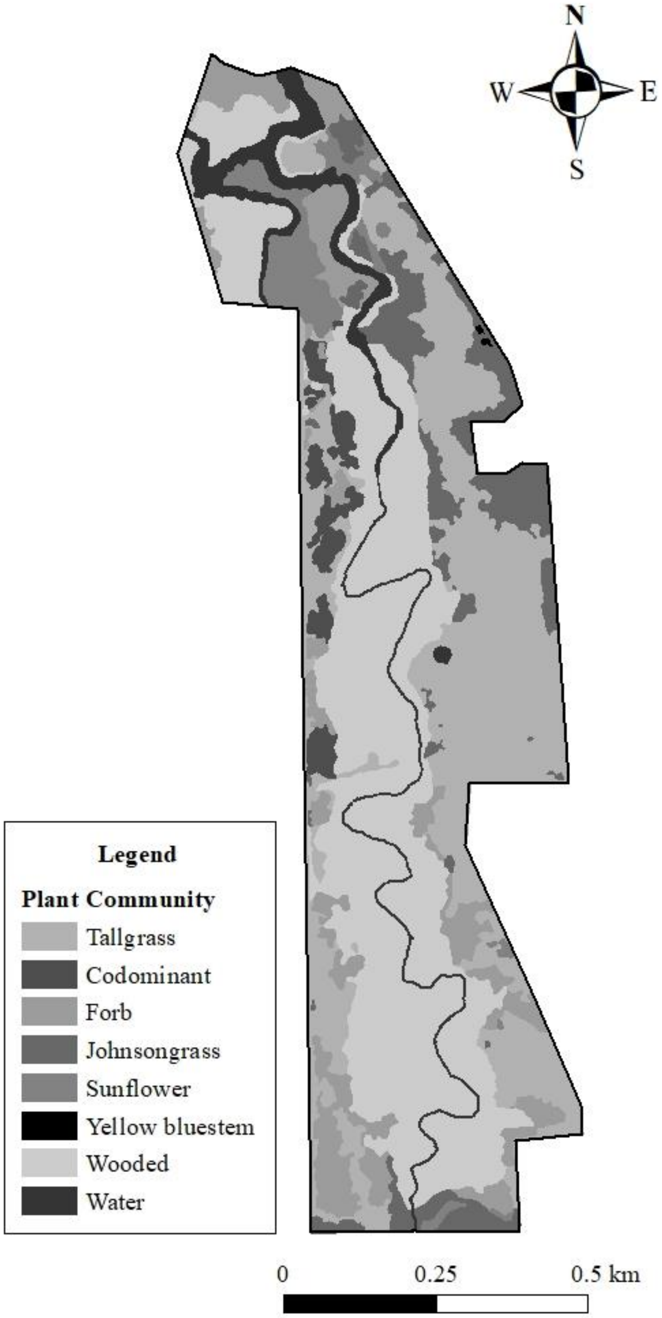

Figure 3.1. Map of study site showing various plant communities and water sources. Due to scale, the water tank 0.35km northeast of the pond is not visible.

