THE INFLUENCE OF HEIFER POST-WEANING RESIDUAL FEED INTAKE ON SUBSEQUENT PRODUCTION, REPRODUCTION, GRAZING BEHAVIOR, SUPPLEMENT INTAKE BEHAVIOR, DRY MATTER INTAKE AND MILK PRODUCTION OF BLACK ANGUS BEEF CATTLE

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree

of

Doctor of Philosophy

in

Animal and Range Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2021

ACKNOWLEDGEMENTS

I would like to acknowledge and thank Montana State University, Montana Agriculture Experiment Stations and specifically the Northern Agriculture Research Center (NARC) for providing the cattle, data and resources for conducting this research and for allowing me to pursue my research and PhD program while working as the livestock operations manager. I would also like to acknowledge and thank the Nancy Cameron Endowment and Performance Nutrition for partial funding of this research. Special thanks to Julia Dafoe for her tireless efforts to maintain the working database on all cattle records at NARC and for her assistance in compiling the needed records and data. Additional thanks to the entire MSU NARC personnel for their assistance with field work and data collection. I would like to specifically thank Dr. Sam Wyffels for his assistance in data management, analysis, and interpretation, as well as assistance with manuscript editing. Thanks to my graduate committee, Dr.'s Tim DelCurto, Darrin Boss, Clayton Marlow and Megan Van Emon for their help and encouragement. I would like to extend my utmost appreciation and gratitude to my co-advisors Dr. Tim DelCurto and Dr. Darrin Boss for all the personal time and effort you spent encouraging and mentoring me along the way. Lastly, and most importantly, I would like to express my gratitude and appreciation to my wife, Danielle, and our family, Dakota, Nicole, Garrett and Paige, for their encouragement, patients, and support throughout this project, without them this would not have been possible.

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ABSTRACT

Residual feed intake (RFI) is a recognized measure of biological efficiency in beef cattle. However, RFI determination is expensive, time consuming and not well studied in beef cattle fed forage-based diets, nor how post-weaning RFI influences grazing behavior, supplement intake behavior or dry matter intake at different ages and physiological stages of production. Thus, the objectives of this research were to investigate how post-weaning RFI influences reproductive and productive performance, grazing behavior, supplement intake behavior as well as dry matter intake at different ages and physiological stages of production. A commercial herd of black Angus cows were utilized to conduct three experimental studies. Results indicate that classification of RFI for replacement heifers had little to no effect on subsequent beef cattle production and reproductive efficiency through the weaning of the 3rd calf. Subtle differences were denoted for cow Julian birth dates based on RFI classification and conception of 1st calf-heifers categorized as low RFI. However, heifer post-weaning RFI had little effect on subsequent cow performance (BW or BCS), grazing behavior, supplement intake behavior, and resource use. In addition, cow age significantly influenced cow performance, grazing behavior, supplement intake behavior, and resource use. We also observed high individual variability in grazing site selection, suggesting that individual-level factors may be driving grazing resource use and grazing behavior. Heifer post-weaning RFI did not influence mature cow dry matter intake, and this was consistent for both lactating and non-lactating beef cows. In contrast, cow age did correspond to quadratic increases of DMI and intake rates of mature cows. However, when DMI was expressed as $g \cdot kg$ body weight^{-1} no differences were observed with respect to cow age in lactating and non-lactating cows. Milk production was influenced by heifer post-weaning RFI for 2/3 and 5/6-yr old cows. Therefore, our studies suggests that selection for low RFI females would not impact overall herd productivity of cattle on foraged-based production systems, and that cow age has more of an impact on resource use, supplement intake, and grazing behavior, as well as DMI than heifer post-weaning RFI while grazing dormant-season mixed-grass prairie rangelands.

CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

It has been estimated that over the next 30 years, the world-wide population will exceed 9 billion, and as a result, food production will need to increase by over 70% (2050 High-level Experts Forum, 2021). Of the total increase in food production, meat will need to increase by approximately 200 million ton and accordingly, there will be greater demand for beef products (2050 High-level Experts Forum, 2021). Simultaneously, urban areas will expand, reducing natural resources and rangeland available for beef cattle production and other agricultural practices. Therefore, advancements in both management and technologies are required to reach a level of animal production that can sustain the anticipated population by 2050 (2050 High-level Experts Forum, 2021).

According to the 2017 US Department of Agriculture (USDA-NASS, 2019) Census, there are more than 720,000 beef cow-calf operations in the United States. This makes beef the single largest segment of US agriculture, as cow-calf operations represent 38% of US farms and ranches. Cattle and calves were the top ranked commodity in US agriculture in 2017, with $77.2 billion in sales with over 69.8 million head of cattle and calves. Montana ranches accounted for $1.73 billion of gross income with over 1.5 million head, contributing over 40% of Montana’s total agricultural sales in 2017 (USDA-NASS, 2019). The majority of Montana cattle operations are cow-calf operations that rely heavily on arid rangelands and supplemental feeds to supply the protein and energy needs of both cows and calves (Galyean and Goetsch 1993; Crowley et al., 2010).

Increasing high feed costs and continued drought have magnified the need for efficiency of cattle production in all segments of beef cattle production (Meyer and Gunn 2015).

Western U.S. cow-calf production systems rely heavily on rangeland forages to supply nutrients for the cow/calf industry (Galyean and Goetsch, 1993) with the primary goal of optimal animal performance while efficiently utilizing the forage resource base (Wyffels et al., 2019). Late season, dormant forage nutrient deficiencies often require protein supplementation to maintain animal production, and performance, and to provide increased economic efficiencies and returns (Bowman and Sowell, 1997; DelCurto et al., 2000). However, the reported effectiveness of protein supplementation programs on grazing beef cattle performance has been inconsistent, likely due to variation in animal-to-animal supplement intake (Bowman and Sowell, 1997; DelCurto et al., 2000; Wyffels et al., 2020a) and variation in animal to animal efficiencies associated with maintenance requirements (Arthur et al., 2001a; Nkrumah et al., 2006; Crowley et al., 2010). Furthermore, it has been reported that roughly two-thirds of mature cow energy requirements are utilized for maintenance (Ferrell and Jenkins, 1984, 1988; Montano-Bermudez et al., 1990; Van der Westhuizen et al., 2004; Meyer et al., 2008) with the remaining one-third being available for growth, production and reproduction. However, substantial animal-to-animal variation, independent of body size and growth, exists in maintenance requirements of cattle (Arthur et al., 2001b, Nkrumah et al., 2006; Crowley et al., 2010).

To improve profitability and sustainability, many beef cow operators have implemented management strategies involving late season dormant forage grazing aimed at minimizing costs involved in harvesting and feeding conserved forages (Adams et al. 1996; Wyffels et al., 2020b). The primary goal in a forage-based livestock production system is to obtain optimal animal performance while effectively utilizing the forage resource base (Wyffels et al., 2020b). Dormant rangeland forages are often deficient in nutrients, often less than 7% CP, which may limit dry matter intake and digestibility (Krysl and Hess 1993; Bowman et al. 1995) and lead to decreased production and performance (Krysl and Hess 1993; Bowman et al. 1995; Mulliniks et al. 2013). Grazing beef cattle are often supplemented to bridge the gap between the limited forage quality and their nutrient requirements and livestock requirements (Horn and McCollum 1987; Galyean and Goetsch, 1993; Bowman and Sanson, 1996). Supplementing protein to grazing beef cattle during times of low forage quality has been reported to improve animal performance and provide increased economic returns (DelCurto et al., 2000). Recent research has demonstrated that cow performance is related to supplement intake behavior (Wesley et al., 2012; Wyffels et al., 2020a), therefore, cow efficiency and residual feed intake (RFI) may also be linked to protein supplement intake behavior.

I. Environmental fit related to beef cattle production environments

The environmental fit theory focuses on the interaction between characteristics of the individual animal and their physical environment whereby the individual not only influences their environment, but the environment, in return, also influences the individual (Grayson et al., 2008). An ever-present topic of discussion in the Western U.S. beef cow industry relates to which cows are best suited to arid, western rangeland environments, focusing on cow size, cow weight and cow body condition score (Hammond et al., 1947; Dickerson, 1978; Stewart and Martin, 1983; Scasta et al., 2015). The basis of this discussion is which cow type is the most efficient at converting consumed forage into product; be it kilograms of calf weaned, average daily gain, or kilograms of milk, often referred to as efficiency (Stevens, 2000; Scasta et al., 2015; Beck et al., 2016). The interest in identifying animals that are best suited for arid, western rangelands is based on the need to optimize efficiency (kg of forage to kg of product) with limited and often decreasing land and forage resource base. Current research is limited pertaining to beef cattle selection criteria that can be utilized to identify animals that best fit extensive, arid, western rangelands (Black et al., 2013; Sprinkle et al., 2020). Past research has identified weaning weight ratio, kg of weaned calf to kg of cow body weight, as an accurate estimate of cow efficiency (Kirkpatrick et al., 1985; Kress et al., 2001; Scasta et al., 2015). Additionally, cow age and body size have been associated with calf weaning weight, milk production, feed intake and cow efficiency (Scasta et al., 2015; Beck et al., 2016).

Previous research focusing on measuring feed efficiency either assumed that cows consume 2 - 2.5% of their body weight daily, have used individual feed bunks, or fecal markers to estimate cow intake (Davis et al., 1983; Kirkpatrick et al., 1985; Kress et al., 2001). However, with current technology utilizing automated feeders and individual electronic identification (EID) tags, we now have the ability to collect accurate individual feed intake data, including intake behavior (visits per day, intake per visit, daily intake, and time spent at feeders) that we have not previously been capable of collecting

(Mendes et al., 2011). This technology is currently being used to collect precise intake date used to assess and report RFI classifications (GrowSafe; GrowSafe DAQ 4000E; GrowSafe System Ltd., Airdrie, AB, Canada), however this equipment is expensive, and the process is labor intensive and time consuming. Similar technology is currently being used on arid western rangelands to monitor and record individual animal supplement intake and intake behavior (C-Lock; Smart Feed systems). Combining these two similar technologies, we now have the ability to collect individual yearling intake data and calculate RFI, then compare these RFI classifications to mature cow supplement intake as well as mature cow efficiency and productivity on extensive arid, western rangelands. We also have the benefit of global position systems (GPS) collars that enable us to monitor and record individual grazing and distribution data, along with geographical locations and vegetation communities that cattle utilize during their daily grazing activities. Recent research focusing on cow efficiency has investigated the relationship of heifer RFI on mature cow productivity, and feed efficiency on Western rangelands (Sprinkle et al., 2019a; Sprinkle et al., 2019b; Sprinkle et al., 2020).

Recent studies have investigated the relationship between heifer post-weaning RFI, grazing behavior (Loyd et al., 2011, Black et al., 2013, Sprinkle et al., 2019a; Sprinkle eta l., 2019b; Sprinkle et al., 2020), intake behavior, cow productivity, and dry matter intake at different ages (Arthur et al., 2005; Basarab et al., 2007; Bradbury et al., 2011; Loyd et al., 2011; Black et al., 2013; Freetly et al., 2020) as well as different physiological stages of production (Kelly et al., 2010a, b; Loyd et al., 2011). There has been considerable research related to the biotic and abiotic features associated with grazing distribution (Coughenour, 1991; Ganskopp, 2001; Bailey, 2005; Stephenson et al., 2016; Wyffels et al., 2019), however, little research has evaluated how heifer post-weaning RFI influences grazing distribution and cow performance on extensive rangeland environments (Sprinkle et al., 2019a; Sprinkle et al., 2019b; Sprinkle et al., 2020).

Although a central aspect of livestock ecosystems, the spatial component of livestock grazing has remained problematic to interpret (Coughenour, 1991). Mechanisms that influence grazing distribution can be classified as either: exogenous, the physical environment in which livestock graze, such as topography and slope, or endogenous, such as social learning and experience, (Dunn et al., 1988; Bailey et al., 1996; Launchbaugh and Howery, 2005; Wallburger et al., 2009; Wyffels et al., 2020c). Topography and distance from water are the two physical characteristics of a landscape that have the largest impacts on grazing distribution of beef cattle (Roath and Krueger 1982; Allred et al. 2011; Kohl et al. 2013). It has been reported that grazing cattle will not use areas further than 3.2-km from water (Pringle et al., 2004; Kohl et al. 2013) or slopes steeper than 11^0 (Van Vuren, 2001). The energetic costs associated with traveling to water increase as slopes gradients increase, such that vertical distance above water reduces cattle grazing use (Roath and Krueger 1982). Cattle are considered central place grazers, meaning they meet their energetic needs with least overall energetic expenditures (Van Vuren 2001). Additionally, traveling and search time influences the energy requirements of grazing livestock (Walker et al., 1985). The energetic costs associated with travel have been reported to increase maintenance requirements from 10 – 25% in grazing animals (Ribeiro et al., 1977; Havstad and Malechek, 1982). Thus, time spent grazing and distance traveled can have considerable impact on individual animal production and efficiency. Recent research has demonstrated that nutrient efficient cows distribute further and outperform less efficient cows (Sprinkle et al., 2019a; Sprinkle et al., 2020). Therefore, it is likely that grazing behavior may vary with cow efficiency and cow age while grazing nutrient deficient forages. However, interactions of exogenous factors with endogenous attributes on grazing behavior are poorly understood (Wallburger et al., 2009).

II. Tools that can/are being used for selecting cattle

A. Cow size

The effect of cow size related to production efficiency has been evaluated by numerous researchers (Taylor, 1971; Morris and Wilton, 1976; Dickerson, 1978; Fitzhugh, 1978; Ferrell and Jenkins, 1985). Morris and Wilton (1976) stated that little variation is expected in biological efficiencies due to differences in size of cows, although considerable changes in outputs and requirements per animal may be induced by changes in cow size. Fitzhugh (1978) suggests that production efficiency might lead to important genotype x production environment interactions, and both Cartwright (1970) and Gregory (1972) suggest that genotype x environment interaction relationships are extremely important to beef production efficiency.

Cow body size may influence calf weaning weight and feed intake, and as a result, cow efficiency (Dinkel and Brown, 1978; Scasta et al., 2015; Beck et al., 2016). Since

1975, average cow weights have increased from an average of 475 kg to 621 kg and this increase in size has been attributed to a 22% increase in daily maintenance requirements associated with a 22-28% increase in dry matter intake (Beck et al., 2016; National Academies of Sciences, 2016). Scasta et al. (2015) suggested that with the increase in selection for performance traits there has been an accompanied increase in cow size. However, previous research has indicated that large cows may not be as well suited to western, arid rangeland-based production settings (Kress et al., 1969; Scasta et al., 2015; Beck et al., 2016).

B. Feed to gain, and RFI

Traditionally, feed efficiency of beef cattle has been expressed as the ratio of dry matter intake to body weight gain (feed to gain or gain to feed), however, selection for high growth rates inevitably increases the maintenance requirements, feed requirements, and intake of cattle, with subsequent higher environmental impacts and feed costs (Okine et al. 2004). Beef cattle feed efficiency has been reported to be the leading indicator of cow-calf productivity and profitability (Koch et al., 1963; Arthur et al., 2001b; Nkrumah et al.; 2006, Berry and Crowley, 2013). Feed efficiency has been defined as the ability of an animal to convert kg of dry matter consumed to kg of product produced and is measured as a ratio between the two (Berry and Crowley, 2013; Scholljegerdes and Summers, 2016). Although feed efficiency is not synonymous with production efficiency, it plays a contributing role in the ability to increase livestock efficiency on a decreasing land and forage base (Berry and Crowley, 2013). Previous research conducted on beef cattle feed efficiency have focused on breeding and genetic selection to improve feed efficiency (Koch et al., 1963; Montano-Bermudez et al., 1990; Archer et al., 2002; Berry and Crowley, 2013).

Net feed efficiency (crews, 1941) or residual feed intake (Koch et al., 1963) is defined as the difference between an animal's actual feed intake and its expected feed requirements for maintenance and growth. Residual feed intake is calculated as the difference between actual feed intake and predicted feed intake with negative or smaller values being more desirable than positive or larger values (Crews, 2005). Cattle that are more efficient than their contemporary group have a lower RFI value with feed intake being lower than predicted and cattle that are less efficient having a higher RFI value with feed intake being greater than predicted. Residual feed intake is an alternative measure of feed efficiency and is phenotypically independent of growth rate and body size (Crews, 2005; Arthur et al., 2008).

Multiple studies have reported that feed intake is a heritable trait in beef cattle (Koch et al., 1963; Fan et al., 1995; Nkrumah et al., 2007; Elzo et al., 2009; Mao et al., 2013; Retallick et al., 2017), with all studies estimating the heritability of feed intake in growing cattle between 0.20 to 0.48. Crowley et al. (2010) reported that RFI is moderately heritable at 0.45, therefore, selecting replacements with low RFI should produce energy-efficient progeny. Estimates of RFI, as well as, feed efficiency are often used with bull tests and sire summaries and, in turn, recommended as a tool to select sires for beef production systems under the expectation of improved efficiency of their offspring, with low RFI selection pressure. However, information regarding the repeatability of RFI at different ages, physiological stages of production, in different environments, and on different diets is limited (Manafiazar et al., 2015; Black et al., 2013; Freetly et al., 2020). It has been previously reported that heifer RFI and mature cow RFI are similar (Archer et al., 1999; Archer et al., 2002; McDonald et al., 2010). However, Meyer et al. (2008) and Lawrence et al. (2012) both concluded that RFI classification determined in heifers was not an adequate predictor of cow DMI while grazing.

Based on the fact that a considerable amount of individual animal variation exists regarding feed intake (Herd et al., 2003) and maintenance requirements (Johnson et al., 2003), there is an opportunity within the beef industry to genetically select for feed efficient cattle which has the potential to maximize profitability and sustainability within all sectors of beef production systems. When feed requirements of the US beef industry are evaluated, it is the breeding cowherd that requires more than half of the total feed requirements compared to feedlot cattle (Carstens and Tedeschi, 2006) indicating that these producers have the potential to improve profitability through improved feed efficiency and reduction in feed costs (Ahola and Hill, 2012). Archer et al. (2002) reported that an improvement in postweaning efficiency would be reiterated in mature animal efficiency based on estimates that a portion of the genetic variation resulting from biological processes regulating intake and efficiency are similar during both life stages. Therefore, improvements in feed efficiency at different stages of production could positively impact total production system efficiency (Crews, 2005). Additionally, possibilities exist for improvement in beef production beyond the cost savings associated with reduced feed requirements. Okine et al. (2001) and Hegarty et al. (2007) reported reductions in methane emissions (9-12%) and manure production (15-17%) from cattle with improved feed efficiency.

Biological mechanisms involved in beef cattle performance, as well as, response to RFI may interact with cow age, physiological stage of production, and availability of feed resources (Loyd et al., 2011; Sprinkle et al., 2020). Numerous factors may influence regulation of satiety in growing cattle, including composition of ration or diet. Freetly et al., (2020) stated that the signals for satiety in high concentrate rations may be associated with chemical signals while those in forage-based diets are probably associated with gut fill. Previous research that has evaluated the impact of selection pressure for low RFI progeny is often inconsistent in respect to body condition, heifer maturity, and reproductive response. Randel and Welch (2013) found that low RFI females were leaner, reached puberty at an older age, and calved later as heifers and subsequent calf crops than their high RFI contemporaries. Similarly, Sprinkle et al., (2020) observed lower initial body condition score in 2-yr-old low RFI cows, but over the winter grazing period low RFI cows had less weight loss and concluded the trial at a similar body condition as the high RFI 2-yr-old cows. In contrast, Basarab and coworkers (2007) summarized 10 years of performance records of dams that produced low, average, and high RFI progeny and concluded that dams who produced low RFI progeny had greater backfat (mm) and were in better condition prior to breeding than dams that produced high RFI progeny. No differences were observed in cow weights or calf 205-day adjusted weaning weights relative to RFI classification of the progeny (Basarab et al., 2007).

