GRAZING, FEED INTAKE, AND MILK PRODUCTION DIFFERENCES IN BEEF COWS OF VARYING EFFICIENCY CLASSIFICATION AND SIZE

by

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ABSTRACT

Metrics that identify beef cow efficiency in extensive rangeland environments has long been desired in both beef cattle research and production settings. However, research is limited relative to matching cattle metrics to western production systems. Previous research has suggested the ratio of calf weight weaned to cow weight, or weaning weight ratio, is an accurate estimate of cow efficiency. Furthermore, milk production has been attributed to influence calf pre-weaning average daily gain. Few studies have evaluated how cow type or cow characteristics influence grazing distribution and supplement consumption on native landscapes. The objectives of this study were to assess cow feed intake, grazing behavior, supplement intake, and milk production differences between cows of differing weaning weight ratio and body weight classification. Individual cow average daily feed consumption, average daily feeding bout duration, number of visits per day, and total time spent eating per day were collected during a feed intake period and a supplement intake period. Total distance traveled and time spent grazing were collected on individual cows with global positioning system collars. Milk samples were analyzed for fat, solids not fat, total solids, protein, and lactose content, and milk yield was calculated as the change in calf weight following a weigh-suckle-weigh procedure. High weaning weight ratio cows consumed more feed when expressed on a g/kg bodyweight basis ($P < 0.001$) but did not differ in supplement consumption ($P > 0.10$). High weaning weight ratio cows produced more milk both in total kg ($P < 0.03$) and when expressed as /kg bodyweight ($P < 0.001$). Heavy bodyweight cows tended to consume more feed than light bodyweight cows ($P < 0.09$) but neither bodyweight group ate more supplement than the other ($P > 0.10$). High weaning weight ratio cows spent an hour longer grazing per day than low weaning weight ratio cows ($P < 0.02$). Total distanced traveled per day did not differ ($P > 0.10$). Results suggest weaning weight ratio and cow size are not accurate metrics of cow efficiency and the use of weaning weight ratio may unintentionally favor cows with higher milk production and higher feed requirements.

CHAPTER ONE

GENERAL INTRODUCTION

An ongoing discussion in the beef cattle industry explores if small or large cows, based on body-weight and body condition score, are more suited for arid, western rangeland based production systems (Hammond et al., 1947; Dickerson, 1978; Stewart and Martin, 1983; Scasta et al., 2015). The foundation to this discussion is what cow type converts forage consumed to more kilograms calf weaned, often referred to as cow efficiency, and optimizes use of diverse, extensive rangeland environments (Dickerson, 1978; Stevens, 2000; Scasta et al., 2015; Beck et al., 2016). Techniques that identify which beef cows in a production setting will produce more calf weight weaned per kilogram of feed consumed with equal reproductive performance has long been sought after in both beef cattle production settings and research (Dinkel and Brown, 1978; Scasta et al., 2015; Beck et al., 2016). The ideal cow for extensive western rangeland beef cattle production systems converts forage consumed to more kilograms calf weaned while optimizing the use of diverse, extensive rangeland environments (Dickerson, 1978; Stevens, 2000; Scasta et al., 2015; Beck et al., 2016).

This interest in developing animals that are suited to western rangeland production environments is based on the need to optimize profits in environments with limited or decreasing resources. There is an increasing pressure for cattle producers to produce more high quality protein on a continuously decreasing land base, because of the continuously expanding human population (FAO, 2009; USDA National Agricultural Statistic Service, 2014; Beck et al., 2017). However, research is limited relative to cattle selection metrics that can be used to identify cattle that fit extensive grazing production systems based on arid, western rangeland ecosystems. Previous research and applied practice has suggested the ratio of calf weight weaned to cow weight, termed weaning weight ratio, is an accurate estimate of cow efficiency (Dinkel and Brown, 1978; Kirkpatrick et al., 1985; Kress et al., 2001; Scasta et al., 2015). In addition, cow body size has been attributed to influence calf weight weaned, feed intake, and as a result, cow efficiency (Dinkel and Brown, 1978; Scasta et al., 2015; Beck et al., 2016). Thus, it is important to understand if small or large cows are more efficient at converting feed into kilograms of calf weaned on western rangelands (Scasta et al., 2015; Beck et al., 2016; Scholljegerdes and Summers, 2016).

However, previous research that examined the effectiveness of cow-calf weaning weight ratio as a metric of cow efficiency either considered direct cow to calf weaning weight ratio or considered cow-calf weaning weight ratio with the addition of some estimate of cow intake. Davis et al. (1983) utilized the assumption that cows consume 2-2.5% body weight daily when examining the use of weaning weight ratio. Whereas Kirkpatrick et al. (1985) used individual feed bunks with limited feeding times when they studied the effectiveness of weaning weight ratio. Kress et al. (2001) used fecal markers to estimate cow intake when evaluating the use of weaning weight ratio. With modern technology (e.g. automated feed bunks and EID tags) there is the ability to acquire accurate individual feed intake data that also includes feed intake behavior attributes (e.g. time spent feeding, number of feeding visits per day, and intake per visit) not previously reported in the literature (Mendes et al., 2011). This technology can produce precise data that can be used to confirm if cow-calf weaning weight ratio is an accurate and effective determinant of cow efficiency (Kirkpatrick et al., 1985). Milk yield and milk constituents have also been attributed to influence calf pre-weaning ADG but have not been revisited in recent years (Mondragon et al., 1983; Beal et al., 1990). Furthermore, as defined by weaning weight ratio, the effects milk production has on pre-weaning calf growth and the influence of cow feed intake on cow efficiency has not been jointly considered.