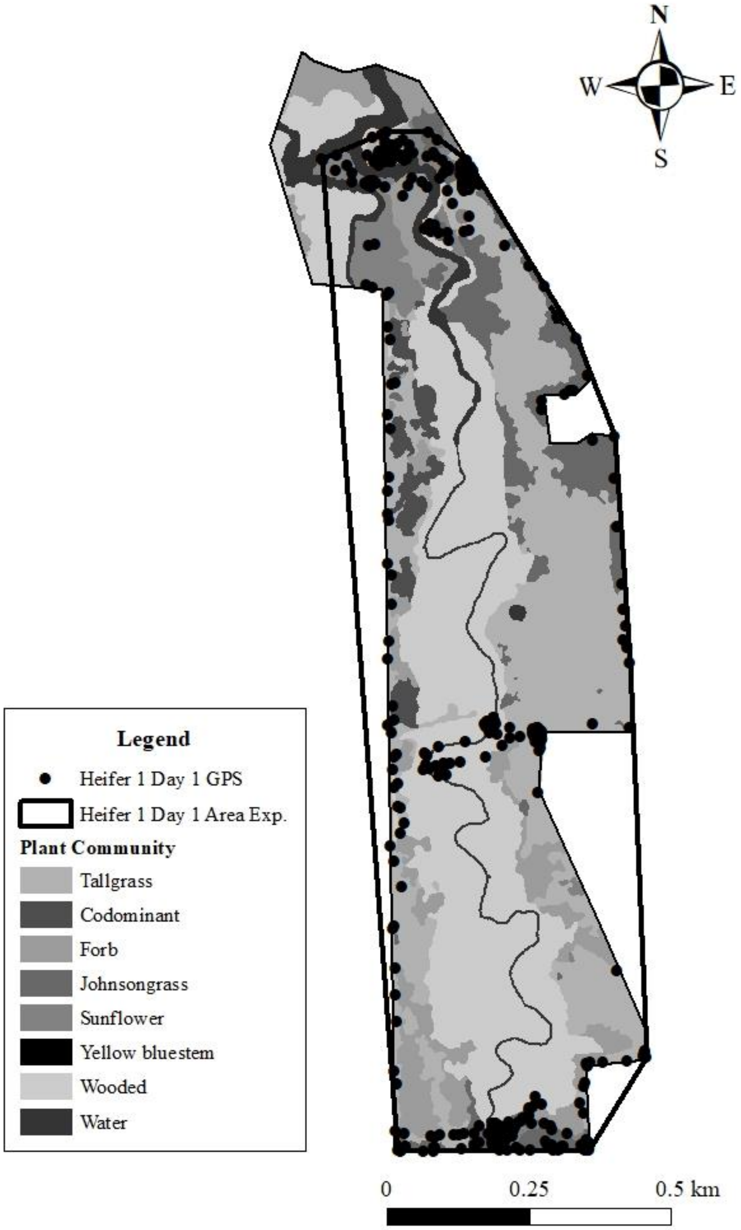

Figure 3.2. An example of the area explored as determined by a minimum convex polygon. The area explored is thus the smallest convex polygon (all angles <180º) completely enclosing all GPS coordinates from each heifer on a daily basis. Error in this method can be seen where the convex polygon encompasses areas outside of the fenceline as a result of the concave pasture shape.

REFERENCES

Ahlberg, C. M., K. Allwardt, A. Broocks, K. Bruno, L. McPhillips, A. Taylor, C. R. Krehbiel, M. Calvo-Lorenzo, C. J. Richards, S. E. Place, U. DeSilva, D. L. VanOverbeke, R. G. Mateescu, L. A. Kuehn, R. L. Weaber, J. M. Bormann, and M. M. Rolf. 2018. Test duration for water intake, ADG, and DMI in beef cattle. Journal of Animal Science 96:3043-3054.

Allred, B. W., S. D. Fuhlendorf, D. M. Engle, and R. D. Elmore. 2011. Ungulate preference for burned patches reveals strength of fire-grazing interaction. Ecology and Evolution 1:132-144.

Althaus, B., G. Papke, and A. Sundrum. 2013. Technical note: use of near infrared reflectance spectroscopy to assess nitrogen and carbon fractions in dairy cow feces. Animal Feed Science and Technology 185:53-59.

Anderson, D. M. 2010. Geospatial methods and data analysis for assessing distribution of grazing livestock. Proceedings of the 4th Grazing Livestock Nutrition Conference July 9-10, 2010 Estes Park, CO, USA. pp. 57-90.

Arango, J. A., L. V. Cundiff, and L. D. Van Vleck. 2002. Breed comparisons of Angus, Brahman, Hereford, Pinzgauer, Sahiwal, and Tarentaise for weight, weight adjusted for condition score, height, and body condition score. Journal of Animal Science 80:3142-3149.

Archer, J. A., P. F. Arthur, R. M. Herd, P. F. Parnell, and W. S. Pitchford. 1997. Optimum postweaning test for measurement of growth rate, feed intake, and feed efficiency in British breed cattle. Journal of Animal Science 75:2024-2032.

Archer, J. A., W. S. Pitchford, T. E. Hughes, and P. F. Parnell. 1998. Genetic and phenotypic relationships between food intake, growth, efficiency, and body composition of mice post weaning and at maturity. Animal Science 67:171-182.

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. Australian Journal of Agricultural Research 50:147-161.

Archer, J. A., A. Reverter, R. M. Herd, D. J. Johnson, 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.

Arthur, P. F., R. M. Herd, J. Wright, G. Xu, K. Dibley, E. C. Richardson. 1996. Net feed conversion efficiency and its relationship with other traits in beef cattle. Proceedings of the Australian Society of Animal Production 21:107-110.

Arthur, P. F., J. A. Archer, R. M. Herd, and G. J. Melville. 2001. Response to selection for net feed intake in beef cattle. Proceedings of the Association for the Advancement of Animal Breeding and Genetics 14:135-138.

Arthur, P. F., and R. M. Herd. 2008. Residual feed intake in cattle. Revista Brasileira de Zootecnia 37:269-279.

Ash, A. J., and D. M. S. Smith. 1996. Evaluating stocking rate impacts in rangelands: animals don’t practice what we preach. Rangeland Journal 18:216-243.