III. Residual feed intake, early development and application

A. Value of technique compared to gain or feed to gain

The performance of beef cattle has traditionally been evaluated using traits that measure total output (i.e. weight gain and/or lean meat carcass yield) without consideration for inputs such as feed requirements for maintenance and/or additional growth. The feed conversion ratio has historically been a useful measure of feed efficiency, however, selection for this ratio trait (Gunsett, 1984) results in heavier mature weights (Koots et al., 1994) which leads to increased feed requirements and therefore is an ineffective method to improve production and biological efficiency (Archer et al., 1999; Johnson et al., 2003). Residual feed intake was first proposed for beef cattle by Koch et al. (1963); expected feed intake was calculated by regressing average daily gain and metabolic mid-test weight on standardized feed intake, and the difference of this value from actual feed intake provided a “residual” or RFI value. The initial limitations to adopting this methodology for predicting feed efficiency on a large-scale basis was the inability to accurately measure feed intake in a feedlot setting. Advancements of individual feed intake recording systems, such as GrowSafe® Feeding Systems (GrowSafe Systems Ltd., Airdrie, Alberta), have made accurate feed intake monitoring possible.

A benefit of RFI over traditional efficiency measures is its ability to assess biological efficiency while maintaining phenotypic independence from most production traits (Arthur et al., 2001a; Archer et al., 1999; Basarab et al., 2003). Even so, the beef production, industry-wide adoption of the RFI concept has been limited. There are aspects associated with RFI that require further research before widespread adoption in the beef industry can occur. At present, RFI is typically measured during a small portion of the growing phase of a young beef animal's life, similar to most other growth and carcass traits. Performance during this time frame is assumed to be reflective of the animal's biological efficiency throughout its entire life (Archer et al., 1999; Basarab et al., 2003; Kelly et al., 2010a, b). However, repeatability estimates of RFI have been variable; moderate to high repeatability's were reported in beef heifers with evidence of reranking (Kelly et al., 2010a) while Durunna et al. (2012) observed that over half of the steers in both the control and feed-swap groups changed RFI by more than 0.5 SD in consecutive feeding periods. Similarly, Durunna et al. (2012) observed 51% of heifers change RFI class when fed the same diet in successive 70-d feeding periods. This implies that further research is needed to investigate repeatability of RFI and potential factors that may influence values.

Historically, beef performance evaluations have been conducted with concentrate-based diets and are assumed to reflect animal performance regardless of diet composition. Typically, central test stations have evaluated bull performance, including RFI, when fed high-energy diets. A lack of literature involving bulls fed forage-based diets limits the comparison of feed intake, growth, carcass traits or biological efficiency for bull performance under different regimes. Recent RFI studies with bulls have utilized corn grain as the primary carbohydrate source (Lancaster et al., 2009; Montanholi et al., 2010). Assessing the variation in biological efficiency for an individual beef animal receiving a forage-based diet followed by a grain-based diet, or vice versa, would improve our understanding of RFI and the effectiveness of selecting more efficient animals to increase the future profitability in cow-calf operations (Montanholi et al., 2010).

B. Backgrounding and feedlot applications

Most RFI studies are based on energy-dense diets focusing on feedlot performance (Lawrence et al., 2014) with limited information pertaining to RFI of cattle offered forage-based diets (Arthur et al., 2005; Black et al., 2013; Freetly et al., 2020). Residual feed intake is typically calculated using phenotypic regression of feed intake on measured traits (Archer et al., 1997; Basarab et al., 2003). For accurate measures of feed efficiency, animals should not experience any nutritional restrictions and the same ration should be supplied ad-libitum for the entire feeding period to reflect true intake (Basarab et al., 2003).

It has been suggested that improved RFI does not have antagonistic effects associated with carcass or product quality (Richardson et al., 2001; McDonagh et al., 2001; Nkrumah et al., 2004). Intramuscular fat (IMF) is an important component of the beef quality grading system in that it represents the degree of carcass marbling and thus influences quality grade scores. Thus, it is linked to beef palatability and carcass value, both of which are key components determining market trends and return on investment. Previous studies (Carstens et al., 2002; Schenkel et al., 2004; Baker et al., 2006) reported no correlation between RFI and IMF. Basarab et al. (2003) reported that there was a tendency for RFI to be correlated with ultrasound marbling in crossbred cattle but found no association between RFI and carcass marbling scores. Furthermore, McDonagh et al.

(2001) reported no differences between high and low RFI groups when measuring Warner-Bratzler shear force of steaks aged for 1 or 14 d. Similarly, Ahola et al. (2011) indicated a similar relationship and also reported a lack of association between RFI and sensory traits. Baker et al. (2006) reported a tendency for lower juiciness and off-flavor scores of steaks from high RFI steers compared with steaks from low RFI steers. Thus, RFI may be associated with important carcass measurements, such as IMF and marbling scores. However, this relationship appears to be unrelated in some studies where RFI has been corrected for body fatness (Ahola and Hill, 2012). Additionally, there appears to be little association between RFI and measurements of end-product quality indicating that selection for RFI should not diminish taste or texture parameters associated with improved beef quality (Baker et al., 2006).

It is well documented within the literature that RFI is not associated with production traits such as ADG (Koch et al., 1963; Arthur et al., 2001a; Arthur et al., 2001b; Basarab et al., 2003). Data reported by Baker et al. (2006) illustrated the potential variation in RFI, with respect to ADG, in that two steers growing at similar rates (~1.46 kg/d) were consuming very different amounts of feed (8.6 kg/d and 11.5 kg/d). This study also indicated that animals with similar RFI values (-0.48 and -0.63) can display different growth rates (1.3 kg/d and 1.6 kg/d, respectively: Hill and Ahola, 2012). Additionally, it has been shown that RFI is positively associated with DMI (Herd and Bishop, 2000; Basarab et al., 2003), indicating that DMI has a greater effect on feed efficiency status than does ADG. The identification of these relationships and their implications for beef production practices has contributed to alleviation of long-term concerns regarding the selection and implementation of RFI and any correlated responses with growth and mature patterns that may occur (Hill and Ahola, 2012).

Body composition is a major determinant of feed energy requirements and therefore, has been recognized as a partial driver of the variation in RFI. Studies within the literature indicate that differential RFI is partially associated with relatively greater lean tissue accretion (i.e., muscle) and a relative decrease in fat deposition (Richardson et al., 2001; Carstens et al., 2002; Basarab et al., 2003). Jensen et al. (1992) reported a positive genetic correlation of 0.17 ± 0.32 between RFI and carcass lean percentage; however, in contrast, Herd and Bishop (2000) reported a negative genetic correlation of -0.47 ± 0.23 for the same relationship. Richardson et al. (2001) indicated that selection for reduced RFI resulted in a trend towards an increase in lean tissue content of carcasses, which agrees with results reported by Herd and Bishop (2000).

IV Use of RFI with cow/calf production

A. Research to date

Production efficiency of cow-calf operations is largely influenced by reproductive performance, as cows must rebreed and wean a calf every 12 months. A variety of factors impact reproductive performance, such as cow age, plain of nutrition, nutrient intake, and body composition. Small negative impacts of low RFI on fertility in Angus cows divergently selected for RFI have been reported (Arthur et al., 2001a; Arthur et al., 2005), where a trend was observed for low RFI cows to calve 5 days later in the year than high RFI cows. Researchers indicated that the calving delay could have resulted from longer gestation length, longer anestrus period, and/or delayed pregnancy in low RFI cows. Basarab et al. (2007) also reported that cows producing low RFI progeny produced their next calf 5-6 days later in the year than cows producing high RFI progeny. Other studies (Johnston et al., 2009; Shaffer et al., 2011) have suggested that high RFI heifers experience the onset of puberty earlier than low RFI heifers due to their increased feed consumption and body condition. Basarab et al. (2007) reported no differences in pregnancy rates of cows producing low and high RFI progeny. Likewise, Donoghue et al. (2011) observed no differences in pregnancy rates of low and high RFI heifers.

Previous research pertaining to beef cattle feed efficiency has focused on RFI and using RFI as a predictor of lifetime cow efficiency and productivity (Lawrence et al., 2012; Waghorn et al., 2012; Bolormaa et al., 2013; Hafla et al., 2013; Manafiazar et al., 2015). However, research that has been conducted examining the use of RFI in forage-based cow/calf production settings outside of feedlot situations have indicated that RFI may not be useful for cow-calf production settings (Meyer et al., 2008; Lawrence et al., 2012; Manafiazar et al., 2015).

Studies have shown no significant differences in pregnancy, calving, or weaning rates between low and high RFI females measured postweaning (Arthur et al., 2005) or from cows which produced low and high RFI progeny (Basarab et al., 2007). While these studies displayed no negative reproductive effects with selection for improved feed efficiency, Blair et al. (2013) reported a trend of low RFI heifers to have a lower first-service conception rate when compared to less efficient females. However, the authors also showed that when RFI was estimated from a breeding group average, calves sired from low RFI bulls were born earlier in the year. Donoghue et al. (2011) also demonstrated a negative relationship between RFI and reproductive fitness where low RFI heifers carried less subcutaneous fat and reached puberty later than high RFI heifers.

Possibilities have been suggested for reasons why low RFI animals may have decreased reproductive fitness. Basarab et al. (2007) first proposed that the feed intake procedure used to calculate RFI favors later maturing animals. This could lead to animals having immature reproductive tracts during the experiment resulting in expected decreased performance when breeding soundness exams and reproductive traits are measured because of the delayed onset of puberty. Pre-pubescent cattle, both male and female, will also expend a reduced amount of energy by exhibiting less sexual activity and having a later development of the reproductive system which favors the RFI phenotype (Awda et al., 2013).

1. Diet differences The effect of diet has been investigated in beef steers and heifers (Crews et al., 2003; Kelly et al., 2010a, b; Durunna et al., 2011; Loyd et al., 2011) by comparing RFI in both grower and finisher diets in successive feeding periods. Kelly et al. (2010a) estimated repeatability to be even greater (R=0.62) between RFI in the grower versus finisher stages with crossbred heifers. Although close to one quarter (24%) of the heifers re-ranked by more than 1 SD of the original RFI, 54% changed rank by less than 0.5 SD, providing evidence that RFI is a moderately consistent trait when measured in the growing and finishing phase of an animal's life, and regardless of whether the diet is roughage or grain-based. Durunna et al. (2011) reported more significant re-ranking of RFI measured between two different feeding periods. They suggest that diet type may

affect feed efficiency, while re-ranking in the two control groups imply that feeding period effects, including ambient temperature, growth phase and/or stage of maturity of the animal, will influence feed efficiency measurements. The observed re-ranking suggests that RFI measured using different diets or at different physiological life stages may be separate measures of efficiency altogether (Durunna et al., 2011). Generally, intake on high quality high concentrate diets is via metabolic signals. Freetly et al., (2020) stated that the signals for satiety in high concentrate rations may be associated with chemical signals. In contrast, low-quality high-fiber diets are generally thought to be regulated by ruminal/reticular volume (gut fill) and passage of fiber through the reticulum to the omasum (Van Soest, 1982).

2. Stage of growth Few studies have determined RFI for beef cattle in consecutive feeding periods. Arthur et al. (2001b) measured feed intake and performance in Charolais bulls over several months and partitioned the entire feeding period into a period that began immediately after weaning followed by a second feeding period that began the following spring. RFI was calculated for each feeding period, with a highly positive genetic correlation (r=0.75) and a lesser, but still positive phenotypic correlation (r=0.43). Evidence supporting observed differences in RFI measured at different stages of an animal's life was reported by Durunna et al. (2012). Of the 190 crossbred heifers fed the same diet in successive feeding periods, 51% changed their RFI group (low, medium and high based on ± 0.5 SD of the mean) in the second feeding period, while 59% of heifers changed their RFI value in the second feeding period by at least 0.5 SD from the first feeding period measurement. These results indicate that RFI measured post-weaning and

as a yearling beef animal should be considered different traits, perhaps due to the differences in tissue deposition during each phase with primarily lean tissue growth in the post-weaning phase versus fat tissue deposition as yearlings (Berg and Butterfield, 1976). However, the positive relationship shown between RFI calculated at different ages suggests improvements can be made in biological efficiency through downward selection on RFI (Arthur et al., 2001b).

3. Age and maturity Just as differences in RFI repeatability have been observed with changes in diet and growth phase, the effect of stage of maturity has also been studied. However, there has been limited research in this area, possibly due to the high costs associated with measuring RFI. Nieuwhof et al. (1992) showed low phenotypic correlations between RFI measured in dairy heifers and again as lactating cows (r=0.07). Herd et al. (1998) evaluated 56 cows of known RFI to determine if heifers that ranked high in net feed efficiency measured post-weaning remained efficient as 3-yr old cows. Intra-ruminal alkane boluses were used to estimate dry matter intake while on pasture, and cows and calves were weighed to determine initial weight, calf weight gain, and final weight. Efficiency was measured using a ratio of calf weight sustained by the cow divided by the dry matter intake of the cow. It was reported that the more efficient dams produced 15% more calf weight per kg of intake than less efficient dams, but although the difference was numerically large the results were not significant.

Archer et al. (2002) calculated the RFI of beef females just after weaning and again as 3-yr old cows. Phenotypic correlations for RFI measured post-weaning and at maturity was moderate (r=0.40), although RFI showed a higher repeatability than ADG or feed conversion rate (r=0.28 and 0.10, respectively). However, genetic correlations of the component traits of RFI were very high between postweaning and mature measurements. In addition, the genetic correlation between RFI measured at different life stages was close to 1 (r=0.98), suggesting that selecting low RFI heifers will result in a more efficient cow herd (Archer et al., 2002). Differences in the magnitude of phenotypic and genetic correlations from the previously mentioned studies can possibly be attributed to different cow types (dairy versus beef), age at which RFI was calculated on cows, and conditions under which the cows were maintained (dry cows versus lactating cows).

Meyer et al. (2008) calculated RFI on Hereford heifers and grouped them into low and high RFI classes. After calving, these females were housed by RFI group on pasture and average forage dry matter intake was estimated using grazing enclosures, weekly rising plate meter readings, and forage harvests every 21 days. The low RFI cows with their calves numerically consumed less feed than the high RFI pairs. The authors concluded that either forage intake did not differ between low and high RFI cattle on pasture, or that methodology and the small sample size used in the experiment limited their ability to detect any noticeable differences (Meyer et al., 2008).

4. Progeny Heritability estimates for RFI range from 0.20 - 0.48 and indicate that genetic improvement through selection may be possible for beef cattle. While most of the feed requirements for beef production can be attributed to the cow herd (Montano-Burmudez et al., 1990), the majority of RFI studies measured feed efficiency in young, growing animals. Moderate heritability estimates for biological efficiency have been reported extensively in a feedlot or bull test setting (Koch et al., 1963; Arthur et al.,

2001b; Nkrumah et al., 2007). These heritability estimates derived from phenotypic and genetic variance are useful; however more meaningful values can be determined using progeny records. Herd et al. (1997) used multiple years of progeny data to compare dam and sire efficiency to subsequent progeny efficiency. Heifers and bulls were evaluated for net feed intake (NFI; synonymous with RFI) after weaning and animals were divided into two separate herds based on high or low efficiencies (RFI). The efficient bulls were mated with the efficient heifers, and vice-versa, to establish two NFI lines. Progeny from the low RFI cows and bulls were significantly more efficient than progeny from high RFI parents providing results that confirm a moderate heritability estimate for biological efficiency (Herd et al., 1997).

In a similar study evaluating RFI of cow progeny, Basarab et al. (2007) showed that dams producing more efficient calves (low RFI group) consumed 1.31 kg/d DM less than cows producing inefficient offspring, with similar progeny weights and pre-weaning ADG. The dams of more efficient progeny correspondingly exhibited lower RFI values than cows producing inefficient calves. This evidence suggests that biological efficiency is a trait that can be inherited and expressed by progeny (Basarab et al., 2007).

V. Limitations of research to date

As stated earlier, most RFI studies are based on energy-dense diets focusing on feedlot performance (Lawrence et al., 2014) with limited information pertaining to RFI of cattle offered forage-based diets (Arthur et al., 2005; Black et al., 2013; Freetly et al., 2020) and even less information related to beef cows (Basarab et al., 2007; Meyer et al., 2008; Manafiazar et al., 2015; Sprinkle et al., 2020). More research is needed related to the lifetime performance of low and high RFI cattle in forage-based rangeland environments aimed at increasing feed efficiency of western beef cattle operations (Manafiazar et al., 2015; Sprinkle et al., 2020). Black et al., (2013) stated the relationship between post-weaning RFI and subsequent reproductive performance and longevity needs to be fully characterized to understand the impact RFI may have in a breeding scenario.

VI. Conclusion

While RFI has been shown to be moderately heritable, and an alternate measure of feed efficiency in feedlot cattle fed high concentrate feedlot rations, there is currently a lack of, and a need for research to examine the influence of heifer post-weaning RFI classification on production and reproduction, supplement intake behavior, grazing behavior, dry matter intake and milk production at different ages and physiological stages as an accurate metric of beef cow efficiency. In Chapter 2, we evaluate the Impacts of heifer post-weaning residual feed intake classification on reproductive and performance measurements of first, second and third parity Angus beef females. In Chapter 3, we evaluate the influence of residual feed intake and cow age on body weight and body condition change, supplement intake, resource use, and grazing behavior of beef cattle winter grazing mixed-grass rangelands. In Chapter 4, we evaluate the influence of residual feed intake classification and cow age on dry matter intake post-weaning and peak lactation of black Angus cows. In Chapter 5, we provide an overall conclusion from our research and discuss how our results can contribute to future studies of residual feed intake and its relevance to commercial beef cattle production.

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CHAPTER TWO

IMPACTS OF HEIFER POST-WEANING RESIDUAL FEED INTAKE CLASSIFICATON ON REPRODUCTIVE AND PERFORMANCE MEASUREMENTS OF FIRST, SECOND AND THIRD PARITY ANGUS BEEF

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Transl. Anim. Sci. 2021.5:1-9 doi:10.1093/tas/txab061

Status of Manuscript:

____ Prepared for submission to a peer-reviewed journal

____ Officially submitted to a peer-reviewed journal

____ Accepted by a peer-reviewed journal

_X__ Published in a peer-reviewed journal

CHAPTER TWO

IMPACTS OF HEIFER POST-WEANING RESIDUAL FEED INTAKE CLASSIFICATON ON REPRODUCTIVE AND PERFORMANCE MEASUREMENTS OF FIRST, SECOND AND THIRD PARITY ANGUS BEEF

Abstract

This study evaluated heifer post-weaning residual feed intake (RFI) classification on reproductive and performance measurements of first, second and third parity Angus beef females. We analyzed the annual, as well as, cumulative production of 347 Angus females from birth through weaning of their 3rd calf. Heifer post-weaning RFI was calculated as the actual dry matter intake minus the predicted dry matter intake based on the average daily gain of the contemporary group on an annual basis. Heifers were categorized based on RFI as either low (< -0.50 SD from mean), average (± 0.50 SD from mean), or high (> +0.50 SD from the mean) within year. There was no RFI × Parity interaction ($P \geq 0.14$) observed for all production/reproduction traits except for conception rates ($P = 0.02$). Julian birth date of cows was influenced by RFI classification ($P < 0.01$) and displayed a quadratic ($P = 0.02$) effect with high RFI cows being born earlier in the calving season than average RFI cows (71.2 vs 75.3 days), but did not differ from low RFI cows (74.0 vs 75.3 days). Cow birth weight, weaning weight, as well as, all other cow weight and body condition measurements were not influenced by RFI classification ($P \geq 0.14$). As expected, there was a linear increase in cow body weight at weaning with increasing parity ($P < 0.01$). Cow RFI classification had no influence on progeny weaning weight, birth date, calving interval, or postpartum interval (*P* ≥ 0.15). Calf birth weights displayed a quadratic parity effect (*P* < 0.01) with 1st calf heifers having calves with lower birth weights than 2nd and 3rd parity calves. Calf 205 day adjusted weaning weights displayed a quadratic effect (*P* = 0.01) with 1st calf heifers weaning lighter calves than 2nd and 3rd parity cows. Weaning weight ratio displayed a linear decrease with increasing parity (*P* < 0.01). Cow conception probability displayed a linear tendency for pregnancy 2 (*P* = 0.09), and a quadratic tendency for pregnancy 4 (*P* = 0.07) as a function of RFI classification, but no effects were observed for pregnancy 1 and 3. Cow artificial insemination (AI) conception rates differed by year of pregnancy (*P* < 0.01) but not RFI classification (*P* = 0.81). In summary, heifer post-weaning RFI classification had minimal effects on beef cattle production and reproductive efficiency.