Additionally, few studies have examined the relationship between cow size, cow efficiency, and grazing behavior. Since extensive grazing systems are embedded in western rangeland beef cattle systems, improving distribution across diverse landscapes is vitally important for the success of these production systems. There has been considerable research on biotic and abiotic features that alter grazing distribution in beef cattle in rangeland environments (Ganskopp, 2001; Bailey, 2005; Stephenson et al., 2016). However, very little research has evaluated how cow type or cow characteristics influence grazing distribution on native landscapes (Bailey et al., 2006; VanWagoner et al., 2006; Walburger et al., 2009). What research has been conducted on this subject has focused on grazing distribution differences between cows of differing breeds, age, and terrain use classification (Bailey et al., 2001; Bailey et al., 2004; Walburger et al., 2009). The influence of cow-calf weaning weight ratio and cow weight on winter grazing behavior and individual supplement intake has not been previously examined. Therefore, there is a need for research to examine the influence of cow size on feed intake, grazing behavior, and milk production, and the use of cow-calf weaning weight ratio as an accurate metric of cow efficiency. With the objective of identifying methods that could be applied to beef cattle production environments and practiced on ranch by beef cattle producers.

CHAPTER TWO

LITERATURE REVIEW

Cow Efficiency Metrics

The term cow efficiency has been used to describe many forms of cow productivity in the beef cattle production system including some forms of feed efficiency, production efficiency, and reproductive efficiency (Koch et al., 1963; Dinkel and Brown, 1978; Archer et al., 2002; Scholljegerdes and Summers, 2016). This term has also been used to describe the ability of a cow to convert feed energy to kilograms of calf produced (ratio of calf weight to cow weight or weaning efficiency; Dinkel and Brown, 1978; Kirkpatrick et al., 1985; Archer et al., 2002; Beck et al., 2016; Scholljegerdes and Summers, 2016). One way cow efficiency ratio has been measured is by comparing kilograms of calf weaned to an individual cow's average body weight through her lifetime.

In one study, Dinkel and Brown (1978) analyzed 122 Angus, Charolais, and Angus x Charolais cows to determine if cow-calf weaning weight ratio was an accurate metric of cow efficiency. Cow efficiency was calculated as the ratio between the total digestible nutrients consumed by the cow from the weaning of her previous calf to weaning of the calf during the year of research and the total digestible nutrients consumed by that year's calf to the weaning weight of that calf. Results from this study suggested that calf weaning-weight alone was the best single predictor of cow efficiency (coefficient = -0.90, R^2 = 0.81). But when weaning weight and cow weight were considered as a ratio, a 3% increase was observed in the R^2 (coefficient = -0.91, R^2 = 0.84). Although Dinkel and Brown (1978) report no advantaged to including cow weight as a ratio to predict efficiency, they concluded that when cow weight and calf weaning-weight was combined as a ratio, an increase was seen in the coefficient for efficiency (coefficient = -0.90, R^2 = 0.81 vs. coefficient = -0.91, R^2 = 0.84). This increase in the reported R^2 value suggests that including cow weight and weaning weight ratio, as a metric of cow efficiency, will increase the accuracy of cow performance estimates.

Davis et al. (1983) examined the relationship between cow traits and progeny traits to determine what influences lifetime efficiency in 160 beef and dairy cross cows. The authors defined efficiency as the ratio between calf and cow lifetime feed intake to calf weight weaned and cow salvage value. Cow weight at weaning of first, second, and third calves was negatively correlated ($P < 0.01$) to cow lifetime efficiency, −0.51, −0.59, and −0.56 respectively. This study suggests the smaller cows were more efficient across their lifetime within this study. However, cow lifetime efficiency cannot be predicted at weaning as a heifer because heifer 240-d weight was not a significant indicator of subsequent lifetime efficiency. The cow trait the authors attributed to influence cow lifetime efficiency the most was amount of feed consumed by the cow between 240-d of age and weaning of her third calf, which had a negative correlation ($P < 0.01$) to efficiency (R^2 = 0.58). Weaning weights of the first (R^2 = 0.06, $P < 0.01$), second (R^2 = 0.04, $P < 0.05$), and third (R^2 = 0.05, $P < 0.05$) calves had a relatively small positive effect on cow efficiency (R^2 = 0.10, $P < 0.01$ when summed). Cow weight at the weaning of her first, second, and third calves and feed consumed from 240 days of age to the weaning of her third calf had the most impact on cow efficiency (R^2 = 0.25, $P < 0.01$ and R^2 = 0.58, $P < 0.01$). The authors concluded that smaller dams were more efficient in their study (Davis et al., 1983). Results from this research indicate that cow feed intake between the age of 240-d to four years of age is a possible metric to estimate continued efficiency. However, long-term data collection is needed to determine feed intake between 240-d to four years of age and thus this technique may not be of practical use.

In a similar study, Kirkpatrick et al. (1985) compared data from five different studies to evaluate the ability of prediction equations to estimate cow efficiency. Cow efficiency was defined as the ratio of calf weaning weight output to cow feed input and calf feed input over three calves. Models containing progeny weight (R^2 = 0.19), cow size (R^2 = 0.27), and cow body condition score (R^2 = 0.30) were the best determinants of weaning efficiency examined. As reported in the results from Davis et al. (1983), progeny weights were positively correlated with efficiency whereas cow size and body condition score were negatively correlated with efficiency (Kirkpatrick et al., 1985). Models that included two-variables explained a larger portion of the variation in explaining efficiency than one variable models. When progeny weight (R^2 = 0.19) and cow size (R^2 = 0.27) were combined, the R^2 value increased to 0.59.