Atwood, S. B., F. D. Provenza, R. D. Wiedmeier, and R. E. Banner. 2001. Influence of free-choice vs mixed-ration diets on food intake and performance of fattening calves. Journal of Animal Science 79:3034-3040.

Bailey, D. W. 1995. Daily selection of feeding areas by cattle in homogeneous and heterogeneous environments. Applied Animal Behaviour Science 45:183-200.

Bailey, D. W., J. E. Gross, E. A. Laca, L. R. Rittenhouse, M. B. Coughenour, D. M. Swift, and P. L. Sims. 1996. Mechanisms that result in large herbivore grazing distribution patterns. Journal of Range Management 49:386-400.

Bailey, D. W., G. R. Welling, and E. T. Miller. 2001. Cattle use of foothills rangeland near dehydrated molasses supplement. Journal of Range Management 54:338-347.

Bailey, D. W. 2004. Management strategies for optimal grazing distribution and use of arid rangelands. Journal of Animal Science 82(E. Suppl.):E147-E153.

Baker, S. D., J. I. Szasa, T. A. Klein, P. S. Kuber, C. W. Hunt, J. B. Glaze Jr., D. Falk, R. Richard, J. C. Miller, R. A. Battaglia, and R. A. Hill. 2006. Residual feed intake of purebred Angus steers: Effects on meat quality and palatability. Journal of Animal Science 84:938-945.

Basarab, J. A., M. G. Colazo, D. J. Ambrose, S. Novak, D. McCartney, and V. S. Baron. 2011. Residual feed intake adjusted for backfat thickness and feeding frequency is independent of fertility in beef heifers. Canadian Journal of Animal Science 91:573-584.

Beauchemin, K. A., M. Kreuzer, F. O'Mara, and T. A. McAllister. 2008. Nutritional management for enteric methane abatement: a review. Australian Journal of Experimental Agriculture 48:21-27.

Bergmann, G. T., J. M. Craine, M. S. Robeson II, and N. Fierer. 2015. Seasonal shifts in diet and gut microbiota of the American bison (*Bison bison*). PLoS ONE 10(11):e014209.

Bingham, G. M., T. H. Friend, P. A. Lancaster, and G. E. Carstens. 2009. Relationship between feeding behavior and residual feed intake in growing Brangus heifers. Journal of Animal Science 87:2685-2689.

Black Rubio, C. M., A. F. Cibils, R. L. Endecott, M. K. Petersen, and K. G. Boykin. 2008. Piñon-juniper woodland use by cattle in relation to weather and animal reproductive state. Rangeland Ecology and Management 61:394-404.

Blackshaw, J. K., and A. W. Blackshaw. 1994. Heat stress in cattle and the effect of shade on production and behaviour: a review. Australian Journal of Experimental Agriculture 34:285-95.

Bonham, C. D., D. E. Mergen, and S. Montoya. 2004. Plant cover estimation: a contiguous Daubenmire frame. Rangelands 26:17-22.

Brelin, B., and E. Brannang. 1982. Phenotypic and genetic variation in feed efficiency of growing cattle and their relationship with growth rate, carcass traits and metabolic efficiency. Swedish Journal of Agricultural Research 12:29-34.

Briggs, J. M, and A. K. Knapp. 1995. Interannual variability in primary production in tallgrass prairie: climate, soil moisture, topographic position, and fire as determinants of aboveground biomass. American Journal of Botany 82:1024-1030.

Broom, D. M. 1992. Animal welfare: its scientific measurement and current relevance to animal husbandry in Europe. In: Phillips, C., and D. Pigginns. Farm Animals and the Environment. CAB, Wallingford, UK 245-253.

Carberry, C. A., S. M. Waters, D. A. Kenny, C. J. Creevey. 2014. Rumen methanogenic genotypes differ in abundance according to host residual feed intake phenotype and diet type. Applied and Environmental Microbiology 80:586-594.

Carstens, G. E., and L. O. Tedeschi. 2006. Defining feed efficiency in beef cattle. In: Beef Improvement Federation Conference, Choctaw, MS, USA, April 18-21.

Chapinal, N., A. M. de Passillé, D. M. Weary, M. A. G. von Keyserlingk, and J. Rushen. 2009. Using gait score, walking speed, and lying behavior to detect hoof lesions in dairy cows. Journal of Dairy Science 92:4362-4374.

Cheverud, J. M. 1988. A comparison of genetic and phenotypic correlations. Evolution 42:958-968.

Connor, E. E., J. L. Hutchison, H. D. Norman, K. M. Olson, C. P. Van Tassell, J. M. Leith, and R. L. Baldwin VI. 2013. Use of residual feed intake in Holsteins during early lactation shows potential to improve feed efficiency through genetic selection. Journal of Animal Science 91:3978-3988.