Key words: beef cattle, heifer, parity, production, reproduction, residual feed intake (RFI)

List of Abbreviations:

AI: Artificial Insemination

BCS: Body Condition Score

BW: Birth Weight

kg: Kilogram

NARC: Northern Agricultural Research Center

MT: Montana

RFI: Residual Feed Intake

WT: Weight

Introduction

Traditionally, feed efficiency of beef cattle has been expressed as the ratio of feed intake to body weight gained (feed to gain or gain to feed), however, selection for high growth rates inevitably increases the maintenance requirements, feed requirements, and intake of cattle, with subsequent higher environmental and feed costs (Okine et al. 2004). As cattle are selected for increased feed efficiency, managers often inadvertently select for larger mature sized cattle, thus, increasing the need for feed inputs in the future. In contrast, net feed efficiency (Byerly, 1941) or Residual Feed Intake (RFI; Koch et al., 1963) is defined as the difference between an animal's actual feed intake and its expected feed requirements for maintenance and growth. RFI is calculated as the difference between actual feed intake and predicted feed intake with negative or smaller values being more desirable than positive or larger values (Crews, 2005). Cattle that are more efficient than their contemporary group have a lower RFI value with feed intake being lower than predicted and cattle that are less efficient having a higher RFI value with feed intake being greater than predicted. RFI is an alternative measure of feed efficiency and is phenotypically independent of growth rate and body size (Arthur et al., 2008; Crews, 2005).

Multiple studies have reported that feed intake is a heritable trait in beef cattle (Koch et al., 1963; Fan et al., 1995; Nkrumah et al., 2007; Elzo et al., 2009; Mao et al., 2013; Retallick et al., 2017), with all studies estimating the heritability of feed intake in growing cattle between 0.28 to 0.44. Crowley et al. (2010), reported that RFI is moderately heritable at 0.45, therefore, selecting replacements with low RFI should produce energy-efficient cows and progeny. Estimates of RFI, as well as, feed efficiency are often used with bull test results and sire summaries and, in turn, recommended as a tool to select sires for beef production systems under the expectation of improved cow efficiency with low RFI selection pressure. However, information regarding the repeatability of RFI at different ages, stages of production, in different environments, and on different diets is limited (Manafiazar et al. 2015, Black et al., 2013 and Freetly et al., 2020).

Biological mechanisms involved in beef cattle performance, as well as, response to RFI classification may interact with cow age, stage of production, and availability of feed resources (Sprinkle et al., 2020). Numerous factors may influence regulation of satiety in growing cattle, including composition of ration or diet. Freetly et al., (2020) stated that the signals for satiety in high concentrate rations may be associated with chemical signals while those in forage-based diets are probably associated with gut fill. Previous research that has evaluated the impact of selection pressure for low RFI progeny is often inconsistent in respect to body condition, heifer maturity, and reproductive response. Randel and Welch (2013) found that low RFI females were leaner, reached puberty at an older age, and calved later as heifers and subsequent calf crops. Similarly, Sprinkle et al., (2020) observed lower initial body condition score in 2-yr-old low RFI cows, but over the winter grazing period low RFI cows had less weight loss and concluded the study at a similar body condition as the high RFI cows. For their study, no differences were observed in body weight, yet weight and body condition losses were lower in the low RFI cattle. In contrast, Basarab and coworkers (2007) summarized 10 years of performance records of dams that produced low, average, and high RFI progeny and concluded that dams who produced low RFI progeny had greater backfat (mm) and were in better condition prior to breeding than dams that produced high RFI progeny. No differences were observed in cow weights or calf 205-day adjusted weaning weights relative to RFI classification of the progeny (Basarab et al., 2007).

Most RFI studies are based on energy-dense diets focusing on feedlot performance (Lawrence et al., 2014) with limited information pertaining to RFI of cattle offered forage-based diets (Arthur et al., 2005; Black et al., 2013; Freetly et al., 2020) and even less information related to beef cows (Basarab et al., 2007; Meyer et al., 2008; Sprinkle et al., 2020). More research is needed related to the lifetime performance of low and high RFI cattle in forage-based rangeland environments aimed at increasing feed efficiency of western beef cattle operations (Manafiazar et al., 2015; Sprinkle et al., 2020). Black et al., (2013) stated the relationship between post-weaning RFI and subsequent reproductive performance and longevity needs to be fully characterized to understand the impact RFI may have in a breeding scenario.

Therefore, objectives of the following research were to evaluate the relationship of heifer post-weaning RFI classification to heifer performance data as calves and subsequent cow performance that includes reproductive efficiency, as well as, production traits, such as cow body weight, body condition, and calf weaning weights, in the absence of selection pressure based on RFI. Our premise was that this age group of cows (yearlings to 4.5 yrs.) would be the most likely to elicit production differences due to RFI classification of post-weaning replacement heifers. We hypothesized that there is no difference between heifer post-weaning RFI classification and reproductive performance or production parameters in beef cattle through their third weaned calf.

Materials and Methods

All procedures of this study were approved by the Montana State University Agricultural Animal Care and Use Committee (AACUC #2018-AA12).

Heifer RFI trials and baseline performance

Starting in 2008 to present, all NARC cattle were utilized in a heifer RFI trial for a minimum of 77 days on a forage-based ration provided in a GrowSafe system (GrowSafe DAQ 4000E; GrowSafe System Ltd., Airdrie, AB, Canada). Calves were weaned on pasture mid-September to early October each year and entered an RFI trial 60 to 75 days post weaning. On average, NARC retained 45-95 AI sired replacement heifers during the study period. Upon trial initiation, and completion, all heifers were weighed post feeding, on two consecutive days to record beginning and ending body weights, then again, every 28 days to record BW gain. A 7-d acclimation period preceded a 70-d feeding trial, while the GrowSafe system recorded individual daily feed intakes. All heifers had free access to 18 GrowSafe feed bunks and ad libitum access to water and forage-based diets, consisting of 30.4 % corn silage, 41.1 % grass hay, and 28.5 % alfalfa on a dry mater basis, formulated to meet maintenance requirement for growing moderate frame beef heifers, 10.5 % CP and 66.0% TDN (NASEM, Beef Cow Requirements, 2016). Individual heifer post-weaning RFI was calculated following previous parameters set forth by Archer et al. (1997), and Arthur et al. (2001). Heifers were categorized as either low (> -0.50 SD from mean; $\bar{x}$ = -0.05), average (± 0.50 SD from mean; $\bar{x}$ = 0.01) or high (< +0.50 SD from the mean; $\bar{x}$ = 0.48) within year (Table 1).

Subsequent cow performance

Mature Black Angus females (n = 347, Table 1) from the Montana State University Northern Agricultural Research Center (NARC) located in Havre Montana were utilized for this study. All mature cows were managed as one contemporary group, wintered at the NARC and summered at the Thackeray Ranch located south of Havre in the Bear Paw Mountains. All females were synchronized, and time AI in early June with exposure to cleanup bulls for an additional 45 days of natural service to calve during March and April the following year. Pregnancy diagnosis of all cows was performed via ultrasonography by a qualified Veterinarian at weaning each year with all calves being weaned early fall, mid-September to early October (150-210 days of age) and returned to the NARC Experiment Station. Calf 205-d weaning weights were adjusted for sex of calf and age of cow following BIF (2020) standards. Postpartum interval was determined by AI date for AI sired calves and back calculated based on calving date for natural service sired calves. Postpartum interval estimates assume that all RFI classifications and cow age have similar gestation length. All pregnant cows remained at the Thackeray Ranch grazing dormant late season forages through early January. Females that were culled from the herd were categorized as either being culled for reproductive reasons (open) or other (structure, disposition, calf died, cow died). For this study, individual animal was considered the experimental unit with RFI classification being the treatment.

Statistical Analysis

Beef cattle production and reproduction parameters including: cow birth weight, cow birth date, cow 205 day adjusted weaning weight, cow yearling weight, cow yearling BCS, cow yearling pregnancy weight, cow yearling pregnancy BCS, cow weight at weaning, cow BCS at weaning, cow years in herd, cow calving interval, cow postpartum interval, calf birth weight, calf 205 day adjusted weaning weight, calf weaning weight ratio, and calf birth date were analyzed using ANOVA with a mixed model including RFI classification, calf number (parity) and the interaction of parity with RFI classification as fixed effects, and individual cow as the random effect. Data were plotted and natural log-transformed if needed to satisfy assumptions of normality and homogeneity of variance (cow birth weight). Log-transformed data were back transformed using the emmeans package in R (Lenth, 2019). Least square means were separated using pairwise comparison when $P < 0.05$. For RFI and parity main effects, pre-planned orthogonal polynomial contrasts were used to determine linear and quadratic effects. Beef cattle reproductive parameters eliciting a binomial response (conception rate, AI conception rate, present at 5 years, culled due to pregnancy status) were analyzed using generalized linear models following a binomial distribution in an ANOVA framework. An alpha $\leq$ 0.05 was considered significant. All statistical analyses were performed in R (R Core Team 2017).

Results

Heifer baseline performance

Julian birth date of retained heifers with differing RFI classification displayed a quadratic ($P = 0.02$) response with high RFI heifers being born earlier in the calving season (71.2 vs 75.3 days) than average RFI heifers but not different than low RFI heifers (Table 2). In contrasts, heifer birth weights, heifer weaning weights, as well as, body weight and condition as yearlings and at pregnancy diagnosis did not differ across RFI classifications ($P \geq 0.14$). Heifer weight and condition averaged 586 kg and 5.25, respectively, at pregnancy diagnosis for the first calf.

Subsequent cow performance

For most subsequent cow performance traits, parity (1st, 2nd or 3rd calf) did not interact with RFI classification ($P > 0.10$). Therefore, data is presented as main effects for RFI classification of dams (Table 2) or parity influences on beef cattle performance (Table 3). Calf BW differed relative to cow RFI classification ($P = 0.03$; Table 2), but a *post hoc* means separation analysis showed no differences with a range of only 38.9 to 39.2 kg. Calf weights at weaning and weaning rate ratio across three calf crops did not differ related to RFI classification of the dams ($P \geq 0.55$) averaging 280 kg and 48%, respectively. In addition, calf Julian birth date, calving interval, and postpartum interval was not influenced by RFI classification of the dam ($P \geq 0.79$) averaging 83.7 days, 366 days, and 84.8 days, respectively.

As expected, parity number did influence cow weight at pregnancy ($P < 0.01$; Table 3) with 3rd parity pregnancy determination weights being heavier than the 2nd and

1^{st}, and 2^{nd} parity pregnancy determination weights being heavier than 1^{st} parity. Calf BW differed by parity (*P* < 0.01) with 1^{st} parity calves being lighter than 2^{nd} and 3^{rd} parity calves. Calf 205-day adjusted weaning weights displayed a quadratic effect (*P* = 0.01) with 1^{st} calf heifers weaning lighter calves than 2^{nd} and 3^{rd} parity cows. In contrast, weaning weight ratio displayed a linear decrease with increasing parity (*P* < 0.01) ranging from 50.8% for 1^{st} parity heifers to 45.3% for 3^{rd} parity cows. Cow postpartum interval displayed a linear effect (*P* < 0.01) with 3^{rd} parity females having fewer days between calving and conception than 1^{st} and 2^{nd} parity females. Calf Julian birth dates were not influenced by parity (*P* = 0.27) and averaged 84.6 days.

Cow conception rates following a 45-day breeding season (Table 4) exhibited an RFI × parity interaction (*P* = 0.02). Within breeding season, 2^{nd} calf cows tended (*P* = 0.09) to display a linear increase in conception with increasing RFI classification. In contrast, cow conception probability for the 4^{th} calf tended (*P* < 0.07) to display a quadratic response with average RFI cows having lower conception than low or high RFI cows. Pregnancy rates of yearling heifers and 2^{nd} calf cows did not differ among RFI classifications (*P* > 0.10) averaging 87.8 and 91.7 %, respectively.

Cows conceiving to AI did not differ by RFI classification (*P* = 0.81) with AI conception averaging 58% across all RFI classifications of the dams. However, AI conception rates were influenced by parity (*P* < 0.01) with 1^{st} and 3^{rd} calf cows having lower conception rates (48.3 and 54.3, respectively) than 2^{nd} and 4^{th} parity calf cows (62.4 and 66.5, respectively). RFI classification displayed a quadratic tendency (*P* = 0.08) with cow longevity (years in herd), with high RFI cows having greater longevity than average RFI cows, with low RFI cows being intermediate. Heifer RFI classification did not impact (*P* = 0.94) probability of remaining in the herd at the age of five averaging 4.5 yrs, and 51.2%, respectively. In addition, the % of females culled because of pregnancy status did not differ by RFI classification (*P* = 0.14) averaging 34.8% over the first 5 years of production.

Discussion

Our study evaluated the production records of 347 replacement heifers for their first 5 production years based on a heifer post-weaning RFI classification. We did see differences in Julian date at calving with low RFI heifers being born later in the calving period than high RFI heifers. However, we did not see any impact of RFI on birth date of progeny. In contrast, Randel and Welch (2013) observed later calving dates for low RFI cattle as heifers and subsequent calving dates as cows. In addition, no differences were detected for cow body condition at breeding or weaning for three consecutive calf crops. Based on performance traits, such as, body weight, body condition score, calf birth weights and longevity in the herd, our results suggest that RFI rankings did not influence cow calf production parameters in our foraged-based environment. This is in general agreement with Manafiazar et al., (2016), which states, RFI has zero phenotypic correlation with production traits and near-zero genetic correlation to production traits in Dairy cows. However, it is important to note that no selection pressure was placed on RFI while selecting replacement heifers, AI sires and cleanup bulls during this study period.

Previous research has reported cow body weight and calf weaning weights over multiple production cycles were similar for cows classified as Low, Medium, and High

RFI (Basarab et al. 2007). Our results agree with this as we observed no difference due to RFI classification of heifers on subsequent body weight or weaning weights of young cows over three calf crops weaned. This would be expected as RFI has been demonstrated to be independent of body weight and growth (Arthur et al. 2005; Crews, 2005, Manafiazar et al., 2016) which concluded that phenotypic and genetic relationship of RFI on body weight is near zero and is consistent from post-weaning through maturity. Most of the differing performance characteristics observed in these studies were attributed to age (parity, or pregnancy number) and would be expected to increase as average annual body weight, birth weights, adjusted 205-day weaning weights, increase with increasing cow age (Renquist et al. 2006).

While RFI may present an opportunity to reduce feed costs, mixed results exist regarding the effect of RFI classification on reproductive performance (Arthur et al., 2011; Basarab et al., 2011; Blair et al., 2013). Damiran et al., (2018) reported a tendency for low RFI heifers to exhibit lower pregnancy rates than high RFI heifers, with fewer low RFI heifers calving in the first cycle compared to high RFI heifers. Arthur et al., (2005) and Blair et al., (2013) reported no differences between high and low RFI lines for pregnancy rate. In contrast, Randel and Welsh (2013), in a review, stated selection for low RFI results in selection of leaner heifers that reach puberty later and concluded that selection for low RFI may impair reproductive efficiency. This is supported by Arthur et al., (2005), who reported that low RFI cows calved 8-d later than high RFI cows, with the progeny of low RFI cows calving 5 to 6-d later than high RFI cows.

In our study, AI conception rates did not differ by RFI classification averaging 58% conception across all RFI classifications. However, AI conception rates were influenced by parity with 1st and 3rd calf cows having lower conception rates (48.3 and 54.3, respectively) than 2nd and 4th calf cows (62.4 and 66.5, respectively). Similar to Arthur et al., (2005) we observed an RFI effect on Julian birth date with high RFI cows being born earlier in the calving season than average RFI cows. However, there was no RFI effect on subsequent calf Julian birth date.

While our study did not observe substantial difference in beef cattle performance through the weaning of the 3rd calf, this does not preclude potential benefits of RFI selection for cattle that eat less forage and/or utilize rangeland areas more efficiently. In fact, the real benefit of selecting for low RFI cattle may relate to intake per unit of production rather than overall production traits per se. In one of the few studies that evaluated forage intake as a function of RFI classification, Lawrence et al. (2014) reported no difference in haylage or pasture forage intake as a result of RFI estimates. In contrast, Basarab et al. (2007) reported that cows that produce low RFI progeny consume less feed than cows that produce high RFI progeny based on a post-weaning intake trial in confinement with a barley silage, barley straw-based ration. In addition, in a sagebrush steppe rangeland environment, Sprinkle et al. (2020) found the low RFI cows lost less weight and body condition than high RFI cows during a fall to early winter grazing period. The authors suggested that low RFI cattle had lower maintenance energy requirements or were more efficient grazers in the limited nutrition winter range environment as compared to high RFI cattle. However, no differences were observed in distance traveled or grazing behavior among low and high RFI cows (Sprinkle et al., 2020). Although difficult to assess, the actual benefit of using RFI classification to select cattle for environmental fitness may hinge on the effect of RFI on forage intake across diverse forage base systems that demonstrate a range of forage quantity, as well as, quality. Black et at., (2013) reported that while RFI for postweaning and lactation phases do not appear to be related, selection of the most feed-efficient heifers based on post-weaning RFI may have economic implications by reducing feed costs and maintaining similar cow performance throughout lactation. Additionally, Damiran et al., (2018) indicated low RFI heifers had lower feed costs than high RFI heifers. Similarly, Manafiazar et al., (2015) reported that low RFI yearling Bos taurus heifers grazing irrigated improved pastures in Alberta, Canada consumed less forage than high RFI heifers. If post weaning heifer RFI classifications are a good predictor of subsequent cow intake and the conversion of forage to calf production, selection of low RFI heifers would be beneficial.

Implications

Classification of RFI for replacement heifers had little to no effect on subsequent beef cattle production and reproductive efficiency through the weaning of the 3rd calf. Subtle differences were denoted for cow Julian birth dates based on RFI classification and conception of 1st calf-heifers categorized as low RFI. However, all other production parameters were similar across RFI classifications of dams, with no difference in kg of calves weaned and longevity traits of the cows. Therefore, our study suggests that selection for low RFI females would not impact overall herd productivity of cattle on foraged-based production systems. However, further research is needed to investigate the relationship of heifer post-weaning RFI classification on subsequent intake of forage base diets that would likely include pasture utilization, foraging behavior, supplement intake behavior, as well as, utilization and distribution in extensive rangeland environments. Research is limited in respect to the relationship of RFI classification and cow intake, as well as, cow age/intake interactions in forage-based production systems.

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Table 1. Number of cows per RFI classification, production year, and three years of calf production. (n=347). Five years of heifer replacements (2010 to 2014) with five years of performance data.