Additionally, Kress et al. (2001) conducted a study using 147 Hereford, Tarentaise, and reciprocal cross cow-calf pairs that evaluated the use of weaning weight ratio as a predictor of cow efficiency. Efficiency was calculated as calf weight divided by the sum of cow forage intake over the trial period and the sum of forage intake on a per unit of cow weight basis. Cow-calf weaning weight ratio was calculated as calf weight divided by cow weight (kg/kg). Least-squares mean results for the Hereford, Tarentaise, and reciprocal cross cows when weaning weight ratio was not included in the model were 6.63, 7.74, and 7.50, respectively, for calf weight divided by cow feed intake on a kg/kg basis. When the ratio between calf weight and cow weight was included in the model the least-squares means were 7.03, 7.38, and 7.25 for Hereford, Tarentaise, and reciprocal cross cows, respectively, for calf weight divided by cow feed intake on a kg/kg basis. When efficiency was defined as calf weight divided by cow feed intake on a per kilogram cow weight basis and cow-calf weight ratio was not included in the model, the least squares means for Hereford, Tarentaise, and reciprocal cross cows were 3.45, 3.95, and 4.0, respectively. However, when cow-calf weight ratio was included in this model the least squares means were 3.68, 3.78, and 3.87 for Hereford, Tarentaise, and reciprocal cross cows. This research indicates that dam breed affected cow efficiency when the ratio of calf weight to cow weight was not included in the model ($P < 0.01$). However, when the ratio between calf and cow weight was included in the models, dam breed was no long significant. Suggesting the ratio between cow weight and calf weight is an accurate indicator of cow efficiency when efficiency is defined as the ratio between cow feed intake, body weight, and calf weight output.

As indicated by these studies, previous research has advocated that weaning weight ratio is a useful and accurate technique for estimating cow efficiency (Dinkel and Brown, 1978; Davis et al., 1983; Kirkpatrick et al., 1985; Kress et al., 2001; Scasta et al., 2015). Dinkel and Brown (1978), Kirkpatrick et al. (1985), and Kress et al. (2001) concluded that weaning weight ratio was the best predictor of cow efficiency out of the efficiency metrics examined in these studies. However, it has been suggested that cow and calf weights need to be adjusted for cow and calf age, calf gender, and cow body condition score for weaning weight ratio to not be unjustly biased towards small and/or young cows (Dinkel and Brown, 1978; Scholljegerdes and Summers, 2016). In conclusion, weaning weight ratio that is formulated from adjusted weight values is a possible accurate predictor of cow efficiency on western rangelands. However, there is very little recent research that examines the use of cow-calf weaning weight ratio as an accurate metric of cow efficiency.

Cow Size

Cow body size has been attributed to influence calf weight weaned and feed intake, and as a result, cow efficiency (Dinkel and Brown, 1978; Scasta et al., 2015; Beck et al., 2016). Thus, it is important to understand if small cows or large cows are more efficient at converting feed into pounds of calf weaned on western rangelands (Scasta et al., 2015; Beck et al., 2016; Scholljegerdes and Summers, 2016). Since 1975, 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 (Beck et al., 2016; National Academies of Sciences, 2016). According to the National Academies of Sciences (2016), a 30% larger cow will also need 22- 28% additional intake in dry matter per day (Beck et al., 2016). Scasta et al. (2015) suggested that with the increase in selection for performance traits there has been an accompanied increase in cow size. Previous research has indicated that large cows may not be as well suited to western, arid rangeland based production settings as smaller cows (Kress et al., 1969; Scasta et al., 2015; Beck et al., 2016).

Evaluating cow size and efficiency of production in a semi-arid environment for 4 years, Scasta et al. (2015) measured 80 Angus x Gelbvieh cows for weaning weights, efficiency, defined by calf weight relative to cow weight, intake requirements, and stocking rates. Their results concluded that efficiency was always greater for smaller cows and that during drought years small cows still produced similar sized calves as to normal precipitation years but that calves from large cows were smaller in drought years ($P < 0.001$). The authors suggested that smaller cows have lower maintenance requirements and thus fit environments with lower resource availability. Furthermore, they concluded that smaller cows proved to have advantages during years with above average precipitation as well. Their concluding statement was that large cows (589 to 634 kg) do not meet their genetic potential in semi-arid environments and offer no advantage over small cows when conditions are favorable. However, cow feed requirements were not actual cow intake but were estimated using animal unit equivalents (AUE). Therefore, results from this research may not be meaningful when examining actual differences between large and small cows.

Also in support of small cows being better suited to western rangeland production systems, Kress et al. (1969) conducted a 4 year study examining the influence of cow body size on cow efficiency using records from 12 identical and 17 fraternal twins. During this study, the authors examined cow efficiency using four different calculations, all of which included cow weight, calf weight, cow feed intake, cow milk production, and calf feed intake. Cow feed intake was determined by tying the cows to individual feed bunks twice a day, daily, and allowing the cows to eat weighted feed *ad-libitum* from 240 day of age to 18 months. Progeny of the original cows were also fed following this technique once the calves had reached 60 days of age. When the entire productive life of these cows were observed, Kress et al. (1969) concluded that lighter cows had a higher likelihood to be more efficient.

Moreover, Beck et al. (2016) evaluated 100 Angus x Hereford x Simmental cows for effects of cows size and stocking rate, calf gain, cow body weight change, feeding requirements, and net returns. Cow feed intake was calculated by the difference in pasture forage production between the start of the study period and the end of the study period. As cow body weight increased, calf body weight at weaning increased but weaning efficiency (kg calf weaned per 100 kg cow body weight) decreased 6.7 kg for each 100-kg increase in cow body weight ($P < 0.01$). Cow body weight had no effect ($P > 0.22$) on hay feeding days and cost. There was also no difference ($P \geq 0.38$) between cow body weight and net returns. However, as stocking rate increased there was a decrease in total expenses by $102/cow and increase in net returns by $70/cow ($P < 0.01$). Stocking rate is an underlying variable for management and can have intrinsic impacts economically and influence strategic management decisions. Simplistically, the current industry belief is that increasing cow size will decrease the carrying capacity of pastures while inversely increasing input costs because of the assumption that large cows eat more than small cows. Overall, results from this research indicated that smaller cows had higher weaning efficiency and cow weight had no effect on net returns.