Crews, D. H. 2005. Genetics of efficient feed utilization and national cattle evaluation: a review. Genetics and Molecular Research 4:152-165.

Dai, P., S. Luan, X. Lu, K. Luo, X. Meng, B. Cao, J. Kong. 2017. Genetic assessment of residual feed intake as a feed efficiency trait in the Pacific white shrimp *Litopenaeus vannamei*. Genetics Selection Evololution 49:np.

Dolezal, S. L., and N. Coe. Hip height and frame score determination. ANSI-3271-4. Dunnington, E. A. 1990. Selection and homeostasis. 4th World Congress on Genetics Applied to Livestock Production. Edinburgh, Scotland. July 23-27, 1990.

Durunna, O. N., F. D. N. Mujibi, L. Goonewardene, E. K. Okine, J. A. Basarab, Z. Wang, and S. S. Moore. 2011. Feed efficiency differences and reranking in beef steers fed grower and finisher diets. Journal of Animal Science 89:158-167.

Durunna, O. N., M. G. Colazo, D. J. Ambrose, D. McCartney, V. S. Baron, and J. A. Basarab. 2012. Evidence of residual feed intake reranking in crossbred replacement heifers. Journal of Animal Science 90:734-741.

Eckard, R. J., C. Grainger, and C. A. M. de Klein. 2010. Options for the abatement of methane and nitrous oxide from ruminant production: a review. Livestock Science 130:47-56.

Enns, R. M. 2013. Understanding and applying economically relevant traits (ERT) and indices for the commercial cattle rancher. Proceedings, The Range Beef Cow Symposium XXIII, Rapid City, SD.

Forage Analyses Procedures. 1993. National Forage Testing Association. pp 79-81.

Forbes, T. D. A., F. M. Rouquette Jr., and J. W. Holloway. 1998. Comparisons among Tuli-, Brahman-, and Angus-sired heifers: Intake, digesta kinetics, and grazing behavior. Journal of Animal Science 76:220-227.

Ganskopp, D., and M. Vavra. 1987. Slope use by cattle, feral horses, deer, and bighorn sheep. Northwest Science 61:74-81.

Ganskopp, D. 2001. Manipulating cattle distribution with salt and water in large arid-land pastures: a GPS/GIS assessment. Applied Animal Behaviour Science 73:251-262.

Ganskopp, D., and D. Bohnert. 2006. Do pasture-scale nutritional patterns affect cattle distribution on rangelands? Rangeland Ecology and Management 59:189-196.

Ganskopp, D. C., and D. W. Bohnert. 2009. Landscape nutritional patterns and cattle distribution in rangeland pastures. Applied Animal Behavior Science. 116:110-119.

Gilbert, H., J. -P. Bidanel, J. Gruand, J. -C. Caritez, Y. Billon, P. Guillouet, H. Lagant, J. Noblet, and P. Sellier. 2007. Genetic parameters for residual feed intake in growing pigs, with emphasis on genetic relationships with carcass and meat quality traits. Journal of Animal Science 85:3182-3188.

Goddard, J. 1968. Food preferences of two black rhinoceros populations. East African Wildlife Journal 6:1-18.

Golden, J. W., M. S. Kerley, and W. H. Kolath. 2008. The relationship of feeding behavior to residual feed intake in crossbred Angus steers fed traditional and no-roughage diets. Journal of Animal Science 86:180-186.

Gomes, R. C., R. D. Sainz, S. L. Silva, M. C. César, M. N. Bonin, and P. R. Leme. 2012. Feedlot performance, feed efficiency reranking, carcass traits, body composition, energy requirements, meat quality and calpain system activity in Nellore steers with low and high residual feed intake. Livestock Science 150:265-273.

Grainger, C., T. Clarke, M. J. Auldist, K. A. Beauchemin, S. M. McGinn, G. C. Waghorn, and R. J. Eckard. 2009. Mitigation of greenhouse gas emissions from dairy cows fed pasture and grain through supplementation with *Acacia mearnsii* tannins. Canadian Journal of Animal Science 89:241-251.

Halfa, A. N., G. E. Carstens, T. D. A. Forbes, L. O. Tedeschi, J. C. Bailey, J. T. Walter, and J. R. Johnson. 2013. Relationships between postweaning residual feed intake in heifers and forage use, body composition, feeding behavior, physical activity, and heart rate of pregnant beef females. Journal of Animal Science 91:5353-5365.