	Yearling[1]			Parity 1			Parity 2			Parity 3		
Year Born	Low	Ave	High	Low	Ave	High	Low	Ave	High	Low	Ave	High
2010	26	36	33	22	31	33	19	26	29	17	21	21
2011	26	28	27	19	21	19	14	21	16	12	19	14
2012	22	18	23	10	10	7	9	8	17	8	6	15
2013	14	20	11	12	20	7	10	18	7	10	15	6
2014	20	26	17	14	21	12	13	21	11	13	18	7

[1]Heifers were categorized as either low (> -0.50 SD from mean), or average (± 0.50 SD from mean) or high (< +0.50 SD from the mean) RFI classes.

Table 2. The influence of RFI classification on birth weight, cow weight, body condition, and subsequent cow performance for 5-years of retained heifers with 5-years of performance data including three weaned calf crops.

	RFI[1]				*P*-value		
						Preplanned contrast	
Category	Low	Ave	High	SE[2]	RFI	Linear	Quadratic
Heifer baseline data							
Birth wt. kg	37.4	36.0	35.5	2.55	0.27	0.27	0.76
Julian birth date[3]	74.0[ab]	75.3[b]	71.2[a]	0.99	< 0.01	0.05	0.02
Weaning wt., kg	239.3	237.4	240.6	5.39	0.14	0.77	0.43
Yearling wt., kg	488.1	501.2	504.4	13.70	0.17	0.08	0.49
Yearling BCS	5.8	5.8	5.9	0.06	0.55	0.59	0.35
Pregnancy wt., kg	586.1	585.7	586.6	4.22	0.83	0.93	0.89
Pregnancy BCS	5.2	5.3	5.3	0.05	0.91	0.20	0.57
Subsequent cow performance							
Calf birth wt., kg[4]	38.9	39.2	39.2	0.70	0.03	0.78	0.88
Calf weaning wt., kg	276.9	281.0	281.0	2.93	0.23	0.36	0.55
Calf weaning wt., ratio[5]	47.8	48.4	48.1	0.68	0.15	0.81	0.57
Calf Julian birth date	85.0	84.1	84.7	1.05	0.86	0.57	0.85
Calving interval, days	366.0	367.0	365.0	1.96	0.74	0.71	0.79
Postpartum interval, days	85.7	84.6	84.3	1.58	0.92	0.57	0.85

[1]Heifers were categorized as either low (> -0.50 SD from mean), or average (± 0.50 SD from mean) or high (< +0.50 SD from the mean) RFI classes.
[2]Pooled standard error of the means.
[3]Means within rows lacking common superscript differ ($P < 0.05$).
[4]A *post hoc* means separation analysis showed no differences
[5]Ratio of calf weaning weight to cow body weight.

Table 3. The influence of parity on beef cow performance, and reproductive parameters for 5-years of retained heifers with 5-years of performance data including three weaned calf crops.

					P-value		
	Parity					Preplanned contrast	
Category	1	2	3	SE[2]	Parity	Linear	Quadratic
Cow wt. at weaning, kg[3]	537.5[a]	591.5[b]	627.3[c]	4.34	< 0.01	< 0.01	0.11
Cow BCS at weaning	5.2	5.2	5.4	0.05	0.28	< 0.01	0.04
Calf birth wt., kg	34.1[a]	40.9[b]	42.4[b]	0.66	< 0.01	< 0.01	< 0.01
Calf weaning wt., kg	271.7[a]	285.8[b]	281.2[b]	2.79	0.03	0.02	0.01
Calf wean wt. ratio	50.8[a]	48.2[b]	45.3[c]	0.69	< 0.01	< 0.01	0.88
Calf Julian birth date	84.5	84.4	84.9	1.07	0.27	0.82	0.80
Calving interval, days	NA	366.0	366.0	1.60	0.22	NA	NA
Postpartum interval, days	87.4[a]	86.6[a]	80.6[b]	1.57	0.02	< 0.01	0.16

[1]Heifers were categorized as either low (> -0.50 SD from mean), or average (± 0.50 SD from mean) or high (< +0.50 SD from the mean) RFI classes.
[2]Pooled standard error of the means.
[3]Means within rows lacking common superscript differ ($P < 0.05$).

Table 4. The influence of RFI classification of heifers on subsequent beef cow conception probability and AI probability and cow longevity spanning 4-breeding seasons and 3 weaned calf crops.

	RFI[1]				*P*-value			Preplanned contrast	
Category	Low	Ave	High	SE[2]	RFI	Pregnancy	RFI × Pregnancy	Linear	Quadratic
Cow conception Probability, %	94.0	93.7	93.3	1.8	0.75	0.05	0.02		
Pregnancy 1	83.6	91.3	88.6	3.4				0.11	0.14
Pregnancy 2	91.0	98.2	96.5	2.3				0.09	0.14
Pregnancy 3	95.9	91.2	87.9	3.2				0.15	0.68
Pregnancy 4	98.0	89.3	96.0	3.1				0.70	0.07
Cow AI conception probability, %	55.0	59.5	59.5	3.3	0.81	< 0.01	0.32	0.36	0.55
Years in herd[3]	4.5	4.3	4.7	0.2	0.07	NA	NA	0.23	0.08
Present at 5 years, %	50.9	53.1	51.4	4.6	0.94	NA	NA	0.95	0.72
Culled due to pregnancy status, %	37.0	29.7	37.8	4.4	0.34	NA	NA	0.90	0.14

[1]Heifers were categorized as either low (> -0.50 SD from mean), or average (± 0.50 SD from mean) or high (< +0.50 SD from the mean) RFI classes.
[2]Pooled standard error of the means.
[3]Length of time cows remained in herd over the 5-year study period.

CHAPTER THREE

THE INFLUENCE OF RESIDUAL FEED INTAKE AND COW AGE ON BODY WEIGHT AND BODY CONDITION CHANGE, SUPPLEMENT INTAKE, RESOURCE USE, AND GRAZING BEHAVIOR OF BEEF CATTLE WINTER GRAZING MIXED-GRASS RANGELANDS

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***Animals* 2021,*11*(6),1518. doi.org/10.3390/ani11061518**

Status of Manuscript:

____ Prepared for submission to a peer-reviewed journal

____ Officially submitted to a peer-reviewed journal

____ Accepted by a peer-reviewed journal

_ X_ Published in a peer-reviewed journal

CHAPTER THREE

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Abstract

The objectives of this study were to evaluate the influence of residual feed intake (RFI) and cow age on supplement intake and grazing behavior of beef cattle winter grazing mixed-grass prairie rangelands over a 2-year period. Cows were grouped by heifer post-weaning RFI and allocated into 6 age classes (1-, 2-, 3-, 4-, 5 – 7-, and ≥ 8-yr-old) for an 84-day winter grazing period each year. Additionally, a subset of 30 cows were randomly selected within age (2, 5 and 8-yr-old) and RFI (Low, High) and fitted with Lotek GPS collars each year to record grazing behavior. Average daily supplement intake (kg · cow^{-1} · d^{-1}) displayed an RFI × cow age interaction ($P < 0.01$), with a linear increase in average daily supplement intake with increasing RFI of 3-yr old cows ($P < 0.01$). Average daily supplement intake (g · kg BW^{-1} · d^{-1}) displayed an RFI × cow age interaction ($P < 0.01$), with a quadratic effect on supplement intake of 3-yr old cows ($P = 0.01$), where high RFI cows consumed more supplement per kg BW than low and average RFI cows ($P < 0.01$). Cow age displayed a quadratic effect on variation of supplement intake ($P < 0.01$) where 1-yr old cows had a greater CV of supplement intake than all other age classes of cows ($P < 0.01$). Time spent at the feeders (min · cow^{-1} · d^{-1}) displayed a tendency for an RFI ×

cow age interaction (*P* = 0.08), however, a quadratic effect of RFI (*P* = 0.01) was observed where 1, 5–7, and ≥ 8-yr old cows spent less time at the feeders than 2, 3 and 4-yr old cows. Distance traveled displayed a cow age by RFI interaction (*P* = 0.02), where high RFI 5-yr old cows traveled further per day than low RFI 5-yr old cows. The probability of grazing site selection relative to distance to supplement or distance to water were not impacted by RFI (*P* = 0.68 and *P* = 0.63, respectively), however was influenced by cow age (*P* ≤ 0.03). Core grazing area (ha) was linearly effected (*P* < 0.01) by cow age, with core grazing area decreasing with increasing cow age. In summary, heifer post-weaning RFI had minimal effects on beef cattle performance, grazing behavior, or resource utilization, however, cow age impacted both grazing behavior and resource use.

Key words: beef cattle, cow age, grazing behavior, residual feed intake (RFI), resource use, supplement intake

List of Abbreviations:

ADF: Acid Detergent Fiber

AUM: Animal Unit Month

BCS: Body Condition Score

BW: Body Weight

CP: Crude Protein

GPS: Global Position System

kg: Kilogram

NDF: Neutral Detergent Fiber

[1]Appreciation is expressed to PerforMix Nutrition Systems, Nancy Cameron Endowment, and the Montana Agriculture Experiment Station for research funding and to the employees of MSU Northern Agricultural Research Center for their assistance with this project. USDA is an equal opportunity employer and service provider.

Introduction

Providing adequate nutrition for animals is the greatest operating cost for cow-calf producers, where supplemental feed can account for 65% of the annual expenses (Arthur et al., 2004, Van der Westhuizen et al., 2004; Meyer et al., 2008). Traditionally, selection pressure has been placed on production traits associated with increasing outputs, which can also result in increased inputs to achieve animal production potential. Since feed costs constitute the greatest proportion of total inputs, selection pressure for efficient animals that have lower feed intake but maintain production could have a great impact on cow-calf profitability (Meyer et al., 2008). It has been reported that roughly two-thirds of mature cow energy requirements are utilized for maintenance (Ferrell and Jenkins, 1984, 1988; Montano-Bermudez et al., 1990). However, substantial animal-to-animal variation, independent of body size and growth, exists in maintenance requirements of cattle (Arthur et al., 2001; Nkrumah et al., 2006; Crowley et al., 2010). Consideration of the lower maintenance requirements for low residual feed intake (RFI) cattle becomes much more important as cattle move into times of negative energy balance such as dormant, late season grazing (Sprinkle et al., 2020). Thus, improving feed efficiency through genetic selection holds significant opportunity for the beef industry.

Residual feed intake is currently being used as a selection tool for purchasing and retaining heifers and for selecting bulls and semen. However, the use and relevance of RFI as a selection tool for the cow-calf industry in the western U.S. needs additional research. Research evaluating the efficacy of using post-weaning RFI values as a selection criteria for beef cattle that fit western rangeland systems is currently lacking. Most RFI studies utilize energy-dense diets and rations focusing on feedlot performance (Lawrence et al., 2014). Research pertaining to RFI in cattle offered forage-based diets is limited (Arthur et al., 2005), with even fewer data available related to beef cattle forage-based production systems (Basarab et al., 2007; Meyer et al., 2008; Sprinkle et al., 2020). As a result, more research is needed to evaluate the utility of RFI estimates on the selection of heifers for extensive forage-based systems (Manafiazar et al. 2015; Kenny et al., 2018; Sprinkle et al. 2020).

Western U.S. cow-calf production systems rely heavily on rangeland forages to supply nutrients for both cows and calves (Galyean et al., 1993). The primary goal in a forage-based livestock production system is to obtain optimal animal performance while effectively utilizing the forage resource base (Wyffels et al., 2019). Seasonal nutrient deficiencies associated with dormant rangeland forages often require protein supplementation to maintain animal performance, production, and provide increased economic returns (Bowman et al., 1997; DelCurto et al., 2000). However, the reported effectiveness of protein supplementation programs on grazing beef cattle performance has been inconsistent, likely due to variation in animal-to-animal supplement intake behavior (Bowman et al., 1997, DelCurto et al., 2000; Wyffels et al., 2020a). Recent research has demonstrated that cow performance is related to supplement intake behavior (Wesley et al., 2012), therefore, RFI, a potential proxy for cow efficiency may also be linked to protein supplement intake behavior. However, information relating cow RFI to protein supplement intake behavior does not currently exist.

Although a central aspect of domestic livestock ecosystems, the spatial component of livestock grazing has remained difficult to interpret (Coughenour, 1991). Mechanisms that influence grazing distribution can be classified as either: exogenous, the physical environment in which livestock graze, such as topography, and slope (Bailey et al., 1996, Beaver et al., 1997), or endogenous characteristics such as social learning, spatial memory, age, and experience, (Dunn et al., 1988, Bailey et al., 1996; Launchbaugh et al., 2005; Wallburger et al., 2009). Thus, cattle grazing the same pasture under similar environmental conditions during different years can have very different grazing patterns (Bailey, 2004). Recent research has demonstrated that low RFI cows (more efficient) have larger distribution patterns and outperform high RFI (less efficient) cows (Sprinkle et al., 2019a; 2020). Therefore, it is possible that grazing behavior may vary with cow RFI (efficiency) and cow age while grazing nutrient deficient forages. However, interactions of exogenous factors with endogenous attributes on grazing behavior are poorly understood (Wallburger et al., 2009). Therefore, the objectives of this study were to evaluate the influence of cow RFI and cow age on 1) weight and body condition change; 2) supplement intake behavior; and 3) grazing behavior, resource use, and distribution patterns of winter grazing beef cattle on mixed-grass prairie rangelands.

We hypothesized that cow RFI and age interact to influence animal performance, supplement intake, and grazing behavior.

Materials and Methods

The use of animals in this study was approved by the Agricultural Animal Care and Use Committee of Montana State University AACUC #2018-AA12. All animals used in this study were provided by the Montana Agricultural Experiment Stations, and the study was conducted at the Northern Agricultural Research Center in Havre, Montana.

Two consecutive years of winter grazing studies were conducted on non-lactating, pregnant commercial Angus cows to evaluate the influence of RFI and cow age on beef cattle performance, supplement intake behavior, grazing behavior as well as distribution and resource use patterns. This study was conducted at the Montana State University Northern Agriculture Research Center's Thackeray Ranch (48°21″ N 109°30′ W), located 21 km south of Havre, MT, USA. Bull Hook Creek, a perennial stream, transects the pasture and is used for livestock watering. Vegetation is dominated by Kentucky bluegrass (Poa pratensis L.), bluebunch wheatgrass (Pseudoroegneria spicata [Pursh] A. Love), and rough fescue (Festuca scabrella Torr.; Reference [20]). Available forage biomass of the study area was estimated by clipping ten randomly located plots to 2 cm in height, immediately prior to grazing, using a 0.25 m2 plot frame. Samples were placed in a forced-air oven at 55 °C for 72 h and then weighed and recorded to calculate dry matter production (kg · ha−1; Table 1). Vegetation samples were weighed individually and composited by year, ground to pass a 1 mm screen in a Wiley mill, and sent to a Dairy One for nutrient analysis (Dairy One, Ithaca, New York).

Supplement intake behavior and animal performance

A commercial herd of bred Angus cows (205 in yr-1 and 203 in yr-2) ranging in age from 1- to 10-yr-old were classified into one of 6 age groups (1-, 2-, 3-, 4-, 5 – 7, and ≥ 8-yr-old) and grazed on rangeland pastures (~1.5 ha · AUM^{-1}) from mid-October to early-January each year. Individual cow body weight (BW) and body condition scores (BCS) were obtained following a 16-hour shrink pre- and post-grazing (Table 2). Body condition scores were based on a 1-9 scale (BCS: 1 = emaciated, 9 = obese, Wagner et al., 1988) and assessed by two trained individuals, then averaged for a final BCS. All cows went through a 70-d post-weaning RFI trial (Archer et al., 1997; and Arthur et al., 2001) post-weaning as heifers, (9 – 11 months of age) using a GrowSafe system (GrowSafe DAQ 4000E; GrowSafe System Ltd., Airdrie, Alberta, Canada) and were classified as either low (< -0.50 SD from mean), average (± 0.50 SD from mean) or high (> +0.50 SD from the mean) RFI within their contemporary age group (Parsons et al., 2021a).

A free-choice, self-fed, canola based pressed block supplement (28.7% crude protein (CP; year 1) and 30% CP (year 2)) was provided ad-libitum to cattle. The target daily-recommended intake range was 0.45 to 0.91 kg · cow^{-1} · d^{-1} with 23% salt, texture, and bitterness to limit daily intake. Individual animals were equipped with an electronic identification tag attached to the left ear for the measurement of daily individual supplement intake (kg · cow^{-1} · d^{-1}; g · kg BW^{-1} · d^{-1}), and time spent at supplement feeders (min· d^{-1}) using centrally located SmartFeed Pro self-feeder systems (C-Lock Inc., Rapid City, South Dakota) with a total of 2 trailers and 8 feeding stations (4 per trailer). Variation in supplement intake, measured as the coefficient of variation (% CV), was based on daily intake estimates for individual animals.

Grazing behavior and resource use

Each year, a subset of 30 cows were randomly selected within age (2, 5, and 8 years old) and RFI (Low, High) and fitted with Lotek GPS collars containing an activity sensor (Lotek Engineering, Newmarket, ON, Canada; 5 collars per RFI × cow age combinations) representing a minimum of 39% of the total cattle population within each RFI × age combination each year. GPS collars were configured to record positions at 15-min intervals, and activity sensor measurements at 5-min intervals to determine distance traveled, location, and duration of grazing activities, as well as resource use (Turner et al., 2000, Ungar et al., 2005, Brosh et al., 2010). Due to limited battery life of GPS collars, supplement intake, grazing behavior and resource use was only measured during the last 45 days of grazing each year. Individual cow was considered the experimental unit to evaluate effects of age and RFI on supplement intake behavior. Grazing activities were derived by the binary classification methods developed by Augustine and Derner (2013) to evaluate time spent grazing and foraging distribution. Observations were limited to grazing to determine critical foraging areas rather than general occupancy Grazing activities were separated from non-grazing activities using the binary classification methods developed by Augustine and Derner (2013) to examine time spent grazing and cattle foraging distribution. By limiting observations to grazing locations we were able to determine important foraging areas rather than general pasture occupancy (Wallburger et al., 2009, Wyffels et al., 2019). Pasture supplement and water locations were recorded by using a handheld GPS unit (spatial error < 10-m). Spatial layers including aspect, terrain ruggedness (sum change in elevation between a grid cell and its eight neighboring cells; Reference [36]) and distance from supplement and water locations were developed by using the spatial analysis tool in ArcGIS (Environmental Systems Research Institute, Redlands, CA, USA) and a digital elevation model at a 30 m^2 resolution.

Statistical analysis

The influence of RFI and cow age on cow BCS, BW, supplement intake behavior, time spent grazing, and distance traveled were analyzed using ANOVA with a generalized linear mixed model including RFI, cow age, and the interactions of RFI and cow age class as fixed effects, and individual cow and year as random effects. Individual animal was considered the experimental unit and an alpha ≤ 0.05 was considered significant. Orthogonal polynomial contrasts were used to determine linear and quadratic effects for each analysis. Means were separated using the Tukey method when $P < 0.05$. Tendencies were reported when significance was $P \leq 0.10$.

To model relative resource selection for cattle grazing late season dormant forages individual GPS-collared cows were defined as the biological unit of interest. We used multiple regression in a resource utilization function (RUF) analysis to relate individual cow space use, quantified as a continuous and probabilistic variable, to pasture level covariates using the ruf.fit package in R (Marzluff et al. 2004; Winder et al. 2014;

Handcock, 2015) . Resource utilization functions increase sensitivity for detecting resource selection and reduce errors associated with location estimation by quantifying inter-animal variation in resource use and independently incorporating an individual's entire distribution of use while accounting for spatial autocorrelation of grazing locations (Marzluff et al., 2004, Kertson and Marzluff 2010, Winder et al., 2014).