Likewise, Stewart and Martin (1983) studied lifetime performance records for 113 Angus cows that were born over a 12 year period to estimate the relationship between cow size, maturation weight, years in the herd, number of calves produced, total calf weight, average calf weight at weaning, and calf weight per cow year in herd. The mean cow size for the herd was 487 ± 5 kg but the authors concluded that optimal cow size for each characteristic considered was 468 kg for years cows remained in the herd, 465 kg for number of calves over the lifetime of the cow, a 471 kg cow produced the most total calf weight, a 493 kg cow produced the most calf weight at weaning, and a 475 kg cow weaned the most calf weight per each individual year. Results from this study indicated that small cows remained in the herd longer, producing more calves over their lifetime, and thus more total calf weight. This research suggests that different cow size may be preferred for achieving different producer goals. If cow-calf producers sell calves at weaning, smaller cows (465-470 kg) may be preferred because of their additional time in the herd, additional number of calves produced, or additional total calf weight produced throughout their life. If producers retain ownership through feeding and harvest, larger cows (475-493 kg) may be preferred because of the additional weight of the calves at harvest. However, the sized cows examined in this research are not representative of modern sized cows with all of the cows included in this dataset being light enough to be considered as small cows for today's standards.

Dinkel and Brown (1978) reported similar trends in the relation to cow body weight and weaning efficiency, when considering cows 2-4 years of age and their calves, with the most efficient cow (8.99 kg TDN to 1 kg calf weaning weight) in their data set weighing 429 kg and the least efficient cow (15.8 kg TDN to 1 kg calf weaning weight) weighing 462 kg. Cow efficiency was calculated as the ratio between total cow and calf total daily nutrition requirements to total calf weight weaned. Cow feed intake was determined by individually feeding cows weighted amounts of feed throughout the two years of the experiment. Cows with efficiencies less than 10 kg of TDN per 1 kg of calf weight weaned averaged 445.4 kg and cows with efficiencies greater than 13 kg of TDN per 1 kg of calf weight weaned averaged 461.3 kg. However, there were cows in this dataset that did not follow the trend mentioned above. One cow weighed 437 kg but had an efficiency of 15.4 kg of TDN per 1 kg calf weight weaned. The smallest cow in the experiment weighed 360.2 kg but had an efficiency of 11.3 kg of TDN per 1 kg of calf weight weaned and the largest cow weighed 577.9 kg had an efficiency of 12.6 kg of TDN per 1 kg of calf weight weaned. Although the authors did not include statistical values, results from this study indicate that ratio of feed to pounds of calf produced may not solely be related to cow size. The authors concluded by stating that excessive attention to cow size alone could result in decreased cow efficiency (Dinkel and Brown, 1978).

Long et al. (1975) used a computer model with data taken from the McGregor Research Center at Texas A&M University to estimate the economic efficiency of cows of differing size in beef cattle breeding systems. Data were taken from straight-bred Angus, Charolais, Hereford, and Jersey cows and these cows were then classed into three body weight groups, small, medium, and large, with the mean weights of 430, 500, and 600 kg, respectively. Cow age through development, mature cow weight, progeny growth, milk production, cow fertility, calf survival, cow longevity, interest incurred on any capital, annual death loss, calving interval, and estimated nutritional requirements were all included in the model used for this research. Results from the model indicated that beef cattle breeding systems that utilize small cows (mean of 430 kg) produced more live weight and gross income, but that they were more expensive to operate than systems using larger cattle (mean 500-600 kg). However, when the breeding system was considered in a pasture environment, smaller cows were more profitable than larger cows.

Previous research tends to agree that small cows achieve more returns, cost less, and are more efficient than large cows in pasture and rangeland settings (Kress et al., 1969; Dinkel and Brown, 1978; Stewart and Martin, 1983; Scasta et al., 2015; Beck et al., 2016). Whereas larger cows succeed in non-pasture settings, resulting in higher returns than small cows under dry-lot conditions or in other production ecosystems (Long et al., 1975; Dinkel and Brown, 1978). The current understanding is that smaller cows require less feed per day and consume less feed overall and thus producers can increase animal number by decreasing cow size and thus have higher monetary gains. However, previous research examining cow efficiency on rangeland has used estimated cow intake or models that predict cow efficiency rather than examining actual cow intake or efficiency in these systems. The interaction of cow size and cow efficiency in rangeland environments in still not well understood.

Feed Efficiency and Intake

Animal feed efficiency is one of the top determinants of animal productivity and profitability (Koch et al., 1963; Arthur et al., 2001; Nkrumah et al., 2006; Berry and Crowley, 2013). Feed efficiency is currently defined as the ability of an animal to convert feed to meat and is measured as a ratio between the two (Berry and Crowley, 2013; Scholljegerdes and Summers, 2016). Although animal feed efficiency is not synonymous with production efficiency, it plays a large role in the ability to increase livestock production on a decreasing land base (Berry and Crowley, 2013). Previous research conducted on beef cattle feed efficiency has 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).