Hammond, A. C., T. A. Olson, C. C. Chase Jr., E. J. Bowers, R. D. Randel, C. N. Murphy, D. W. Vogt, and A. Tewolde. 1996. Heat tolerance in two tropically adapted *Bos taurus* breeds, Senepol and Romosinuano, compared with Brahman, Angus, and Hereford cattle in Florida. Journal of Animal Science 74:295-303.

Harrison, R. O., J. W. Young, A. E. Freeman, and S. P. Ford. 1989. Effects of lactational level on reactivation of ovarian function, and interval from parturition to first visual oestrus and conception in high-producing Holstein cows. Animal Science 49:23-28.

Haque, M. N., H. H. Hansen, I. M. L. D. Storm, J. Madsen. 2017. Comparative methane estimation from cattle based on CO_2 production using different techniques. Animal Nutrition 3:175-179.

Herd, R. M., P. F. Arthur, R. S. Hegarty, and J. A. Archer. 2002. Potential to reduce greenhouse gas emissions from beef production by selection for reduced residual feed intake. 7th World Congress on Genetics Applied to Livestock Production, Montpellier, France.

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. Journal of Animal Science 81:E9-E17.

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. Australian Journal of Experimental Agriculture 44:423-430.

Herd, R. M., and P. F. Arthur. 2009. Physiological basis for residual feed intake. Journal of Animal Science 87(E. Suppl.):E64-E71.

Herring, W. O. and J. K. Bertrand. 2002. Multi-trait prediction of feed conversion in feedlot cattle. In: Proceedings of the Beef Improvement Federation. 34th Annual Research Symposium Meeting, University of Nebraska, Omaha. Pg. 89-97.

Holechek, J. L., R. D. Pieper, and C. H. Herbel. 2011. Range Management Principles and Practices. Prentice Hall, Upper Saddle River, NJ.

Jacobs, J. 1974. Quantitative measurement of food selection: a modification of the forage ratio and Ivlev's Electivity Index. Oecologia 14:413-417.

Jones, F. M., F. A. Phillips, T. Nayor, and N. B. Mercer. 2011. Methane emissions from grazing Angus beef cows selected for divergent residual feed intake. Animal Feed Science and Technology 166-167:302-307.

Kelly, A. K., M McGee, D. H. Crews Jr., A. G. Fahey, A. R. Wylie, and D. A. Kenny. 2010a. Effect of divergence in residual feed intake on feeding behavior, blood metabolic variables, and body composition traits in growing beef heifers. Journal of Animal Science 88:109-123.

Kelly, A. K, M. McGee, D. H. Crews Jr., T. Sweeney, T. M. Boland, and D. A. Kenny. 2010b. Repeatability of feed efficiency, carcass ultrasound, feeding behavior, and blood metabolic variables in finishing heifers divergently selected for residual feed intake. Journal of Animal Science 88:3214-3225.

Kenoyer, L. A. 1929. Plant physiognomy. Ecology 10:409-414.

Kerley, M. S. 2010. Impact of selection for residual feed intake on forage intake by beef cows and feed efficiency of progeny. In: Proceedings of the Florida Ruminant Nutrition Symposium, Florida, USA.

Knapp, A. K., J. M. Blair, J. M. Briggs, S. L. Collins, D. C. Hartnett, L. C. Johnson, and E. G. Towne. 1999. The keystone role of bison in North American tallgrass prairie: Bison increase habitat heterogeneity and alter a broad array of plant, community, and ecosystem processes. BioScience 49:39-50.

Knight, C. W. 2016. Intake, reproductive, and grazing activity characteristics of range cattle on semi-arid rangelands. Dissertation, The University of Arizona.

Knight, C. W., D. W. Bailey, and D. Faulkner. 2018a. Low-cost global positioning system tracking collars for use on cattle. Rangeland Ecology and Management 71:506-508.

Knight, C. W., D. W. Bailey, W. Manderville, and J. Wilker. 2018b. Data correction and analysis of spatial data using lower-cost global positioning system tracking collars. Society for Range Management 71st Annual Meeting. Abstract. Sparks, NV.

Koch, R. M., L. A. Swiger, D. Chambers, and K. E. Gregory. 1963. Efficiency of feed use in beef cattle. Journal of Animal Science 22:486-494.

Lalman, D., and C. Richards. Nutrient requirements of beef cattle. Oklahoma Cooperative Extension Service E-974.

Launchbaugh, K. L., and L. D. Howery. 2005. Understanding landscape use patterns of livestock as a consequence of foraging behavior. Rangeland Ecology and Management 58:99-108.

Lawrence, P., D. A. Kenny, B. Earley, D. H. Crews Jr., and M. McGee. 2011. Grass silage intake, rumen and blood variables, ultrasonic and body measurements, feeding behavior, and activity in pregnant beef heifers differing in phenotypic residual feed intake. Journal of Animal Science 89:3248-3261.