Due to the pasture management unit defining the area of grazing cattle, GPS data were used to build RUFs quantifying animal selection of environmental and vegetation conditions within the pasture (third-order scale; Johnson 1980). We created a raster representing the specific utilization density distribution for the grazing locations of each individual in the pasture using the adehabitatHR and raster packages in R (Calenge, 2006; Hijmans, 2020). Relative use values were bound between 1 and 99, for each 30 m^2 cell based off of the relative volume of utilization distribution in that cell (Marzluff et al. 2004). Landscape covariates expected to influence resource utilization included distance to supplement and water (horizontal), elevation, terrain ruggedness and aspect. Using the raster function in R, landscape covariates and individual relative use rasters were stacked and converted to spatially explicit data files as input for the ruf.fit package (Kertson and Marzluff 2010; Handcock, 2015). Prior to modeling, individual relative use values were log-transformed to meet the assumptions of multiple regression models. Resource utilization functions with standardized β coefficients were generated and evaluated for each individual to represent the influence of the landscape covariates on cattle resource utilization (Marzluff et al. 2004, Kertson et al. 2011; Handcock, 2015).

Standardized coefficients with 95% confidence intervals that did not overlap zero were considered significant predictors of resource use (Marzluff et al. 2004, Winder et al. 2014). If a resource utilization coefficient was significantly different from zero, we inferred that resource use was greater or less than expected based on availability of the resource within the experimental pasture (Marzluff et al. 2004, Winder et al. 2014). For environmental factors eliciting high herd-level variability in grazing resource utilization (herd-level SE of standardized coefficients > 0.25; Wyffels et al., 2020b), we conducted a post hoc analysis evaluating the effects of RFI, cow age, and the interaction of RFI and cow age on resource use coefficients relative to each habitat covariate using ANOVA with a generalized linear mixed model including year as a random intercept. An alpha ≤ 0.05 was considered significant. Pre-planned orthogonal polynomial contrasts were used to determine linear and quadratic effects for cow age in each analysis. Means were separated using the Tukey method when $P < 0.05$. Tendencies were reported when significance was $P \leq 0.10$. All statistical analyses were performed in R (R Core Team, 2017).

Core grazing areas for individual cows were estimated using the kernel utilization distribution function in the adehabitatHR package in R (Calenge, 2006; Figure 1). Kernel utilization distributions are three-dimensional representations of estimated distribution of use, used to calculate home range (Clapp and Beck, 2015). The estimated values of use for the kernel utilization distributions containing only grazing locations were then used to create a contour representing 50% of the volume of use delineating core grazing areas (Heupel et al., 2004; Kie et al,. 2010; Garitano-Zavala et al., 2013). The area of the 50%

contours were calculated using the gArea function in the rgeos package of R (Bivand and Rundel, 2020). Due to pasture management unit defining the extent of core grazing areas of cattle, contours representing core grazing areas were bound by pasture boundary. The influence of RFI and cow age on core grazing area was analyzed using ANOVA with a generalized linear mixed model including RFI, cow age, and the interactions of RFI and cow age as fixed effects, and year as a random intercept. Individual animal was considered the experimental unit and an alpha ≤ 0.05 was considered significant. Pre-planned orthogonal polynomial contrasts were used to determine linear and quadratic effects for cow age. Means were separated using the Tukey method when $P < 0.05$. Tendencies were reported when significance was $P \leq 0.10$.

Results

Supplement intake behavior and animal performance

Body weight change over the 84-day grazing period exhibited a tendency for an RFI × cow age interaction ($P = 0.08$). Specifically, 4-year-old cows BW change decreased linearly with increasing RFI ($P < 0.01$), averaging 22.69 ± 23.66, 2.59 ± 23.31, and -12.49 ± 23.60 kg weight change for low, average, and high RFI, respectively. No RFI differences ($P > 0.44$) were observed for change of cow BW within all other cow ages. Cow age influenced ($P = 0.02$) weight change, over the 84-day grazing period; however, no linear or quadratic responses were noted ($P \geq 0.19$) with weight changes ranging from −5.01 ± 22.87 kg (yearlings) to 8.72 ± 22.92 kg (3-year-old cows) with all other cow age being intermediate. Change in BCS exhibited a tendency ($P = 0.07$) for a quadratic effect of cow age ($P = 0.01$), with 1-year-old cows losing BCS (−0.10 ± 0.10

units) compared to 4-year-old cows gaining BCS (0.15 ± 0.10 units) with all other cow age being intermediate over the 84-day grazing period.

Average daily supplement intake (kg · cow^{-1} · d^{-1}) displayed an RFI × cow age interaction ($P < 0.01$; Figure 2), with RFI exhibiting a linear effect on 3-year-old cows ($P < 0.01$) where supplement intake increased with increasing RFI (Figure 2C). However, RFI had no effect on supplement intake for other cow age ($P > 0.28$). Supplement intake expressed as g · kg^{-1} BW^{-1} · d^{-1} displayed an RFI × cow age interaction ($P < 0.01$). Specifically, a quadratic effect of RFI was observed on supplement intake of 3-year-old cows ($P = 0.01$; Figure 2I), where high-RFI cattle consumed more supplement than low- and average-RFI cattle ($P < 0.01$). However, RFI had no effect on supplement intake for other cow ages ($P > 0.23$). Likewise, RFI effects were not observed for variation of supplement intake (% CV; $P > 0.69$). However, there was a quadratic effect of cow age on variation in supplement intake ($P < 0.01$; Figure 3), where 1-year-old cows had a larger CV of supplement in-take than all other ages ($P < 0.01$).

There was no effect ($P > 0.13$) of RFI or cow age observed on supplement intake rate, with supplement intake rate averaging 60.6 ± 32.0 g · min^{-1}. Time spent at the feeders was quadratically influenced ($P < 0.01$) by cow age, where 2-, 3-, and 4-year-old cows spent more time at the feeders than 1-, 5 – 7-, and ≥ 8-year-old cows ($P < 0.02$; Figure 4). However, time spent at the feeders exhibited a tendency for an RFI × cow age interaction ($P = 0.08$), with a quadratic effect ($P = 0.03$) of RFI for 5 – 7-year-old cows, where average-RFI cows tended to spend more time at the feeders than high-RFI cows ($P = 0.08$).

Grazing behavior and resource use

Distance traveled displayed a cow age × RFI interaction (P = 0.02), where high-RFI 5-year-old cows traveled further per day than low-RFI 5-year-old cows (P < 0.03), and low-RFI 8-year-old cows tended (P = 0.08; Figure 5) to travel further than high-RFI 8-year-old cows. No RFI effects (P < 0.71) were observed on distance traveled for 2-year-old cows. Distance traveled ranged from 3.00 ± 0.09 for 2-year-old cows to 2.49 ± 0.09 km · d−1 for 8-year-old cows. Time spent grazing was not influenced by cow age (P = 0.29) nor RFI (P = 0.40), averaging 6.06 ± 0.44 h · d^{-1}.

Herd-level grazing resource utilization for cattle on dormant rangeland forage was not impacted by aspect ($\hat{\hat{\beta}}$ North = 0.02 ± 0.01; $\hat{\hat{\beta}}$ South = −0.01 ± 0.01; $\hat{\hat{\beta}}$ East = −0.02 ± 0.02; $\hat{\hat{\beta}}$ West = −0.01 ± 0.02), elevation ($\hat{\hat{\beta}}$ = 0.07 ± 0.37), distance to supplement ($\hat{\hat{\beta}}$ = −0.37 ± 0.51), distance to water ($\hat{\hat{\beta}}$ = 0.04 ± 0.44), or terrain ruggedness ($\hat{\hat{\beta}}$ = −0.06 ± 0.03; Figure 6). However, resource utilization relative to elevation, distance to supplement, and distance to water were highly variable among individuals (herd-level SE of standardized coefficients > 0.25; Figure 7). Therefore, we conducted a post hoc analysis evaluating the effects of RFI, cow age, and the interaction of RFI and cow age on grazing resource utilization relative to elevation, distance to supplement, and distance to water.

Cow age did not interact with RFI (P > 0.11) when evaluating the probability of grazing site selection relative to elevation, distance from supplement and water. As a result, only RFI and cow age main effects are reported. The probability of grazing site selection relative to elevation was not influenced by RFI (P = 0.62) or cow age (P =

0.16). The probability of grazing site selection relative to distance to supplement was not impacted by RFI (*P* = 0.68), but was linearly influenced by cow age ($\hat{\hat{\beta}}$ 2-years old = 0.06 ± 0.08; $\hat{\hat{\beta}}$ 5-years old = −0.31 ± 0.08; $\hat{\hat{\beta}}$ 8-years old = −0.90 ± 0.08; $P < 0.01$) with older cows grazing closer to supplement locations than younger cows (Figure 8A). The probability of grazing site selection relative to distance to water was also not impacted by RFI (*P* = 0.63); however, it was quadratically influenced by cow age ((($\hat{\hat{\beta}}$ 2-years old = −0.20 ± 0.08; (($\hat{\hat{\beta}}$ 5-years old = −0.10 ± 0.08; ($\hat{\hat{\beta}}$ 8-years old = 0.44 ± 0.08; *P* = 0.03) with 8-year-old cows selecting grazing locations further from water than 2- and 5-year-old cows (Figure 8B).

Core grazing area (ha) was linearly affected by cow age ($P < 0.01$), with core grazing area decreasing with increasing cow age (Figure 9). There was no effect of RFI on core grazing area (*P* = 0.71), but a tendency for a cow age × RFI interaction was observed (*P* = 0.07). However, there were no differences observed for RFI within cow age ($P > 0.10$) relative to size of core grazing area.

Discussion

While the estimation of RFI on young bulls and developing heifers is becoming a more popular practice in the US beef industry, the use of RFI of post-weaned heifers as a selection criterion for retention of replacement females for forage-based rangeland environments has not been well studied. Conventional wisdom suggests that cattle with low RFI values are more efficient in converting nutrients to maintenance energy and body weight gain. Few research experiments have investigated the effects of RFI on beef cattle performance, supplement intake and grazing behavior or resource use while grazing late season dormant rangelands. If low-RFI cattle have lower maintenance requirements, selection for low-RFI cattle on low quality late-season mature rangelands could lead to cattle that are more efficient while grazing on low-energy and low-protein diets, assuming that low-RFI cattle have lower maintenance requirements when facing nutritionally stressful periods.

Sprinkle and coworkers (2020) were the first to examine the effects of RFI on livestock performance while grazing low-quality dormant forages; however, their research focused solely on 2-year-old cows. In contrast, our study focused on the effects of RFI across multiple age groups on supplement intake behavior, grazing behavior, and resource use while grazing low quality dormant mixed-grass rangelands. Most of the research investigating the effects of RFI on cattle performance has occurred on both irrigated and improved dryland summer pastures (Lawrence et al., 2012; Knight et al., 2015; and Manafiazar et al., 2015). All the above-mentioned research trials can be characterized as having adequate forage quality to meet maintenance requirements with the exception of Sprinkle et al., (2020), where their grazing and forage conditions were similar to those experienced during our research trial.

Previous research by Sprinkle et al., (2019a) reported that low-RFI cows grazing summer rangelands in central Idaho travel further and graze longer than high-RFI cows at warmer temperatures. Conversely, we observed no effect of RFI on grazing behavior, and resource use during our late fall/early winter grazing trial. However, 5-year-old high-RFI cows did travel further than low-RFI 5-year-old cows, and low-RFI 8-year-old cows tended to travel further than high-RFI 8-year-old cows with no observed differences among 2-year-old cows. Sprinkle et al., (2020) reported that while grazing late season dormant rangelands in Idaho that low RFI 2-yr-olds lost less weight and body condition compared to high RFI 2-yr-olds with no difference in daily distance traveled or foraging rate (bites · m^{-1}). Conversely, we observed a decrease in BW change with increasing RFI classification for 4-yr old cows, with no observed changes in cow BW within all other cow ages. However, we did not observe effects of RFI classification on BCS change, and the differences we observed in distance traveled and core grazing area were associated with cow age and not RFI classification. Similarly, Sprinkle et al., (2019b) also reported no difference in distance traveled or time spent grazing between low RFI and high RFI 2-yr old cows grazing supplemented fall pastures in central Idaho. Our results are also consistent with Meyer et al. (2008), where RFI did not affect BW and BCS change or supplement intake while grazing during late winter and early spring.

Although limited, previous experiments evaluating supplement intake of mixed-age beef herds have reported that younger cows spent less time at the supplement feeders and consumed less supplement than older cows (Earley et al., 1999; Sowell et al., 2003). In contrast, Wyffels et al., (2020b) reported younger cattle consumed more supplement and visited the supplement feeders more often than older cows. Results from our research are similar to Wyffels et al., (2020b), where we observed a quadratic effect in supplement intake related to cow age where 1-yr old cows consumed more and had a larger CV of supplement intake than older cows.

Previous research reported that cow age significantly impacted grazing behavior and distribution with older cows grazing further from water and using higher elevations than younger cows (Wallburger et al., 2009; Wyffels et al., 2020c). Our results agree with these reports, where older cows selected grazing locations further from water than younger cows. Wyffels et al., (2020c) reported similar results to our study, where older cows selected grazing locations closer to supplement and herd-level resource utilization was negatively related to terrain ruggedness on mixed-grass prairie rangelands. In our study we observed that herd-level grazing resource utilization of cattle grazing dormant mixed-grass prairie rangelands was not impacted by aspect, elevation, or terrain ruggedness.

Our research suggests that in dormant forage grazing environments heifer post-weaning RFI has little effect on supplement intake behavior (with the exception of 3-yr old cows), grazing behavior, or resource use. We observed no RFI impact on BW or BCS change over the 84-d grazing period, with the exception of 4-yr old cows. Our results agree with previous research by Walker et al., (2015) that suggests post-weaning RFI is independent of mature cow BW and may have little impact on the efficiency of cattle winter grazing on dormant rangelands. However, despite the lack of differences in supplement intake behavior, grazing behavior, and resource use in our study, if cows selected for low RFI have the same performance parameters as high RFI cows while consuming less feed, selection for low RFI cattle would still be warranted. As a result, further research is needed to investigate the relationship of heifer post-weaning RFI classification and dry-matter intake of cows at different ages and stages of production.

Implications

Heifer post-weaning RFI classification had little effect on subsequent performance (BW or BCS), grazing behavior, supplement intake behavior, or resource use. However, cow age significantly influenced subsequent performance, grazing behavior, supplement intake behavior and resource use. We also observed high individual variability in grazing site selection, suggesting individual-level factors may be driving grazing resource use and grazing behavior. Therefore, our research suggests that cow age has more impact on resource use, supplement intake and grazing behavior than heifer post-weaning RFI classification while dormant season grazing on mixed-grass prairie rangelands.

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Table 1. Average yearly grass available biomass (kg · ha^{-1}), crude protein (CP %), acid detergent fiber (ADF %), neutral detergent fiber (NDF %), and total digestible nutrients (TDN %) of the experimental pasture for the 2 years of grazing (2018 - 2019, 2019 - 2020) at the Northern Agricultural Research Center Thackeray Ranch, Havre, MT, USA.

	Grass production (kg/ha)	CP (%)	ADF (%)	NDF (%)	TDN (%)
Year 1	1790	5.4	41.9	63.2	56.0
Year 2	1456	5.4	39.9	66.9	55.0

Table 2. Initial body weight (BW)and body condition score (BCS) for 6 age classes of cattle (± SE) across a 2-year grazing trial (2018 – 2019, 2019 – 2020) at the Northern Agricultural Research Center Thackeray Ranch, Havre, MT, USA.

	Age class					
	1	2	3	4	5 to 7	≥ 8
Initial BW, kg						
Year 1	489.6 ± 5.30	495.3 ± 7.55	565.4 ± 11.04	597.0 ± 8.88	617.2 ± 8.72	610.6 ± 9.28
Year 2	467.5 ± 4.20	508.4 ± 7.05	561.0 ± 9.16	616.7 ± 12.41	637.5 ± 6.75	624.6 ± 8.27
Initial BCS[1]						
Year 1	5.76 ± 0.04	5.24 ± 0.08	5.52 ± 0.11	5.59 ± 0.09	5.56 ± 0.08	5.59 ± 0.07
Year 2	5.76 ± 0.05	5.21 ± 0.05	5.16 ± 0.11	5.47 ± 0.09	5.52 ± 0.06	5.41 ± 0.07
Final BW, kg						
Year 1	497.0 ± 5.84	524.4 ± 7.11	496.4 ± 10.05	624.9 ± 6.36	644.3 ± 7.70	641.8 ± 9.39
Year 2	448.7 ± 4.28	490.6 ± 7.04	547.7 ± 7.58	595.8 ± 11.64	606.8 ± 7.02	609.9 ± 8.24
Final BCS						
Year 1	5.66 ± 0.04	5.06 ± 0.10	5.41 ± 0.09	5.63 ± 0.05	5.61 ± 0.06	5.45 ± 0.07
Year 2	5.67 ± 0.05	5.29 ± 0.05	5.39 ± 0.07	5.69 ± 0.09	5.65 ± 0.06	5.57 ± 0.07

[1]Body condition score based on a 1–9 scale: 1 = emaciated, 9 = obese

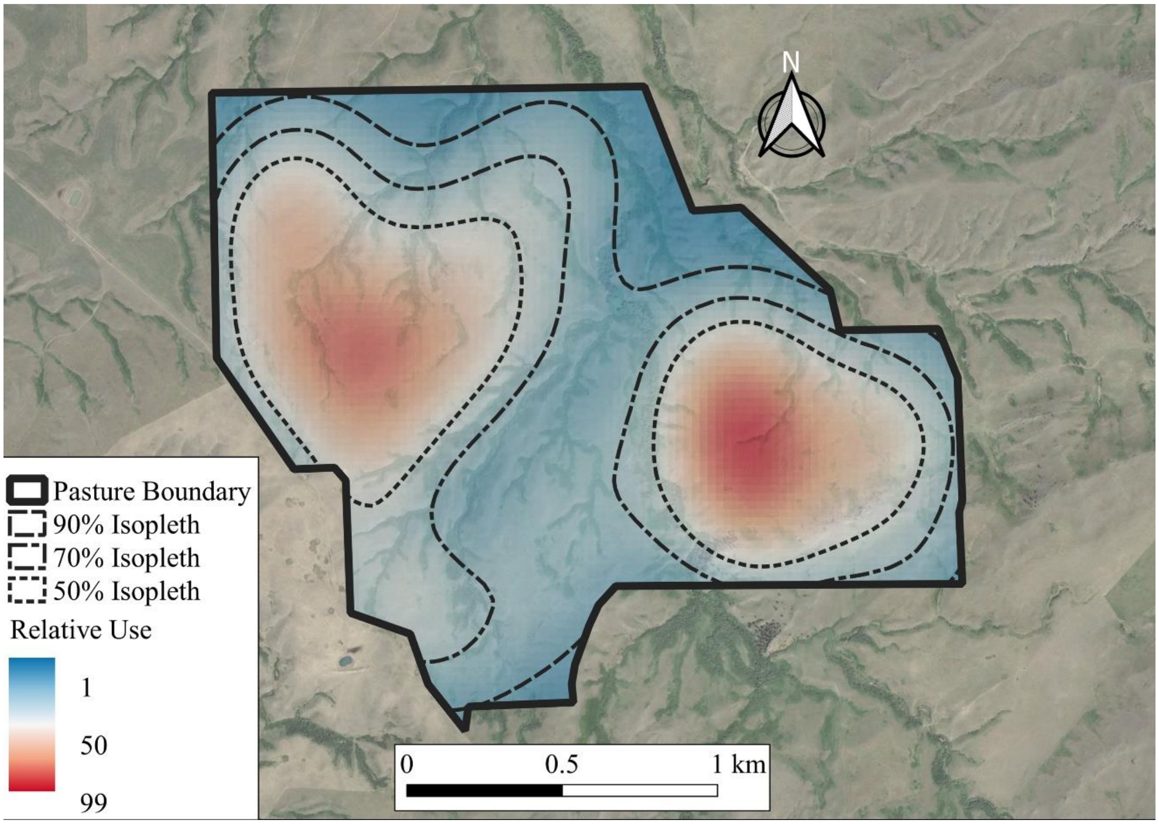

Figure 1. Isopleth showing relative use by cattle grazing dormant mixed grass prairie in 2018-2019 and 2019-2020 at the Northern Agriculture Research Center's Thackeray Ranch, Havre, MT, USA.