Current research pertaining to beef cattle feed efficiency has been focusing on residual feed intake (RFI) and using RFI as a predictor of lifetime cow efficiency (Lawrence et al., 2012; Waghorn et al., 2012; Bolormaa et al., 2013; Hafla et al., 2013; Manafiazar et al., 2015). Residual feed intake is a measurement of feed efficiency that is independent of variables such as animal size or rate of growth (Herd and Arthur, 2009; McDonald et al., 2010; Lawrence et al., 2011). Because of this independence, researchers attribute RFI as a valuable way to study the physiological mechanisms that underlie feed efficiency (Meyer et al., 2008; Herd and Arthur, 2009). Furthermore, it has been reported that RFI is moderately heritable and therefore could constitute a better selection index than current ratio-traits linked to feed-to-gain ratios (F:G; Arthur et al., 2001; Meyer et al., 2008; Herd and Arthur, 2009). However, research that has been conducted examining the use of RFI in production settings outside of feedlot situations has indicated that RFI may not be useful for cow-calf production settings (Meyer et al., 2008; Lawrence et al., 2012; Manafiazar et al., 2015). Additionally, although many studies have evaluated RFI in growing animals, there have been few to evaluate the potential to use RFI in productive females (Hafla et al., 2013).

Waghorn et al. (2012) analyzed 1,052 Holstein-Friesian heifers fed an alfalfa cube diet to determine if RFI had practical application to the forage based, dairy industry of New Zealand. Results from this study indicate that DMI was highly related to body weight (R^2

= 0.75), and only moderately related to feed conversion efficiency and feed to gain ratio (R^2 = 0.34). Average daily gains did not differ (P = 0.57) when the top 10% and bottom 10% of RFI classified heifers were compared. However, DMI and RFI values were different between the two groups (P < 0.001), with DMI differing by 21.6% between the high and low RFI heifers. Although this research is similar to published data on U.S.A. feedlot beef animals, the authors concluded that it is still not understood if RFI would accurately predict cow intake when grazing in a pasture setting.

Basarab et al. (2007) evaluated 222 yearling calves and their dams (n = 136) for 10 production cycles, measuring progeny RFI and overall maternal lifetime production efficiency. Their results indicated dams that produced low RFI progeny had 2-3 mm more back fat thickness (P < 0.05), consumed less feed during the second trimester (P < 0.05), and calved later than medium and high RFI classes (P < 0.001). Additionally, they reported that efficient progeny and dams consumed less feed, had improved feed-to-gain ratio, and frequented feed less than inefficient animals (Basarab et al., 2007). Furthermore, Hafla et al. (2013) determined if RFI classifications of beef heifers would influence forage utilization, body composition, feeding behavior, and physical activity. Heifers classified as low RFI consumed 17% less forage (P < 0.01) but had similar body weight, body weight gain, body condition score, and ultrasound measurements. Interestingly, RFI classification did not alter calving dates unlike what Basarab et al. (2007) reported, but Hafla et al. (2013) reported that calves born to low RFI heifers were lighter at birth than calves born to high RFI heifers (P < 0.01). Additionally, low RFI heifers spent 26% less time (P < 0.01) at the GrowSafe bunks than high RFI heifers, although bunk visit frequency did not differ. Their results indicated that heifers identified as having low RFI values had greater efficiency for forage utilization when pregnant with minimal impacts on growth, body composition, and calf performance (Hafla et al., 2013).

Following this trend, Walker et al. (2015) evaluated 38 crossbred Angus cows for contrasts in dry-matter intake (DMI), RFI, and endocrine markers, on the basis of cow size and RFI classification over a 70-day feeding period. During lactation, the heavy cows (573 ± 39 kg), defined by body weight and frame score, had a 4.8% higher DMI compared to the light cows (488 ± 30 kg; $P = 0.03$). Additionally, during lactation the high and medium RFI classed cows had higher DMI than the low RFI cows ($P < 0.01$). During non-lactation, the heavy cows had 8.9% greater DMI than the light cows ($P < 0.01$), with the heavy cows consuming 0.7 g/kg cow weight more than the light cows. Data from this study suggested the heavy body weight classified cows and cows classed as high RFI animals were not as efficient as light body weight classified cows and low RFI classed cows.

While evaluating beef females for differences in production efficiency between RFI classifications is insightful, it does not necessarily apply to grazing systems. This, in part, is due to the fact that individual animal intake is required to establish the data for RFI and is often impractical for cow/calf producers (Kress et al., 2001). In one study, Meyer et al. (2008) applied 42 Hereford beef cows with known RFI classification to grazing enclosures. Numerically, there was a 21% difference between low and high RFI classifications for DMI, however it was not statistically significant (12.4 kg/d vs. 15.6 kg/d; $P = 0.23$). Performance, mainly body weight and body condition score did not differ between the classifications during the grazing period of 84-days ($P > 0.05$). Meyer et al. (2008)

concluded there was no intake and performance difference between RFI classifications during the grazing period. Therefore, using RFI as a measure of efficiency in forage based grazing environments may not be a valuable or reliable measure.

Similarly, Lawrence et al. (2012) evaluated grass silage intake from 85 Simmental and Simmental x Holstein heifers with predetermined RFI classifications. Heifers from different RFI groups did not differ in live weight, ADG, or feed conversion ratio ($P > 0.05$) at any point over the study. However, RFI was positively correlated with DMI during the RFI measuring period, although only moderately ($R^2 = 0.35$; $P < 0.001$), but not correlated with DMI during the grazing portion of the study ($R^2 = 0.004$; $P = 0.57$). Back fat thickness, visual muscle score, and frame size did not differ between low and high RFI heifers. The authors concluded that despite the large difference of DMI between the high and low RFI heifers during the feeding trial, there was no detectible difference between the groups when the heifers were on grass (Lawrence et al., 2012).

Manafiazar et al. (2015) examined 48 crossbred *bos taurus* heifers with known RFI classification for feed intake performance on summer pasture. During the grazing period, high and low RFI heifers did not differ in body weight, back-fat thickness, or ADG. In contrast from the results reported by Meyer et al. (2008) and Lawrence et al. (2012), low RFI heifers consumed 5.3% less forage on a kg DM d^{-1} basis than high RFI heifers when grazing (8.2 ± 0.08 vs. 8.66 ± 0.09; $P < 0.001$). However, even though RFI determined in dry-lot conditions for post-weaning heifers was attributed as being positively correlated ($R^2 = 0.09$; $P = 0.04$) to RFI for pregnant heifers in a pasture setting, this relationship was weak (Manafiazar et al., 2015). Results indicate that RFI values determined in a dry-lot setting are only slightly correlated to feed intake while in a pasture setting. Suggesting that RFI may not be valuable in determining future cow intake in grazing environments.