Lawrence, P., D. A. Kenny, B. Earley, and M. McGee. 2013. Intake of conserved and grazed grass and performance traits in beef suckler cows differing in phenotypic residual feed intake. Livestock Science 152:164-166.

Lechowicz, M. J. 1982. The sampling characteristics of electivity indices. Oecolgia 52:22-30.

Lucy, M. C. 2001. Reproductive loss in high-producing dairy cattle: where will it end? Journal of Dairy Science 84:1277-1293.

Manafiazar, G., J. A. Basarab, V. S. Baron, L. McKeown, R. R. Doce, M. Swift, M. Undi, K. Wittenberg, and K. Ominski. 2015. Effect of post-weaning residual feed intake classification on grazed grass intake and performance in pregnant beef heifers. Canadian Journal of Animal Science 95:369-381.

Marty, J. T. 2005. Effects of cattle grazing on diversity in ephemeral wetlands. Conservation Biology 19:1626-1632.

McAllister, T. A., and C. J. Newbold. 2008. Redirecting rumen fermentation to reduce methanogenesis. Australian Journal of Experimental Agriculture 48:7-13.

McCann, J. C., L. M. Wiley, T. D. Forbes, F. M. Rouquette Jr., and, L. O. Tedeschi. 2014. Relationship between the rumen microbiome and residual feed intake-efficiency of Brahman bulls stocked on bermudagrass pastures. PLoS ONE 9:e91864.

McDonagh, M. B., R. M. Herd, E. C. Richardson, V. H. Oddy, J. A. Archer, and P. F. Arthur. 2001. Meat quality and the calpain system of feedlot steers following a single generation of divergent selection for residual feed intake. Australian Journal of Experimental Agriculture 41:1013-1021.

McManus C., E. Prescott, G. R. Paludo, E. Bianchini, H. Louvandini, and A. S. Mariante. 2009. Heat tolerance in naturalized Brazilian cattle breeds. Livestock Science 120:256-264.

Meyer, A. M., M. S. Kerley, and R. L. Kallenbach. 2008. The effect of residual feed intake classification on forage intake by grazing beef cows. Journal of Animal Science 86:2670-2679.

Miller, L. L., P. B. Siegel, and E. A. Dunnington. 1992. Inheritance of antibody response to sheep erythrocytes in lines of chickens divergently selected for fifty-six-day body weight and their crosses. Poultry Science 71:47-52.

Moore, S. S., F. D. Mujibi, and E. L. Sherman. 2009. Molecular basis for residual feed intake in beef cattle. Journal of Animal Science 87(E. Suppl.):E41-E47.

Myer, P. R., T. P. L. Smith, J. E. Wells, L. A. Kuehn, and H. C. Freetly. 2015. Rumen microbiome from steers differing in feed efficiency. PLoS ONE 10:e0129174.

Naik, S. N. 1978. Origin and domestication of Zebu cattle (*Bos indicus*). Journal of Human Evolution 7:23-30.

NASEM. 2016. Nutrient Requirements of Beef Cattle (8th Edition). The National Academies Press, Washington, D.C.

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. Journal of Animal Science 84:145-153.

Oksanen, J., F. G. Blanchet, M. Friendly, R. Kindt, P. Legendre, D. McGlinn, P. R. Minchin, R. B. O'Hara, G. L. Simpson, P. Solymos, M. H. H. Stevens, E. Szoecs, and H. Wagner. 2018. Vegan: Community Ecology Package. R package version 2.4-6. https://CRAN.R-project.org/package=vegan.

Olff, H., and M. E. Ritchie. 1998. Effects of herbivore on grassland plant diversity. Trends in Ecology and Evolution 13:261-265.

Osuji, P. O. 1974. The physiology of eating and the energy expenditure of the ruminant at pasture. Journal of Range Management 27:437-443.

Paudyal, S., F. P. Maunsell, J. T. Richeson, C. A. Risco, D. A. Donovan, and P. J. Pinedo. 2018. Rumination time and monitoring of health disorders during early lactation. Animal 12:1484-1492.

Pépin, D., C. Adrados, C. Mann, and G. Janeau. 2004. Assessing real daily distance traveled by ungulates using differential GPS locations. Journal of Mammalogy 85:774-780.

Pfister, J. A. 2000. Food aversion learning to eliminate cattle consumption of pine needles. Journal of Range Management 53:655-659.

Pinchak, W. E., M. A. Smith, R. H. Hart, J. W. Waggoner Jr. 1991. Beef cattle distribution patterns on foothill range. Journal of Range Management 44:267-275.