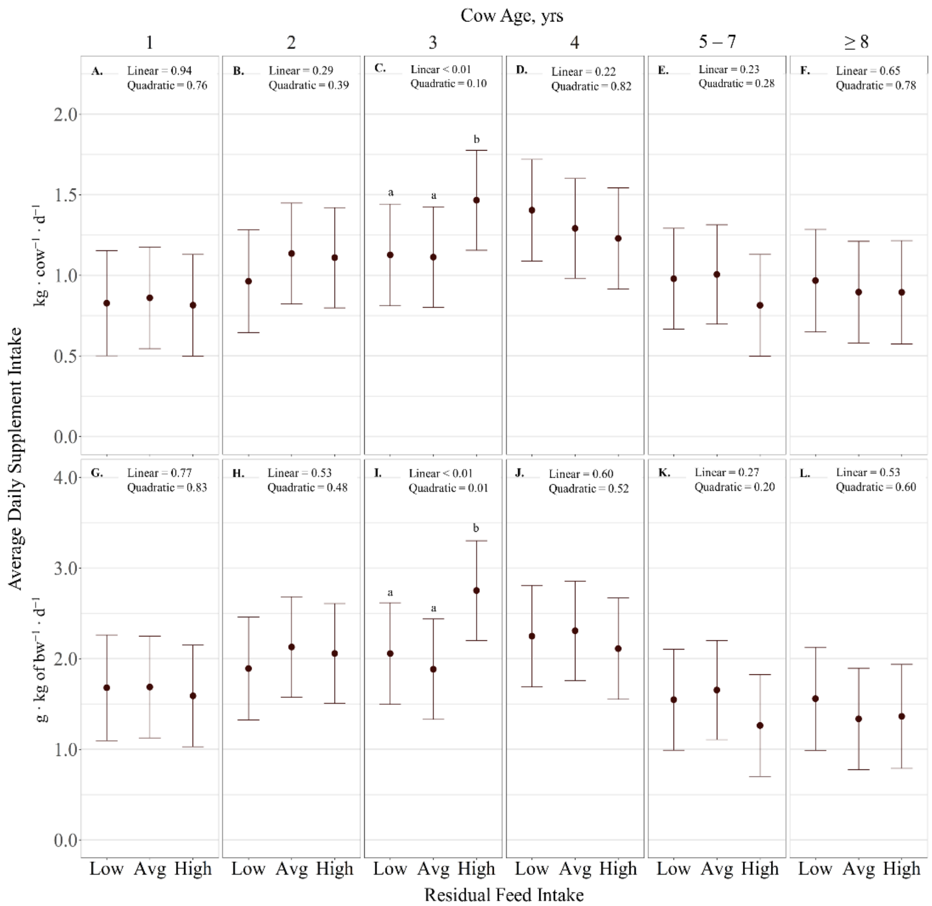

Figure 2. Influence of RFI × cow age ($p < 0.01$) on average daily supplement intake (expressed as g · kg^{-1} of BW · d^{-1} (A – F), as well as kg · cow^{-1} · d^{-1} (G – L) ± SE) by cattle grazing dormant mixed-grass prairie in 2018/2019 and 2019/2020 at the Northern Agriculture Research Center's Thackeray Ranch, Havre, MT, USA. Means lacking common letters (a, b) differ ($P < 0.05$).

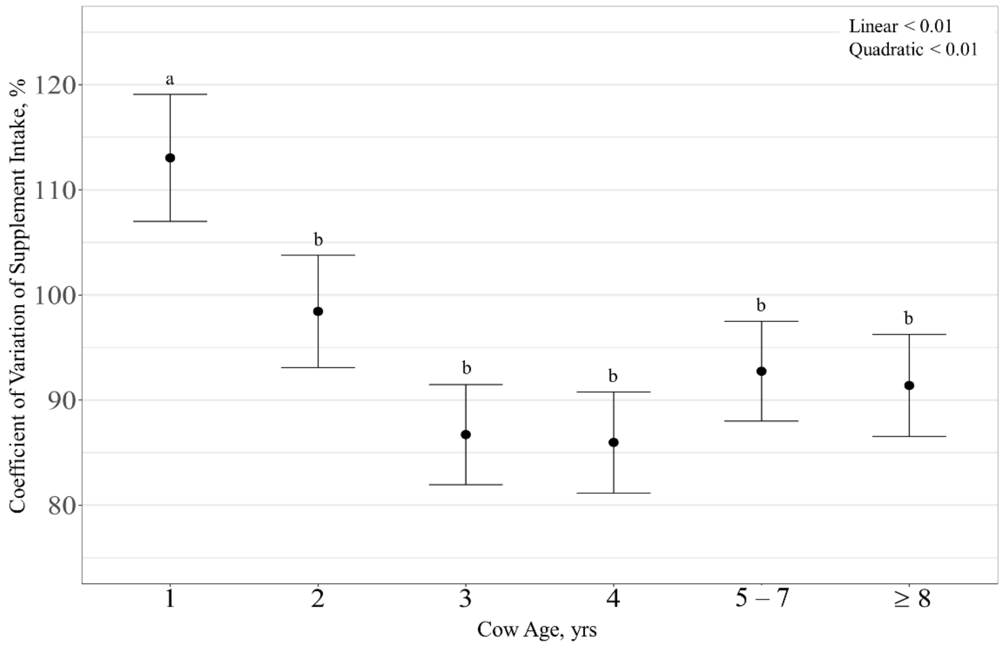

Figure 3. Influence of cow age on coefficient of variation of supplement intake (expressed as % ± SE) by cattle grazing dormant northern mixed-grass prairie in 2018/2019 and 2019/2020 at the Northern Agriculture Research Center's Thackeray Ranch, Havre, MT, USA. Means lacking common letters (a, b) differ ($P < 0.05$).

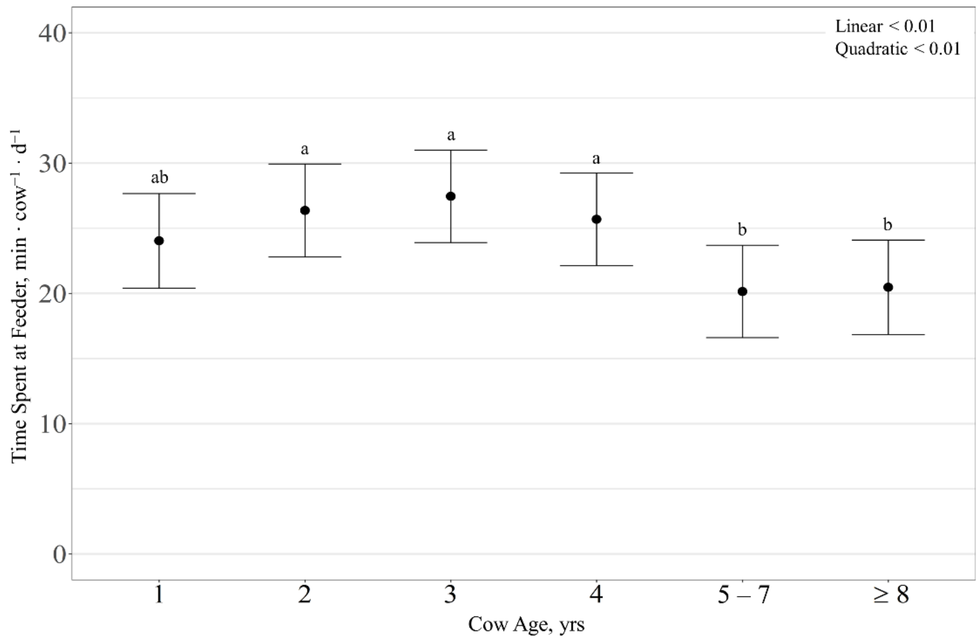

Figure 4. Influence of cow age on average daily time spent at supplement feeder (expressed as minutes · cow^{-1} · d^{-1} ± SE) by cattle grazing dormant northern mixed-grass prairie in 2018/2019 and 2019/2020 at the Northern Agriculture Research Center's Thackeray Ranch, Havre, MT, USA. Means lacking common letters (a, b) differ (P < 0.05).

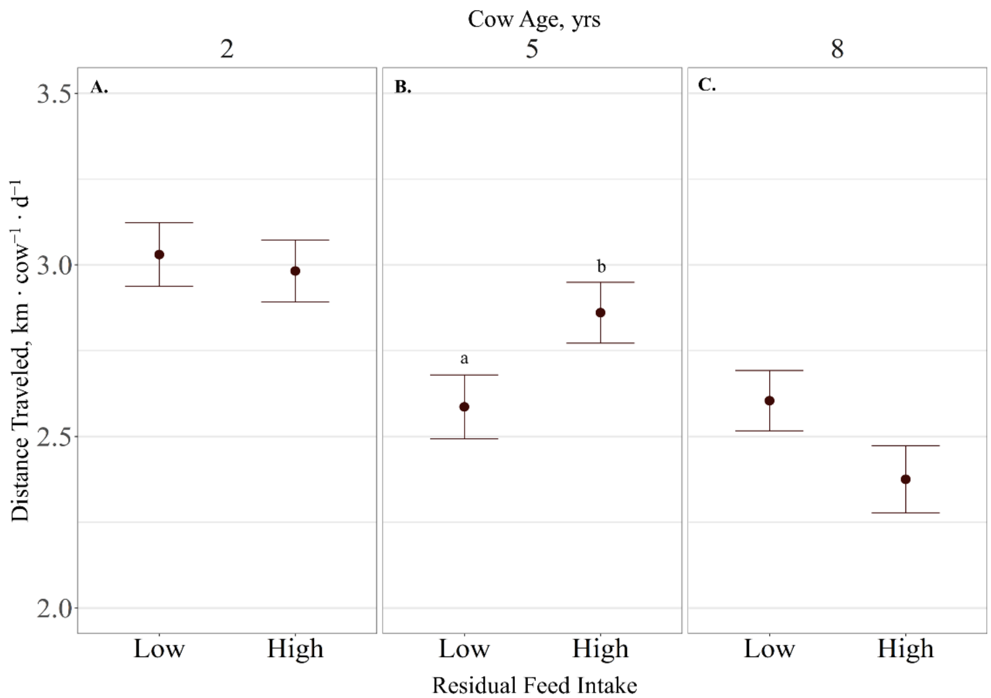

Figure 5. Influence of residual feed intake × cow age (A – C; *p* = 0.02) on average distance traveled expressed as km cow^{-1} · d^{-1} ± SE) by cattle grazing dormant northern mixed-grass prairie in 2018/2019 and 2019/2020 at the Northern Agriculture Research Center's Thackeray Ranch, Havre, MT, USA. Means lacking common letters (a, b) differ ($P < 0.05$).

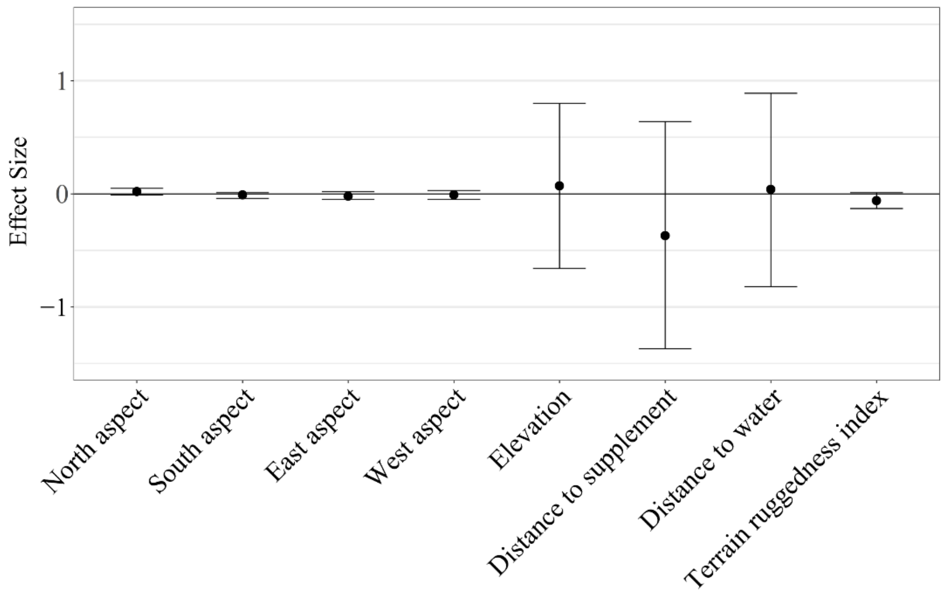
Effect Size
1
0
−1
North aspect
South aspect
East aspect
West aspect
Elevation
Distance to supplement
Distance to water
Terrain ruggedness index

Figure 6. Mean standardized herd-level effect size ($\hat{\bar{\beta}}$ ± 95% CI) for cattle grazing dormant northern mixed-grass prairie in 2018/2019 and 2019/2020 at the Northern Agriculture Research Center's Thackeray Ranch, Havre, MT, USA.

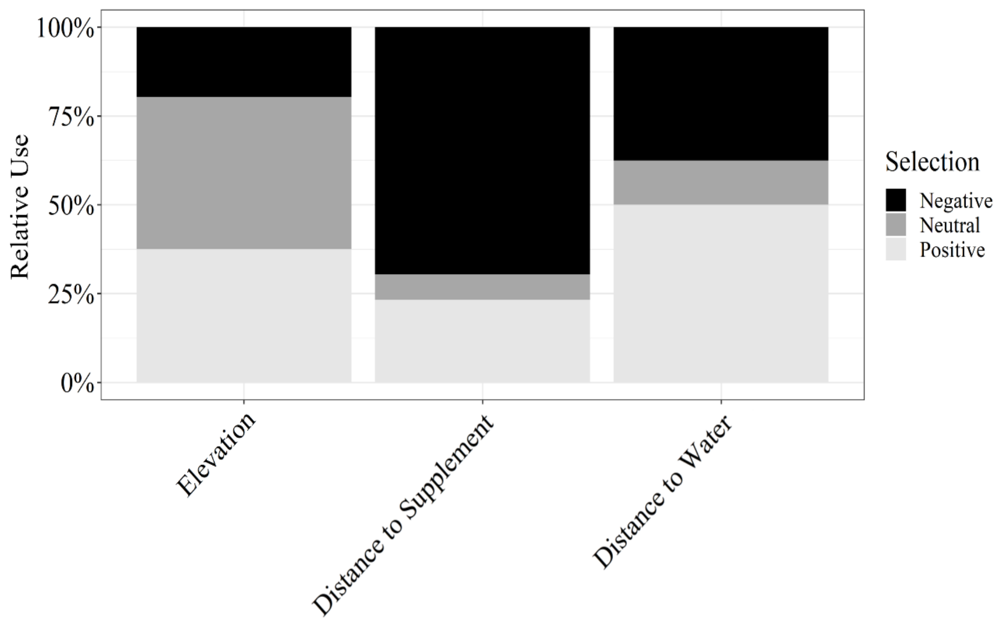

Figure 7. Influence of elevation, distance to supplement, and distance to water on relative use by cattle grazing dormant northern mixed-grass prairie in 2018/2019 and 2019/2020 at the Northern Agriculture Research Center's Thackeray Ranch, Havre, MT, USA.

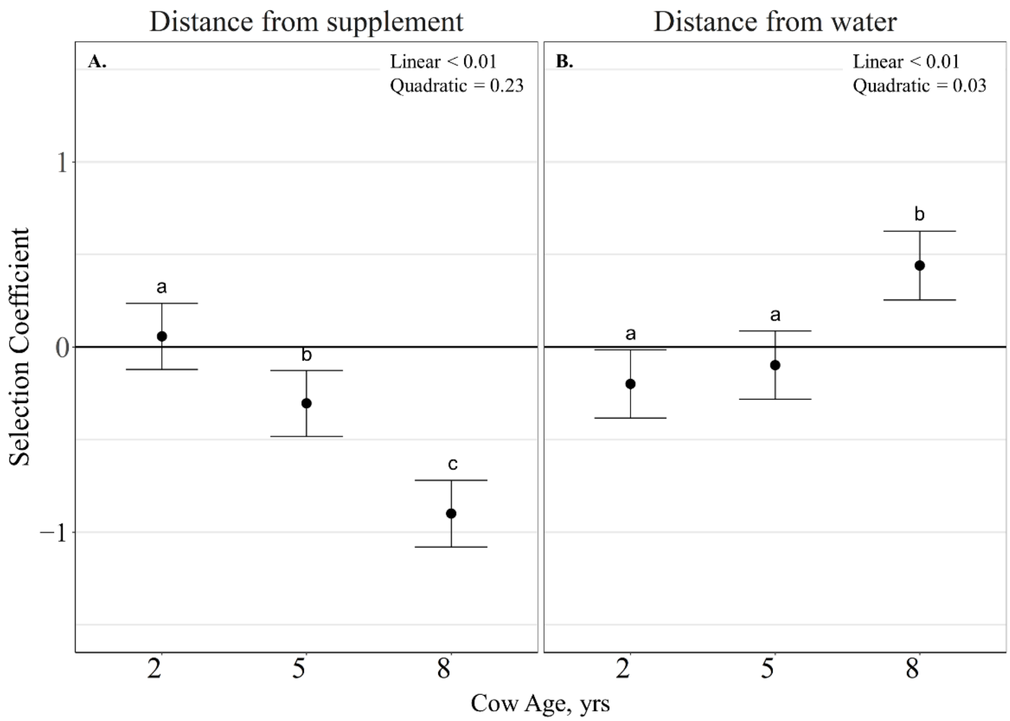

Figure 8. Influence of cow age on distance from supplement (A) and distance from water (B; expressed as slope estimate ± CI) of cattle grazing dormant northern mixed-grass prairie in 2018/2019 and 2019/2020 at the Northern Agriculture Research Center's Thackeray Ranch, Havre, MT, USA. Means lacking common letters (a, b) differ ($p < 0.05$).