Residual feed intake has been suggested to follow the same trend for cows when previously classified for RFI as heifers (Arthur et al., 1999; Archer et al., 2002; Herd et al., 2006; McDonald et al., 2010). However, the studies that report this consistency determine RFI classification using the same feed stuff as cows as when RFI was determined in heifers. Suggesting that RFI will work on feedstuffs other than concentrated feeds so long as the same feed type that was fed to animals as yearlings are again fed to cows in subsequent studies. 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. Therefore, an alternative method needs to be found and used for predicting beef cow feed efficiency in pasture and rangeland environments.

Milk Production

Milk production in beef cows has long been attributed to have a major influence on the weight gain of calves, which is an important contributor to beef cattle efficiency (Totusek et al., 1973; Mondragon et al., 1983; Beal et al., 1990). Understanding how milk yield and constituents contributes to calf gain is an important factor in understanding cow efficiency. There are several methods used to obtain milk yield in beef cows. The calf weight gain method, also known as the weigh-suckle-weigh method, has been recognized as being the most feasible for cow-calf production settings while still giving accurate yield estimates (Melton et al., 1967; Totusek et al., 1973; Mondragon et al., 1983; Beal et al., 1990). However, when a milking machine is available and use is practical, results from a milking machine are most repeatable (Gleddie and Berg, 1968; Beal et al., 1990).

Williams et al. (1979a) tested three separation intervals that had been used previously in the literature to compare which of the three would result in the best estimate of milk production in beef cows. These separation intervals were 4, 8, and 16 hours where the calves would be sorted from their dams, held separately for either 4, 8, or 16 hours, then weighed, allowed to suckle, then weighed again and the weight difference was used as the estimate of milk production. Results from this study indicated the 8-hour separation time lead to the most accurate estimate of milk yield production, was moderately repeatable (R^2 = 0.61), and had the highest correlation with calf ADG (R^2 = 0.21) during early lactation. Additionally, Williams et al. (1979b) analyzed cow physical measurements to determine the correlation between physical attributes such as body height, weight, weight to height ratio, and body condition score of the cow, with milk production. Although these measurements were highly repeatable (R^2 = 0.94, 0.95, 0.89, 0.85, 0.85, and 0.80, respectively), none were significantly correlated to milk production estimates.

Furthermore, Totusek et al. (1973) compared the weigh-suckle-weigh method of milk production estimation with the hand milking technique. The weigh-suckle-weigh method resulted in higher and less variable yield estimates than the hand milking technique over the entire 210-day estimation period. Correlation between the 210-day weigh-suckle-weigh milk yield estimate and the hand-milking estimate was 0.95. Calf weight and calf ADG were both highly correlated with the 210-day weigh-suckle-weigh milk yield, 0.88 and 0.88 respectively. The authors concluded the weigh-suckle-weigh method resulted in more accurate estimates for determining milk production in beef cows than hand milking. In addition, weigh-suckle-weigh samples collected on four or five consecutive days and then averaged together resulted in the highest correlated estimates with the 210-day milk yield (R^2 = 0.83 and R^2 = 0.87), whereas single day estimates were considerably less correlated (R^2 = 0.23 on day 70; R^2 = 0.67 on day 120; R^2 = 0.61 on day 190) with the 210-day milk yield.

Beal et al. (1990) compared the weigh-suckle-weigh method with machine milking for repeatability (0.35 vs. 0.97 respectively; $P < 0.01$) and correlation estimate with calf ADG (0.76 vs. 0.75 respectively; $P < 0.05$). The weigh-suckle-weigh method caused re-ranking of cows based on repeated measures of milk production and this technique resulted in lower correlations between single milk production estimates and calf gain than machine milking, 0.44 vs. 0.70 at 50-d and 66-d postpartum ($P > 0.05$), 0.24 vs. 0.73 at 136-d and 123-d postpartum ($P < 0.01$), and 0.40 vs. 0.74 at 189-d and 179-d postpartum ($P < 0.05$; Beal et al., 1990). However, when four weigh-suckle-weigh cycles were averaged together the repeatability of milk production and the correlation of milk yield to calf gain were similar to the results of machine milking (0.76 vs. 0.75; $P > 0.05$). Despite this, the authors concluded that machine milking is the most repeatable and accurate method for milk production estimates out of the methods examined in this experiment.

Even though methods and results vary for beef cow milk production, yield, and constituents, the results from studies that use these measuring techniques are still relevant to understanding the relationship between milk production and efficiency in beef cows. Melton et al. (1967) compared the influence of milk production and constituents on calves of 15 Hereford, 15 Angus, and 15 Charolais cows. Milk yield and total solids were different across breeds and age of cow (*P* < 0.01) but percent butterfat and solids were not significant. With Charolais having the highest yield (784 kg) over the 175-d experimental period, Angus having the second (664 kg), and Herefords having the lowest (581 kg). Milk yield declined from the beginning of the study, day-77 of lactation, to the end for all breeds with the mean yield declining from 5.09, 4.30, 4.13, 3.87, 3.27, to 2.64 kg/day over each month of the experimental period. Older cows were also found to produce more milk than young cows (*P* < 0.01). Correlation between milk yield and calf ADG were highest (R^2 = 0.34; *P* < 0.01) for the first period of the study, two months postpartum. However, correlations between butterfat, solids-not-fat (SNF), and total solids with total calf gain were non-significant and near zero.