Porath, M. L., P. A. Momont, T. DelCurto, and N. R. Rimbey, J. A. Tanaka, and M. McInnis. 2002. Offstream water and trace mineral salt as management strategies for improved cattle distribution. Journal of Animal Science 80:346-356.

Provenza, F. D. 1995. Postingestive feedback as an elementary determinant of food preference and intake in ruminants. Journal of Range Management 48:2-17.

Provenza, F. D., J. J. Villalba, L. E. Dziba, S. B. Atwood, and R. E. Banner. 2003. Linking herbivore experience, varied diets, and plant biochemical diversity. Small Ruminant Research 49:257-274.

Rauw, W. M., E. Kanis, E. N. Noordhuizen-Stassen, and F. J. Grommers. 1998. Undesirable side effects of selection for high production efficiency in farm animals: a review. Livestock Production Science 56:15-33.

Redfearn, D. D., and T. G. Bidwell. Stocking rate: the key to successful livestock production. Oklahoma Cooperative Extension Service PSS-2871.

Reynolds, C. K., H. F. Tyrrell, P. J. Reynolds. 1991. Effects of diet forage-to-concentrate ratio and intake on energy metabolism in growing beef heifers: whole body energy and nitrogen balance and visceral heat production. The Journal of Nutrition 121:994-1003.

Richardson, E. C., R. M. Herd, and V. H. Oddy. 2000. Variation in body composition activity and other physiological processes and their associations with feed efficiency. In ‘Feed efficiency in beef cattle. Proceedings of the feed efficiency workshop’. (Eds J. A. Archer, R. M. Herd, P. F. Arthur). pp 46-50. University of New England, Armidale, NSW.

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. Australian Journal of Experimental Agriculture 41:1065-1072.

Robert, B., B. J. White, D. G. Renter, and R. L. Larson. 2009. Evaluation of three-dimensional accelerometers to monitor and classify behavior patterns in cattle. Computers and Electronics in Agriculture 67:80-84.

Russell, M. L., D. W. Bailey, M. G. Thomas, and B. K. Witmore. 2012. Grazing distribution and diet quality of Angus, Brangus, and Brahman Cows in the Chihuahuan Desert. Rangeland Ecology and Management 65:371-381.

Sainz, R. D., and P. V. Paulino. 2004. Residual feed intake. UC Davis: Sierra Foothill Research and Extension Center.

Sawaguchi, I., K. Nishida, M. Shishiuchi, and S. Tatsukawa. 2003. Positioning precision and sampling number of DGPS under forest canopies. Journal of Forest Research 8:133-137.

Sawalhah, M. N. 2014. Livestock and vegetation responses to stocking rate treatments in two rangeland ecosystems of New Mexico. Dissertation. New Mexico State University.

Scholtz, M. M., J. B. J. van Ryssen, H. H. Meissner, and M. C. Laker. 2013. A South African perspective on livestock production in relation to greenhouse gases and water usage. South African Journal of Animal Science 43:247-254.

Senft, R. L., L. R. Rittenhouse, and R. G. Woodmansee. 1983. The use of regression models to predict spatial patterns of cattle behavior. Journal of Range Management 36:553-557.

Senft, R. L., M. B. Coughenour, D. W. Bailey, L. R. Rittenhouse, O. E. Sala, and D. M. Swift. 1987. Large herbivore foraging and ecological hierarchies. BioScience 37:789-795 & 798-799.

Shaffer, K. S., P. Turk, W. R. Wagner, and E. E. D. Felton. 2011. Residual feed intake, body composition, and fertility in yearling beef heifers. Journal of Animal Science 89:1028-1034.

Shike, D. W. 2012. Beef Cattle Feed Efficiency. Accessed October 17, 2018.

Silanikove, N. 2000. Effects of heat stress on the welfare of extensively managed domestic ruminants. Livestock Production Science 67:1-18.

Silverstein, J. T., M. Hostuttler, and K. P. Blemings. 2005. Strain differences in feed efficiency measured as residual feed intake in individually reared rainbow trout, *Oncorhynchus mykiss* (Walbaum). Aquaculture Research 36:704-711.

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko. 2007. Agriculture. In: Metz, B., O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer. (Eds.), Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA.

Smith. P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mary, C. Rice, B. Scholes, O. Sirotenko, M. Howden, T. McAllister, G. Pan, Romanenkov, U. Schneider, S. Towprayoon, M. Wattenbach, and J. Smith. 2008. Greenhouse gas mitigation in agriculture. Philosophical Transactions of the Royal Society B. 363:789-813.

Soil Survey Staff. Natural Resources Conservation Service. United States Department of Agriculture. Web Soil Survey. Accessed August 2017.