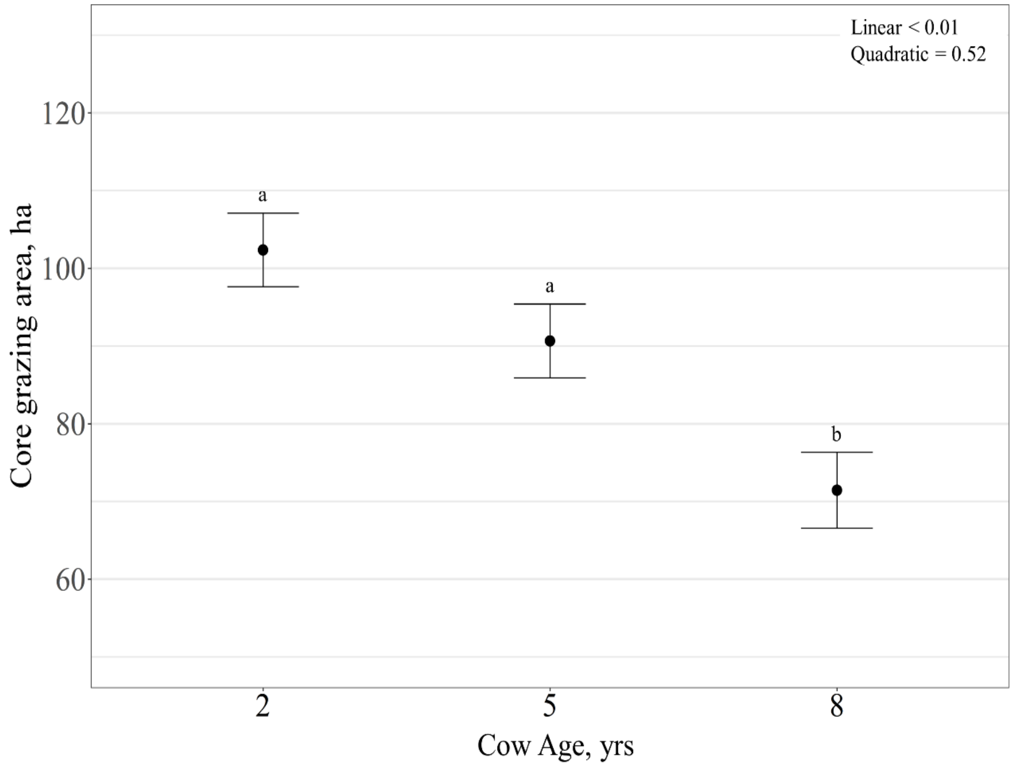

Figure 9. Influence of cow age on core grazing area (expressed as ha ± SE) by cattle grazing dormant northern mixed grass prairie in 2018-2019 and 2019-2020 at the Northern Agriculture Research Center's Thackeray Ranch, Havre, MT, USA.

CHAPTER FOUR

THE INFLUENCE OF RESIDUAL FEED INTAKE AND COW AGE ON DRY MATTER INTAKE POST-WEANING AND PEAK LACTATION OF BLACK ANGUS COWS

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***Animals* 2021,11,1822. doi.org/10.3390/ani11061822**

Status of Manuscript:

____ Prepared for submission to a peer-reviewed journal

____ Officially submitted to a peer-reviewed journal

____ Accepted by a peer-reviewed journal

_X__ Published in a peer-reviewed journal

CHAPTER FOUR

THE INFLUENCE OF RESIDUAL FEED INTAKE AND COW AGE ON DRY MATTER INTAKE POST-WEANING AND PEAK LACTATION OF BLACK ANGUS COWS

Abstract

The objectives of this study were to evaluate the influence of heifer post-weaning residual feed intake (RFI) and cow age on dry matter intake (DMI) as well as, milk production of dry-lotted beef cattle at different ages and stages of production. Fifty-nine non-lactating, pregnant, (Study 1) and fifty-four lactating, non-pregnant (Study 2) commercial black Angus beef cows ranging in age from 2- to 10-yr of age were stratified by age and RFI and fed free-choice hay pellets in a GrowSafe feeding system. Cows were grouped by age to evaluate the effects of RFI, and cow age on average daily individual supplement intake, variation of supplement intake (CV), and intake behavior, as well as, milk production following a 21-d dry-lot DMI period. Cow body weight (BW) and body condition score (BCS) at the initiation of study 1 exhibited a cow age × RFI interaction ($P < 0.02$) with low RFI 5/6-yr old cows having a lighter BW and lower BCS than high RFI cows. Cow DMI ($kg \cdot d^{-1}$) and intake rate ($g \cdot min^{-1}$) displayed a cow age effect ($P < 0.01$) with an increase in DMI and intake rate with increasing cow age. Cow BW and BCS at the initiation of study 2 exhibited a cow age × RFI interaction ($P < 0.01$) with low RFI 5/6-yr old cows having a lower BW and BCS than high RFI cows and low RFI 8/9-

yr old cows having a higher BW and BCS than high RFI cows. Calf BW displayed a cow age × RFI interaction ($P < 0.03$) with low RFI 3/4-yr old cows having heavier calves than high RFI cows. Cow DMI (kg · d^{-1}) and intake rate (g · min^{-1}) displayed a cow age effect ($P < 0.02$) with an increase in DMI and intake rate with increasing cow age. Milk production, (kg and g · kg BW^{-1}) displayed a cow age × RFI interaction ($P < 0.01$) where both 3/4-yr old and 6/7-yr old low RFI cows produced more milk than high RFI cows. Neither DMI intake (g · kg BW^{-1}), % CV, or time spent at the feeder (min · d^{-1}) were effected by cow age, RFI or cow age × RFI ($P > 0.32$) during either DMI trial. In summary, heifer post-weaning RFI had minimal effects on beef cattle DMI or intake behavior, however, some differences were observed in milk production when compared at different ages and stages of production.

Key words: age and stage of production, beef cattle, dry matter intake, residual feed intake (RFI)

Introduction

Supplemental nutrition for animals is the greatest operating cost for cow-calf producers where supplemental feed can account for 65% of the annual expenses (Arthur et al., 2004; Van der Westhuizen et al., 2004; Meyer et al., 2008). Traditionally, selection pressure has been placed on production traits associated with increasing outputs (average daily gain, weaning weight, yearling weight, etc…), which can also result in increased inputs to achieve animal production potential. Since feed costs constitute the greatest proportion of total inputs, selection pressure for efficient animals that have lower feed intake but maintain production, or average intake with higher production, could have a great impact on cow-calf profitability (Meyer et al., 2008). Thus, improving feed efficiency through genetic selection holds significant opportunity for the beef industry.

Residual feed intake (RFI) is currently being used as a selection tool for purchasing and retaining heifers and for selecting bulls. Most studies have used steers and terminal heifers when evaluating RFI's impact on various aspects of beef cattle production (Arthur et al., 2001; Kelly et al., 2010a,b). However, the use and relevance of RFI as a selection tool for the cow-calf industry needs additional research (Basarab et al., 2007; Manafaizar et al., 2015; Parsons et al., 2021). Most RFI studies have included energy-dense diets and rations focusing on feedlot performance (Arthur et al., 2001; Kelly et al., 2010a, b; Lawrence et al., 2014). Research pertaining to RFI in cattle offered forage-based diets is limited (Arthur et al., 2005), with even fewer data available related to beef cattle forage-based production systems (Basarab et al., 2007; Meyer et al., 2008; Sprinkle et al., 2020; Parsons et al., 2021). As a result, more research is needed to evaluate the utility of RFI estimates on the production of beef cattle in extensive forage base systems (Manafiazar et al. 2015; Sprinkle et al. 2020; Kenny et al., 2018).

The use of RFI for beef cattle selection in rangeland environments is based on the assumption that heifer post-weaning RFI will be expressed throughout the lifetime productivity of that heifer (Parsons et al., 2021a). Past research suggests that RFI is a moderately heritable trait (Herd et al., 2000), however, few published studies exist comparing RFI of individuals of 2 different physiological states (Kelly et al., 2010a,b; Loyd et al., 2011). Multiple studies have investigated feed efficiency in young, premature cattle, but few have quantified how RFI relates to feed efficiency at different ages and stages of production (Loyd et al., 2011; Black et al., 2013; Freetly et al., 2020). The repeatability of RFI between growing and finishing phases of beef cattle production has recently been examined (Kelly et al., 2010b; Durunna et al., 2012), but there are few reports demonstrating the relationship of RFI of growing females compared with those same females as mature, lactating (Black et al., 2013; Broleze et al., 2020), and non-pregnant, non-lactating beef cows (Freetly et al., 2020).

Research evaluating heifer post-weaning RFI on subsequent cow intake and intake efficiency is limited. Therefore, the objectives of these research studies were to: 1) evaluate the effects of heifer post-weaning RFI on non-lactating, pregnant, beef cows dry matter intake (DMI) at different cow ages; and 2) evaluate the effects of heifer post-weaning RFI on lactating, non-pregnant, beef cow DMI at different cow ages, as well as peak milk production. We hypothesized that heifers identified as low RFI eat less than high RFI cows and the influence of RFI may interact with cow age.

Materials and Methods

The use of animals in this study was approved by the Agricultural Animal Care and Use Committee of Montana State University AACUC #2018-AA12. These studies were conducted at the Northern Agricultural Research Center, located in Havre, Montana. All cattle were synchronized and time artificially inseminated (AI) corresponding to initial calving date of March 15, with exposure to cleanup bulls occurring approximately 7 days post AI for an additional 45 days. Calves were strategically weaned mid-

September to mid-October each year with the timing based on fall forage conditions and/or cow body condition.

All cows were managed as one contemporary group post-weaning in the fall to calving in the spring of each year. All heifers/cows were exposed to electronic feed bunks as heifers and again during winter supplement studies.

Heifer RFI trials

Starting in 2011, all Northern Agricultural Research Center cattle have been utilized in a heifer RFI trial for a minimum of 77 days on a forage-based ration provided in a GrowSafe system (GrowSafe DAQ 4000E; GrowSafe System Ltd., Airdrie, AB, Canada). Calves were weaned on pasture mid-September to early October each year and entered an RFI trial 60 to 75 days post weaning. On average, 45-95 AI sired replacement heifers were retained annually. Upon RFI trial initiation, and completion, all heifers were weighed post feeding, on two consecutive days to record beginning and ending body weights (BW), then again, every 28 days to record BW gain. A 7-d acclimation period preceded a 70-d feeding trial, while the GrowSafe system recorded individual daily feed intakes. All heifers had free access to 16-32 GrowSafe feed bunks and ad libitum access to water and forage-based diets, consisting of 30.4% corn silage, 41.1% grass hay, and 28.5% alfalfa on a dry mater basis, formulated to meet requirements for growing moderate frame beef heifers (10.5% CP and 66.0% TDN; NASEM, 2016). Individual heifer post-weaning RFI was calculated following parameters set forth by Archer et al., 2002 and Arthur et al., 2001:

RFI_{Phe} = FI-β w($_{phe}$)×MWT-βg($_{phe}$)×DG,

where RFI_{phe} = phenotypic residual feed intake, FI = daily feed intake, MWT = metabolic body weight at mid-test, DG = average daily gain, and βw($_{phe}$) and βg($_{phe}$) = partial regression coefficients of animal's FI on MWT and DG, respectively. Heifers were classified as either low (> -0.50 SD from mean), or high (< +0.50 SD from the mean) within year (Parsons et al., 2021a).

Two feed intake studies were conducted to evaluate the impacts of heifer post-weaning RFI at differing ages and stages of beef cattle production. Individual BW and body condition scores (BCS) were recorded and cattle were placed in a GrowSafe feeding system for DMI analysis over a 21-d period. For each study, treatments were replicated in two pens, each containing 16 GrowSafe feeding units. Individual animal intake was continuously recorded. The system was monitored daily for unaccounted feed balance. When greater than 5% of the feed disappearance was unaccounted for, the GrowSafe system automatically deemed the 24-h period as failed. Therefore, we selected the last 7 days of the 21-d period that met the criteria to calculate average DMI per individual animal for each DMI study. Variation in dry matter intake ($kg \cdot d^{-1}$), measured as the coefficient of variation (% CV), was based on daily intake estimates for individual animals.

Study 1: Non-lactating pregnant cow DMI

Fifty-nine non-lactating, pregnant, black Angus females were utilized to evaluate the impacts of heifer post-weaning RFI on DMI post weaning. All cows were fed commercially available free-choice alfalfa/straw pellet formulated to meet nutrient requirements for non-lactating, pregnant cows (Table 1; CHS Nutrition, Sioux Falls, SD; NASEM, 2016). At the initiation of the trial (14-d post weaning), cows were classified by age, (1/2- 4/5- and 7/8-yrs old; Table 2) and within age class represented both low and high RFI, and dry-lotted for 16 hours to obtain uniform shrunk BW and BCS.

Study 2: *Lactating non-pregnant cow DMI*

Fifty-four lactating, non-pregnant, black Angus females were utilized to evaluate the impacts of heifer post-weaning RFI (low and high) and cow age (3/4, 6/7, and 9/10-yrs cows) and dry-lotted for 16 hours to obtain uniform shrunk BW and BCS. Cows were selected by the same age and RFI criteria as described for study 1. However, for this study, we only utilized cows that calved within the first 42 days of the calving period. Calf BW and Julian birth date were measured to characterize the influence of cow age and RFI. All cows were fed commercially available free-choice alfalfa/grass base pellet formulated to meet NRC requirements for lactating cows for the DMI study (Table 1; CHS Nutrition, Sioux Falls, SD; NASEM, 2016). At the conclusion of the 7-d DMI period, a weigh-suckle-weigh trial was conducted to evaluate the impacts of heifer post-weaning RFI and cow age on milk production following methods detailed by Williams et al., 1979. For our study, we utilized an 8-hr calf removal protocol.

Statistical analysis

For both study 1 and 2, the influence of RFI and cow age on initial cow BCS and BW were analyzed using ANOVA with a generalized linear model including RFI, cow age and the interactions of RFI and cow age as fixed effects. Additionally, the influence of RFI and cow age on intake and intake behavior were analyzed using ANOVA with a generalized linear mixed model including RFI, cow age, and the interactions of RFI and cow age as fixed effects, and individual cow and pen as random effects. When RFI × cow age interactions were observed means were separated within age groups. Individual animal was considered the experimental unit and an alpha ≤ 0.05 was considered significant. Orthogonal polynomial contrasts were used to determine linear and quadratic effects for cow age. Means were separated using the Tukey method when $P < 0.05$. Tendencies were reported when significance was $P \leq 0.10$. All statistical analyses were performed in R (R Core Team 2020).

Results

Study 1: Non-lactating pregnant cow DMI

Cow BW displayed a cow age × RFI interaction ($P < 0.01$) where 4/5-yr old low RFI cows had a lighter BW than high RFI cows, however, low RFI 7/8-yr old cows tended ($P = 0.06$) to have greater BW than high RFI cows (Table 2). No differences in BW were observed between RFI classifications in 1/2-yr old cows ($P = 0.17$). Cow BCS also displayed a cow age × RFI interaction ($P = 0.02$) where low RFI 4/5-yr old cows had lower BCS than high RFI 4/5-yr old cows with no differences observed between RFI in other cow ages ($P \geq 0.24$). Both DMI ($kg \cdot d^{-1}$) and intake rate ($g \cdot min^{-1}$) displayed a cow age effect ($P < 0.01$) with a quadratic increase with increasing cow age ($P \leq 0.02$; Table 2). Specifically, young cows (1/2-yr old) ate less and had lower intake rates than older cows ($P < 0.01$). Neither DMI ($g \cdot kg\ BW^{-1}$), intake variation (% CV), or time spent at the feeder ($min \cdot d^{-1}$) were affected by cow age or RFI ($P \geq 0.16$), averaging 28.8 $g \cdot kg\ BW^{-1}$, 19.0 % CV, and 107.5 $min \cdot d^{-1}$, respectively.

Study 2: Lactating non-pregnant cow DMI

Cow BW displayed a cow age × RFI interaction ($P < 0.01$), with low RFI 5/6- and 8/9-yr old cows having a greater BW than high RFI 5/6- and 8/9-yr old cows ($P \leq 0.01$; Table 3). Similar to cow BW, cow BCS displayed a cow age × RFI interaction ($P < 0.01$) where low RFI 5/6-yr old cows had lower BCS than high RFI 5/6-yr old cows ($P < 0.01$), whereas, low RFI 8/9-yr old cows had higher BCS than low RFI 8/9-yr old cows ($P < 0.01$).

Calf BW, measured at weigh-suckle-weigh, displayed a cow age × RFI interaction ($P < 0.03$), where calf BW from 2/3-yr old cows were lower in high RFI 2/3-yr old cows compared to low RFI cows ($P = 0.02$; Table 3). Calf Julian birth date was effected by cow age ($P < 0.01$) with calf birth date increasing linearly with increasing cow age ($P < 0.01$; Table 3). There was also a tendency for an RFI effect on calf Julian birth date ($P = 0.09$) with low RFI cows tending to calve later in the calving season than high RFI cows, averaging 72.2 and 73.9 for high and low RFI, respectively.

Cow DMI ($kg \cdot d^{-1}$) displayed a cow age effect ($P < 0.01$) with a quadratic increase in DMI with increasing cow age ($P < 0.01$; Table 3). Similarly, intake rate ($g \cdot min^{-1}$) displayed a cow age effect ($P < 0.02$) with a linear increase ($P < 0.01$) in intake rate with increasing cow age. In contrast, neither DMI intake ($g \cdot kg\ BW^{-1}$), % CV, nor time spent at the feeder (min · d^{-1}) were effected by cow age, or RFI, averaging 21.7 g · kg BW^{-1}, 11.7 % CV, and 149.7 min· d^{-1}, respectively.

Cow milk production (kg) displayed a cow age × RFI interaction ($P < 0.01$; Table 3), with 2/3-yr old and 5/6-yr old low RFI cows producing more milk than high RFI cows of the same age ($P < 0.01$). In addition, cow milk production (g · kg body $weight^{-1}$), displayed a cow age × RFI interaction ($P < 0.01$) with 2/3-yr old and 5/6-yr old low RFI cows producing more milk per kg of BW than high RFI cows of the same age ($P < 0.01$), however, no differences were observed in 8/9-yr old cows ($P = 0.48$).

Discussion

It has been reported that as cattle grow and mature, composition of their gain changes from protein accretion to fat deposition (Trenkle et al., 1977). Since the expense of protein accrual is less than for fat deposition, the efficiency that cattle convert feed into BW gain is reduced as they mature (Ferrell et al., 1985). Multiple research papers have reported on the changes in feed efficiency (RFI) of cattle at different stages of physiological growth. Durunna et al., (2012) reported that following two consecutive 70-d RFI periods, 49% of the heifers maintained their original RFI classification, whereas 51% had a different RFI classification, indicating re-ranking exists in heifers despite receiving the same basal diet. Loyd et al., (2011) suggested that RFI determined during the pre-pubertal period may only be a moderate predictor of post-pubertal RFI.

Archer et al., (2002) reported a moderate correlation of 0.40 between RFI measured in heifers post-weaning and later as non-gestating, non-lactating 3-yr old cows.

Freetly et al., (2020) compared the RFI classification of yearling heifers following an 84-d RFI intake trial with subsequent RFI classification of 5-yr old non-pregnant, non-lactating cows, and reported that feed intake and ADG are heritable and genetically correlated between heifers and cows. Black et al., (2013) compared the RFI classification of growing heifers following a 70-d RFI trial and subsequently as 3-yr old lactating beef cows and reported heifers that were the most feed efficient consumed less feed as lactating cows while maintaining similar performance. However, they reported that correlations between heifer and mature cow RFI values were not significant indicating that within-animal feed efficiency was not maintained as the calves developed from growing heifers to mature, lactating cows.

Results from our research are in general agreement with previous research where intake tends to change between ages and physiological stages of production of female beef cows, indicating that heifer post-weaning RFI may not be a reliable predictor of mature cow feed intake. In contrast, cow age had a substantial impact on intake, and intake behavior. Previous research reported that cow age significantly impacted grazing behavior and terrain use when comparing older cows to younger cows (Wallburger et al., 2009, Wyffels et al., 2020, Parsons et al, 2021a). Furthermore, although limited, previous studies evaluating supplement intake of mixed-age beef herds have reported that younger cows spent less time at feeders and consumed less feed than older cows (Earley et al., 1999, Sowell et al., 2003). In contrast, Wyffels et al., (2020) reported younger cattle consumed more and visited the feeders more often than older cows. Parsons et al., (2021b) observed a quadratic effect in intake related to cow age where 1-yr old cows consumed more supplement and had a larger CV of intake than older cows.