Similarly, Gleddie and Berg (1968) examined milk production in 42 Hereford, Angus, Charolais, Galloway, and reciprocal crosses. Gleddie and Berg (1968) also found that dam breed had a significant influence on milk yield with breed accounting for 82.5% of the variation observed in yield. However, results from their study state that Angus cows had the highest milk production out of the breeds examined. Interestingly, the correlation between milk yield and calf consumption was only moderate (R^2 = 0.34). The authors reported that milk yield declined over the lactation period (*P* < 0.01) but that butterfat and total solids continued to increase over the lactation period, although the increase was not significant. Milk constituents averaged 3.9% fat, 3.5% protein, 9.1% SNF, and 13% total solids. Similar to the results from Melton et al. (1967), Gleddie and Berg (1968) found that milk yield was moderately correlated to calf ADG from birth (R^2 = 0.53) to weaning (R^2 = 0.69) but that calf ADG was essentially uncorrelated with milk constituents.

Investigating the effectiveness of several milk components on variation of gain in pre-weaned calves, Jeffery and Berg (1971) evaluated 377 Hereford, Angus, Galloway, Charolais, and reciprocal crosses. Milk components examined were yield, total energy, total protein, total solids, and percent fat, protein, and solids-not-fat. Mean 24-hour milk yield varied from 3.8 to 6.1 kilograms throughout the study. Butterfat, protein, and solids-not-fat percentages ranged from 4.10 to 5.77, 3.28 to 3.93, and 8.67 to 9.50, respectively. Correlation between milk yield averages and calf ADG to weaning ranged from 0.73 to 0.78. Milk constituents tended to only be slightly correlated to calf ADG and were mostly non-significant. The authors of this study concluded that milk yield alone was more accurate than any other single milk variable at predicting the response of calf growth rate.

Totusek et al. (1973) came to a similar conclusion as Jeffery and Berg (1971). In their study they examined 36 lactation records from 24 Angus, Hereford, Shorthorn, Brahman, Santa Gertrudis, and reciprocal crosses. In conjunction with other authors, milk yield was observed to decrease over the lactation period. Milk yield variables were highly correlated (R^2 = 0.64) to calf gain whereas milk constituent percentages were not (R^2 = 0.07 percent fat and R^2 = 0.05 percent total solids). However, total milk fat and total milk solids were correlated to 210-day calf weight (R^2 = 0.59 and R^2 = 0.64; $P < 0.01$). Although, the correlation between milk yield adjusted for total milk fat and solids and non-adjusted milk yield was R^2 = 0.96. Therefore, the authors concluded that an estimate of milk constituents is unnecessary so long as an accurate estimate of milk yield is collected.

Additionally, Totusek et al. (1973) suggested that when only a single milk yield estimate can be taken, it should be collected between 112 to 190 days postpartum. When single milk yield estimates were collected at 30, 120, and 190 days postpartum, estimates from day 112 and 190 had higher correlations to total 210-day milk yield than estimates collected at day 30 (R^2 = 0.66, R^2 = 0.61, and R^2 = 0.23, respectively).

Differing in results from that of previous literature, Mondragon et al. (1983) conducted a study on 270 cows of differing *Bos torus*, *Bos indicus*, dairy type, and crossed cows. Results from this study indicated that Charolais and British cattle breeds had similar milk yields, which differed from the results of Melton et al. (1967) and Gleddie and Berg (1968). Additionally, no interaction was observed between breed group or age of cow in this study ($P > 0.05$), again differing from Melton et al. (1967). Also differing from the results of previous research, Mondragon et al. (1983) reported that fat percentages were highest at the beginning of lactation and decreased throughout the lactation period while protein and lactose remained constant. However, similar to previous research, results from this study indicated that milk yield had a significant positive effect on calf weaning weights and the inclusion of milk constituents did not improve the percent of variation explained in calf weaning weights.

Using an alternative method to estimate the influence that milk production has on cow efficiency during a feed efficiency study, Davis et al. (1983) examined the relationship between feed intake and milk production on calf weight and calf weaning weight. Throughout their study period, Davis et al. (1983) had groups of cows that indicated milk production was both positively and negatively correlated with cow efficiency. Milk production data from twin born Hereford cows had a positive correlation ($R^2 = 0.49$, $P < 0.01$) with lifetime cow efficiency, suggesting that increased milk production would improve calf production. However, data from twin born, composite breed cows born later had a negative correlation between milk production and cow lifetime efficiency, and depending on breed composition ranged from −0.33 to −0.99. The results from Hereford cows born over the same period as the composite breed cows indicated a correlation between milk production and efficiency near zero. The authors concluded the effect of milk production on lifetime cow efficiency indicated in this study was due to both the milk production potential of the cow and the ability of the calf to utilize the available milk (Davis et al., 1983).

Results from these studies all suggest that milk yield is an important factor in calf growth pre-weaning and thus is a possible influence on cow efficiency (Melton et al., 1967; Totusek et al., 1973; Mondragon et al., 1983; Beal et al., 1990). Totusek et al. (1973), Williams et al. (1979a), and Beal et al. (1990) all concluded that repeated, combined consecutive day measures of weigh-suckle-weigh is the most practical and accurate method for estimating milk yield. Some of these studies indicated that milk yield is influenced by breed and by age of cow, although not all studies indicated these same results (Melton et al., 1967; Gleddie and Berg, 1968; Mondragon et al., 1983). Milk constituent percent vary throughout the lactation period and milk constituents have not been indicated to be significantly correlated to calf ADG or pre-weaning growth (Melton et al., 1967; Totusek et al., 1973; Williams et al., 1979a; Mondragon et al., 1983). However, it is still important to examine cow milk constituents when considering the influence of milk attributes on calf performance and cow efficiency since previous research has not focused on this relationship. Milk yield should be considered when examining cow influence on calf production and cow efficiency because of the correlation between milk yield and calf pre-weaning gain.