Stephenson, M. B., and D. W. Bailey. 2017. Do movement patterns of GPS-tracked cattle on extensive rangeland suggest independence among individuals? Agriculture 7:58.

Stuth, J., J. Abdi, and D. Tolleson. 2003. Direct and indirect means of predicting forage quality through near infrared reflectance spectroscopy. Field Crops Research 84:45-56.

Tate, K. W., E. R. Atwill, N. K. McDougald, and M. R. George. 2003. Spatial and temporal patterns of cattle feces deposition on rangeland. Journal of Range Management 56:432-438.

Taylor, C. S., H. G. Turner, and G. B. Young. 1981. Genetic control of equilibrium maintenance efficiency in cattle. Animal Science 32:179-194.

Tomkins, N. W., and R. A. Hunter. 2004. Methane mitigation in beef cattle using a patented anti-methanogen. In: Eckard, R. J, W. Slattery (Eds.), Proceedings of the 2nd Joint Australia and New Zealand Forum on Non-CO_2 Greenhous Gas Emissions from Agriculture. CRC for Greenhous Accounting, Lancemore Hill, Canberra. October 2003.

Tomkins, N., and P. O’Reagain. 2007. Global positioning systems indicate landscape preferences of cattle in the subtropical savannas. The Rangeland Journal 29:217-222.

Tyrl, R. J., T. G. Bidwell, R. E. Masters, R. D. Elmore. 2008. Field guide to Oklahoma plants: commonly encountered prairie, shrubland, and forest species. Oklahoma State University.

USDA. 2004. Port Series. National Cooperative Soil Survey.

Vallentine, J. F. 1990. Grazing Management. Academic Press, Inc. San Diego, CA.

van Eerden, E., H. van den Brand, G. De Vries Reilingh, H. K. Parmentier, M. C. M de Jong, and B. Kemp. 2004. Residual feed intake and its effect on *Salmonella enteritidis* infection in growing layer hens. Poultry Science 83:1904-1910.

Walker, J. W., R. K. Heitschmidt, and S. L. Dowhower. 1985. Evaluation of pedometers for measuring distance traveled by cattle on two grazing systems. Journal of Range Management 38:90-93.

Walker, J. W., and R. K. Heitschmidt. 1989. Some effects of a rotational grazing treatment on cattle grazing behavior. Journal of Range Management 42:337-342.

Warren, H. E., N. D. Scollan, G. R. Nute, S. I. Hughes, J. D. Wood, and R. I. Richardson. 2008. Effects of breed and a concentrate or grass silage diet on beef quality in cattle of 3 ages. II: Meat stability and flavor. Meat Science 78:270-278.

Wei, L. Y., W. M. S. Gomaa, B. N. Ametaj, T. W. Alexander, and W. Z. Yang. 2019. Feeding red osier dogwood (*Cornus sericea*) to beef heifers fed a high-grain diet affected feed intake and total tract digestibility. Animal Feed Science and Technology 247:83-91.

Wesley, R. L., A. F. Cibils, J. T. Mulliniks, E. R. Pollak, M. K. Petersen, and E. L. Fredrickson. 2012. An assessment of behavioural syndromes in rangeland-raised beef cattle. Applied Animal Behaviour Science 139:183-194.

Woodward, S. L., G. C. Waghorn, and P. Laboyrie. 2004. Condensed tannins in birdsfoot trefoil (*Lotus corniculatus*) reduced methane emissions from dairy cows. Proceedings of the New Zealand Society of Animal Production 64:160-164.

VITA

James Nolan Craun

Candidate for the Degree of

Master of Science

Thesis: THE EFFECT OF RESIDUAL FEED INTAKE ON ANGUS HEIFER GRAZING DISTRIBUTION, DIET SELECTION, AND BEHAVIOR

Major Field: Natural Resource Ecology and Management

Biographical:

Education:

Completed the requirements for the Master of Science in Natural Resource Ecology and Management at Oklahoma State University, Stillwater, Oklahoma in December, 2018.

Completed the requirements for the Bachelor of Science in Natural Resource Ecology and Management at Oklahoma State University, Stillwater, Oklahoma in 2016.

Experience:

- Graduate Research Assistant 2016-2018
  Oklahoma State University, Stillwater, OK
- Oral Presentations: Society for Range Management (Sparks, NV) and Oklahoma Natural Resources Convention (Tulsa, OK) 2018
- Teaching Assistant, NREM 3613 “Principles of Range Management” 2017
  Oklahoma State University, Stillwater, OK
- Restoration Research Technician 2016
  Fittstown, OK
- Undergraduate Research Technician 2014-2016
  Oklahoma State University, Stillwater, OK

Professional Memberships:

- Society for Range Management 2012-2018