Broleze et al., (2020) states that measuring RFI in lactating animals is important, however, RFI does not accurately reflect production efficiency. This is because the RFI models that are used to calculate residual traits for lactating cows do not account for the energy partitioning into the various components, some of which are more financially important (e.g., milk fat and protein yield) than others (metabolic BW; (Berry et al., 2012)). Previous research found no relationship between milk yield (obtained by weigh-suckle-weigh technique) and RFI, with low RFI and high RFI cows having similar milk yield (Black et al., 2013, Lawrence et al., 2014, Walker et al., 2015). Rutledge et al., (1971) reported that dams nursing female calves produced significantly more milk than those nursing male calves. In contrast, Melton et al., (1967) and Christian et al., (1965) found no significant difference in dam's milk yield attributable to sex of calf while Pope et al., (1968) reported an advantage for cows nursing male calves.

In this study, cow milk production ($g \cdot kg\ BW^{-1}$) was impacted by both cow age and RFI with 3/4 and 6/7-yr old low RFI cows producing more milk than high RFI cows of the same age. Regardless of unit of measurement, the difference in milk production (kg vs $g \cdot kg\ BW^{-1}$) were consistent across young and middle-age cows. This suggests that heifer post-weaning RFI may be related to milk production of young and middle-aged cows. Few research trials have compared low RFI to high RFI lactating, non-pregnant beef cows (Black et al., 2013, Montanholi et al., 2010, Lawrence et al., 2014). Previous research report that low RFI (more efficient) and high RFI (less efficient) cows produce similar quantities of milk, but the former consumed less dry matter per day (Black et al., 2013, Walker et al., 2015, Souza et al., 2019). To our knowledge, this is the first study comparing post-weaning heifer RFI to subsequent milk production of beef cows across multiple age classes.

Implications

Heifer post-weaning RFI did not influence mature cow dry matter intake, and this was consistent for both lactating and non-lactating beef cows. In contrast, cow age did correspond to quadratic increases of DMI and intake rates of mature cows. However, when DMI was expressed as g · kg body weight^{-1} no differences were observed with respect to cow age in lactating and non-lactating cows. Milk production was influenced by heifer post-weaning RFI for 3/4 and 6/7-yr old cows, however, did not influence 9/10-yr old cows. Therefore, our research suggests that cow age has greater impacts on dry matter intake than RFI, however, the relationship between RFI of heifers and subsequent mature cow milk production warrants further investigation.

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Table 1. Ingredients and nutrient composition (DM basis) of the commercially available hay pellets provided ad-libitum to cows in GrowSafe pens during the 21-d DMI trials, fall 2019 and spring 2020.

Item	Non-lactating, pregnant cow	Lactating, non-pregnant cow
Ingredient, %		
Alfalfa hay	49.53	79.05
Straw	49.52	
Corn, ground		20.0
Ultramin 12-6	0.75	0.75
Trace mineral mix[1]	0.20	0.20
Nutrient value, %		
DM	93.6	90.4
CP	10.5	16.8
ADF	40.4	34.0
TDN	62.0	65.1
NEm	0.63	0.67
NEg	0.36	0.40
Nel	0.64	0.67
Ca	0.96	1.79
P	0.19	0.21
S	0.19	0.21
Mg	0.20	0.27
Na	0.02	0.02
K	2.03	2.03

[1]Trace mineral mix: 285.5 ppm Fe, 71.0 ppm Zn, 59.0 ppm Mn, 25.0 ppm Cu, 1.6 ppm I, 1.45 ppm Mo, 0.4 ppm Se, 1.0 IU/kg vitamin A, 0.1 IU/kg vitamin D, 1.7 IU/kg vitamin E

Table 2. Cow body weight (BW) and body condition scores (BCS) of 3 age classes of non-lactating, pregnant beef cows (Study 1).

	Cow age, yrs									
	1/2		4/5		7/8			*P*-value		
Category	Low RFI	High RFI	Low RFI	High RFI	Low RFI	High RFI	SE[1]	Age	RFI	Age × RFI
Cows n	10	10	10	10	10	9				
Cow BW[2]	435.2	444.1	470.2[a]	497.4[b]	567.7	557.9	4.66	< 0.01	0.17	< 0.01
Cow BCS[3]	5.38	5.45	5.43[a]	5.65[b]	5.38	5.28	0.06	< 0.01	0.35	0.02
DMI kg · d^{-1}	12.86	12.58	15.15	17.07	16.59	16.59	1.00	< 0.01	0.77	0.21
DMI g · kg BW^{-1}	29.57	28.24	26.63	28.69	29.35	30.22	1.68	0.57	0.48	0.43
DMI g · min^{-1}	92.24	92.60	145.88	144.83	135.04	132.45	7.95	< 0.01	0.97	0.98
% CV[4]	15.95	22.41	22.50	17.76	16.53	20.67	3.37	0.62	0.16	0.21
Time @ feeder min · d^{-1}	144.65	139.92	105.39	123.12	131.69	132.28	9.51	0.45	0.67	0.44

[1]Pooled standard error of the means
[2]Cow body weight (kg) at initiation of trial
[3]Cow body condition score at initiation of trial
[4]Coefficient of variation for intake expressed as kg · d^{-1}
[*]Means within row and cow age lacking common superscript differ ($P < 0.05$)

Table 3. The influence of heifer post-weaning RFI on subsequent beef cow performance and dry matter intake behavior of 3 age classes of lactating, non-pregnant beef cows average 60-d post-partum (Study 2).

	Cow age, yrs							*P*-value		
	2/3		5/6		8/9					
Category	Low RFI	High RFI	Low RFI	High RFI	Low RFI	High RFI	SE[1]	Age	RFI	Age × RFI
Cows n	7	10	9	10	9	9				
Cow BW[2]	397.5	408.4	541.8^{a}	476.7^{b}	534.2^{a}	516.8^{b}	4.96	< 0.01	0.12	< 0.01
Cow BCS[3]	4.22	4.19	4.75^{a}	4.95^{b}	4.72^{a}	4.50^{b}	0.05	< 0.01	0.69	< 0.01
Calf n	6	10	9	10	9	9				
Calf BW[4]	97.3^{a}	91.9^{b}	95.1	97.9	104.9	101.8	1.55	< 0.01	< 0.02	< 0.03
Calf Julian birth date	70.2	66.8	75.5	73.4	76.1	76.6	1.41	< 0.01	0.09	0.38
DMI kg · d^{-1}	18.22	18.41	22.90	24.00	23.84	23.10	1.00	< 0.01	0.88	0.57
DMI g · kg BW^{-1}	45.74	44.88	42.48	41.71	45.00	45.19	1.87	< 0.02	0.74	0.95
DMI g · min^{-1}	127.70	123.71	166.33	162.48	168.58	163.12	11.58	0.02	0.81	0.99
% CV[5]	13.25	12.91	9.01	11.17	12.54	11.49	1.46	0.68	0.88	0.45
Time @ feeder min · d^{-1}	149.42	154.30	140.00	153.07	149.28	152.41	11.99	0.99	0.75	0.88
Milk production kg	3.89^{a}	2.77^{b}	4.88^{a}	4.22^{b}	4.23	4.28	0.16	< 0.01	< 0.01	< 0.01
Milk production g · kg BW^{-1}	9.76^{a}	6.82^{b}	9.17^{a}	7.32^{b}	8.04	8.42	0.38	< 0.01	< 0.01	< 0.01

[1]Pooled standard error of the means
[2]Cow body weight (kg) at initiation of trial
[3]Cow body condition score at initiation of trial
[4]Calf body weight (kg) at weigh-suckle-weigh
[5]Coefficient of variation for intake expressed as kg · d^{-1}
*Means within row and cow age lacking common superscript differ ($P < 0.05$)

CHAPTER FIVE

CONLUSIONS AND FUTURE RESEARCH NEEDS

Traditionally, feed efficiency of beef cattle has been expressed as the ratio of feed intake to body weight gained (feed to gain or gain to feed). However, selection for high growth rates inevitably increases the maintenance requirements, feed requirements, and intake of cattle with subsequent higher environmental and feed costs (Okine et al. 2004). In contrast, net feed efficiency (Byerly, 1941) or Residual Feed Intake (RFI; Koch et al., 1963) is defined as the difference between an animal's actual feed intake and its expected feed requirements for maintenance and growth. Residual feed intake is calculated as the difference between actual feed intake and predicted feed intake with negative or smaller values being more desirable than positive or larger values (Crews, 2005). RFI is an alternative measure of feed efficiency and is phenotypically independent of growth rate and body size (Arthur et al., 2008; Crews, 2005).

Multiple studies have reported that feed intake is a heritable trait in beef cattle (Koch et al., 1963; Fan et al., 1995; Nkrumah et al., 2007; Elzo et al., 2009; Mao et al., 2013; Retallick et al., 2017), with all studies estimating the heritability of feed intake in growing cattle between 0.20 to 0.48. Crowley et al. (2010), reported that RFI is moderately heritable at 0.45, therefore, selecting replacements with low RFI should produce energy-efficient cows and progeny. However, information regarding the repeatability of RFI at different ages, stages of production, in different environments, and on different diets is limited (Manafiazar et al. 2015; Black et al., 2013; and Freetly et al., 2020). Biological mechanisms involved in beef cattle performance, as well as, response to RFI classification may interact with cow age, stage of production, and availability of feed resources (Sprinkle et al., 2020). Numerous factors may influence regulation of satiety in growing cattle, including composition of ration or diet. Freetly et al., (2020) stated that the signals for satiety in high concentrate rations may be associated with chemical signals while those in forage-based diets are probably associated with gut fill. Previous research that has evaluated the impact of selection pressure for low RFI progeny is often inconsistent in respect to body condition, heifer maturity, and reproductive response. Randel and Welch (2013) found that low RFI females were leaner, reached puberty at an older age, and calved later as heifers and subsequent calf crops. In contrast, Basarab and coworkers (2007) summarized 10 years of performance records of dams that produced low, average, and high RFI progeny and concluded that dams who produced low RFI progeny had greater backfat (mm) and were in better condition prior to breeding than dams that produced high RFI progeny.

Most RFI studies are based on energy-dense diets focusing on feedlot performance (Lawrence et al., 2014) with limited information pertaining to RFI of cattle offered forage-based diets (Arthur et al., 2005; Black et al., 2013; Freetly et al., 2020) and even less information related to beef cows (Basarab et al., 2007; Meyer et al., 2008; Sprinkle et al., 2020). More research is needed related to the lifetime performance of low and high RFI cattle in forage-based rangeland environments aimed at increasing feed efficiency of western beef cattle operations (Manafiazar et al., 2015; Sprinkle et al., 2020). Black et al., (2013) stated the relationship between post-weaning RFI and subsequent reproductive performance and longevity needs to be fully characterized to understand the impact RFI may have in a breeding scenario. Prior to our studies, little information was available that evaluated the impacts of heifer post-weaning RFI on subsequent reproduction and production performance, protein supplementation intake and grazing behavior and dry matter intake at differing ages and physiological stages of production, as well as milk production at peak lactation.

Our research provides a comprehensive analysis evaluating the influence of heifer post-weaning RFI classification on lifetime productivity, grazing behavior and supplement intake behavior, as well as, dry matter intake at different ages and physiological stages of production. Our objectives were to 1) evaluate the relationship of heifer post-weaning RFI classification on lifetime productivity (reproduction and production) of beef cattle in semi-arid rangeland scenario, 2) evaluate the relationship of heifer post-weaning RFI classification and cow age on grazing behavior and supplement intake behavior, and 3) evaluate the relationship of heifer post-weaning RFI classification and cow age on dry matter intake at different ages and physiological stages of production, as well as, milk production at peak lactation.

Results of our first study suggest that heifer post-weaning RFI classification had little to no effect on subsequent beef cattle production and reproductive efficiency through the weaning of the 3rd calf. Subtle differences were denoted for cow Julian birth dates based on RFI classification and conception of 1st calf-heifers categorized as low RFI. However, all other production parameters were similar across RFI classifications of dams, with no difference in kg of calves weaned and longevity traits of the cows.

Therefore, our study suggests that in the absence of pressure, selection for low RFI females would not impact overall herd productivity of cattle on extensive forage-based production systems. However, further research is needed to investigate the relationship of heifer post-weaning RFI classification on subsequent intake of forage base diets that would likely include pasture utilization, foraging behavior, supplement intake behavior, as well as, utilization and distribution in extensive rangeland environments. Research is limited in respect to the relationship of RFI classification and cow intake, as well as, cow age/intake interactions in forage-based production systems.

Results of our second study suggest that heifer post-weaning RFI classification and had little effect on subsequent cow performance (BW or BCS change), grazing behavior, supplement intake behavior, and resource use. However, cow age significantly influenced cow performance, grazing behavior, supplement intake behavior, and resource use. We also observed high individual variability in grazing site selection, suggesting that individual-level factors may be driving grazing resource use and grazing behavior. Therefore, our research suggests that cow age has more of an impact on resource use, supplement intake, and grazing behavior than heifer post-weaning RFI while grazing dormant-season mixed-grass prairie rangelands.

Results of our third study suggest that heifer post-weaning RFI classification did not influence mature cow dry matter intake, and this was consistent for both lactating and non-lactating beef cows. In contrast, cow age did correspond to quadratic increases of DMI and intake rates of mature cows. However, when DMI was expressed as $g \cdot kg$ body $weight^{-1}$ no differences were observed with respect to cow age in lactating and non-lactating cows. Milk production was influenced by heifer post-weaning RFI for 2/3 and 5/6-yr old cows, however, did not influence 8/9-yr old cows. Therefore, our research suggests that cow age has greater impacts on dry matter intake than RFI, however, the relationship between RFI of heifers and subsequent mature cow milk production warrants further investigation.

Our overall conclusions are that while RFI is moderately heritable, and an accurate predictor of growth on a high concentrate feedlot ration; in the absence of selection pressure, it has limited application to cow/calf efficiency while grazing mixed grass dormant rangelands or when compared to dry matter intake at different ages and physiological stages of production of beef cattle on forage base diets. Furthermore, we find that selection pressure focused on post-weaning RFI may have limited to no effect on subsequent cow herd feed needs, production and reproduction efficiencies. All three studies suggest that heifer post-weaning RFI is not a viable metric for improving beef cow efficiencies on Northern mixed grass prairie beef cattle production systems. We found that cow age had a larger impact and influence on the results of our studies than RFI. It is important to remember that at no time during the 10+ years of data collection and analysis on this commercial black Angus cow herd was RFI ever used as a selection tool. In other words, no females or semen were ever divergently selected for or against RFI classification.

Although RFI has proven to be an accurate predictor of feedlot cattle feed efficiency while on high concentrate rations, we feel that our findings, along with other recent research reports, indicate that post-weaning RFI may have limited accuracy at predicting feed efficiency, grazing behavior, supplement intake behavior or milk production of mature beef cows on forage-based management systems. We observed limited accuracy of heifer post-weaning RFI relative to predicting mature cow production, reproduction and/or feed efficiency in black Angus beef cows in north central Montana. We feel it is important for future research to evaluate the impacts of RFI in different geographical locations, with different forages (cool season vs. warm season) under different management scenarios and with different breeds of beef cattle. We encourage future research focused on beef cattle efficiency on foraged based rangelands. Western beef producers will continue to seek out potential metrics that might help in the selection of beef cattle for limited nutrition rangeland beef production systems. Future research may relate to post weaning heifer feed efficiency (kg gain per kg intake) or dry matter intake expressed as kilograms of feed per day but also expressed as kg of feed consumed per kg of body weight of the animal and how this relates to performance and production and reproduction parameters.

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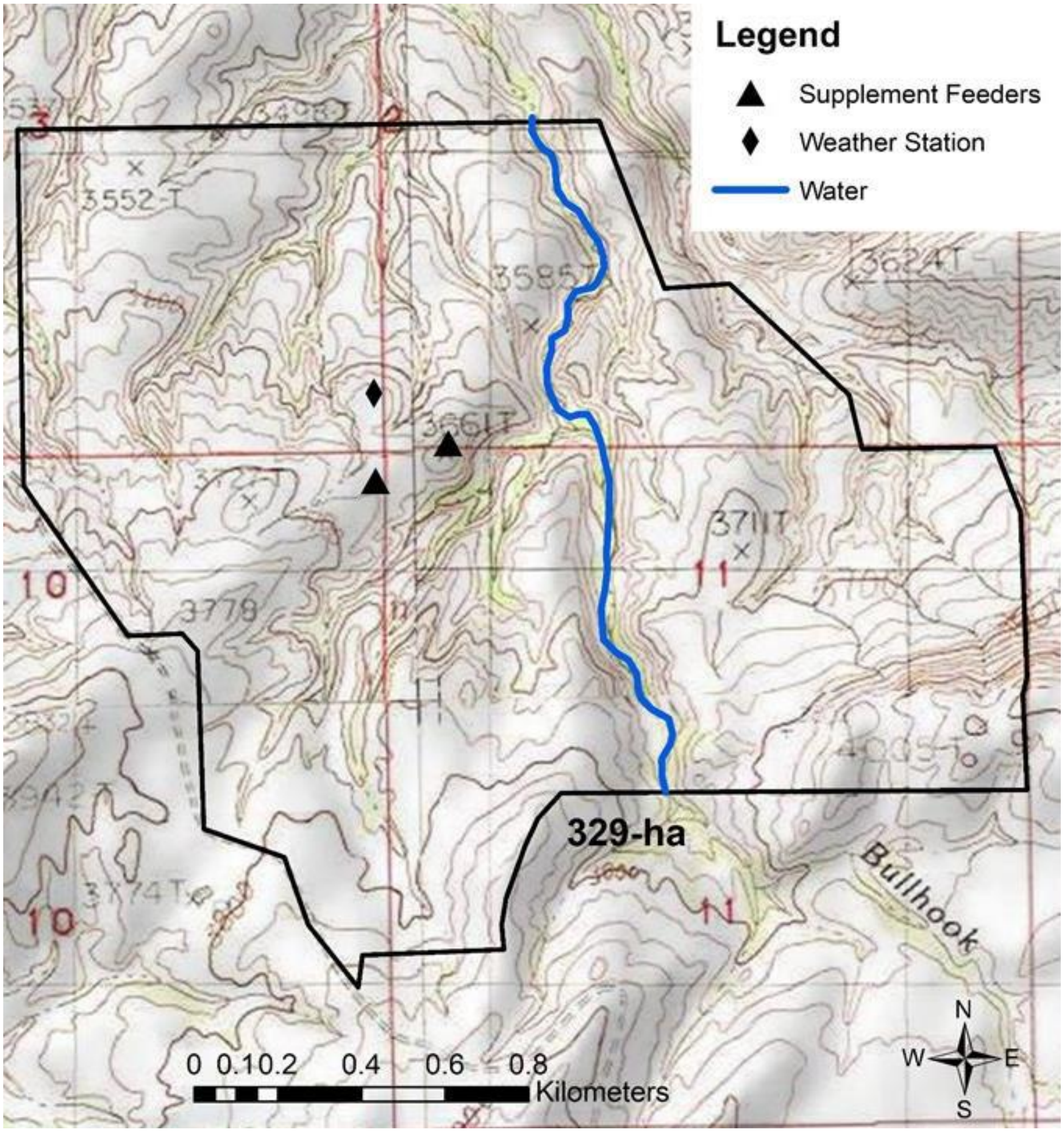
APPENDICES

APPENDIX A

PASTURE TOPOGRAPHY AND WATER, AND SUPPLEMENT LOCATIONS FOR STUDY AREA



Topography and water location for rangeland pastures winter grazed by cattle in 2018 – 2019 & 2019 – 2020 at the Montana State University, Northern Agricultural Research Center, Havre, MT (Wyffels et al., PhD Dissertation, Montana State University. 2019)