Grazing Distribution and Resource Use

Since extensive grazing systems are embedded in western rangeland beef cattle systems, attaining uniform distribution across landscapes is vitally important for the success of these production systems. There has been considerable research on biotic and abiotic features that alter grazing distribution in beef cattle on rangeland environments (Williams, 1954; Roath and Krueger, 1982; Bailey and Welling, 1999; Bailey, 2004; Rawluk et al., 2014; Stephenson et al., 2016). Additionally, research has indicated that cattle prefer riparian areas to upland steppe or forests (Gillen et al., 1984; Howery et al., 1996; Parsons et al., 2003; Dalldorf et al., 2013; Rawluk et al., 2014). It is now well known that improving watering sources, increasing the number, and widely distributing water access points throughout a pasture aids in the sustainability of the range and grazing distribution observed in cattle (Williams, 1954; Roath and Krueger, 1982; Ganskopp, 2001; Porath et al., 2002; Bailey, 2004; Bailey, 2005; DelCurto et al., 2005; Rawluk et al., 2014). Considerable research has also been conducted on the use of supplement and minerals to increase grazing distribution in arid rangeland environments (Williams, 1954; Bailey and Welling, 1999; Ganskopp, 2001; Bailey, 2004; Stephenson et al., 2016). Other techniques such as fencing, herding, and time of utilization have also been studied for effectiveness of influencing grazing distribution patterns in western production settings (Williams, 1954; Roath and Krueger, 1982; DelCurto et al., 2000; Bailey, 2005; Rawluk et al., 2014).

However, very little research has evaluated how cow type or cow characteristics influence grazing distribution on native landscapes. Furthermore, few studies have examined the relationship between cow efficiency and grazing distribution. Bailey et al. (2001) evaluated differences in grazing patterns and individual cow performance on 183 and 159 Hereford, Hereford x Tarentaise, and Tarentaise cows that were either lactating or not lactating. The authors reported that non-lactating cows distributed further vertically away from water sources than lactating cows ($P < 0.05$). Additionally, non-lactating cows utilized forage on steeper slopes than lactating cows ($P < 0.05$) over the second year of the experiment. Interestingly, the lactating cows distributed further horizontally from water than non-lactating cows ($P < 0.05$) over the first year of the study. Also in the first year of study, the young cows (3 year olds) were observed grazing both vertically and horizontally further from water than older cows (≥ 5 years of age; $P < 0.05$). Interestingly, results from this study indicated a breed affect, where full Tarentaise and mostly Tarentaise (≥ ¾ Tarentaise) cross cows distributed further vertically from water over the entirety of the study and utilized steeper slops the second year than the Hereford and Hereford dominated cross cows ($P < 0.05$). No grazing distribution differences were observed between cows of differing height, weight, body condition score, calving date, or calf weight weaned in this study. This data suggests that breed selection and age of cow could have an influence on grazing distribution, but that body size should not affect grazing distribution.

Further research by Bailey et al. (2004) tracked the activity and location of 4 hill climber cows and 5 bottom dweller cows, cows that had been classified by rank of average slope use and vertical distance traveled to water by horseback observers the year previous to this study, with Lotek 2000 GPS collars to compare their rangeland use habits. Hill climber cows were reported to spend more time (14%; $P = 0.02$) than bottom dweller cows (6.5%) on 20-30 degree slopes. Additionally, hill climber cows tended to spend less time at water (within 200 m of a water source; $P = 0.07$) than bottom dwellers. However, the two types did not differ in horizontal distance traveled from water, but hill climbers traveled further vertically from water ($P < 0.01$). Similar to Bailey et al. (2001), cows that were deemed as hill climbers in Bailey et al. (2004) were mostly Tarentaise (≥ 50% Tarentaise), whereas cows deemed as bottom dwellers were mostly Hereford cattle (≥ 50% Hereford). These results suggest that cow breed may affect grazing distribution in rangeland environments. However, only 9 cows were examined in the study conducted by Bailey et al. (2004), so the results from his study may have overestimated the accuracy of these results due to the small sample size. Furthermore, research conducted by Herbel et al. (1967) compared grazing distribution patterns of Hereford cattle to Santa Gertrudis cattle on arid rangeland. Results from this research indicated there were no breed effects on grazing distribution. However, the authors of this research never listed what the sample size was for their experiment. The difference in results between Bailey et al. (2004) and Herbel et al. (1967) could be due to environmental differences between the experiment locations, the environment differences under which the breeds were developed, or poor sample size and experimental design.

A similar study was continued by Bailey et al. (2006) and these authors reported similar results as Bailey et al. (2001) and Bailey et al. (2004). Based on a normalized and integrated index of observed terrain use and individual cow location recorded by Lotek 2000 GPS collars, hill climber and bottom dweller cows from two separate origin herds were compared. As reported above, hill climber cows tended to use steeper slopes and traveled further from water ($P = 0.06$) than bottom dweller cows. Additionally, pastures grazed by hill climbers had more uniform utilization and distance traveled from water sources ($P < 0.05$), and riparian stubble was taller ($P = 0.01$) than in pastures grazed by bottom dwellers. Breed differences were not examined in this study although some of the same Hereford and Tarentaise cows were used in this study as previous studies. However, a difference in grazing distribution was observed between age classes of cow ($P < 0.01$) with cows 3-4 years of age observed grazing gentler slopes than cows ≥ 5 years of age ($P < 0.05$).

Walburger et al. (2009) also found an interaction between cow age and grazing distribution when they monitored 269 cows using a LORAN-C automated telemetry system in a forested setting. In contrast to Bailey et al. (2006), Walburger et al. (2009) found that cows < 4 years of age selected lower elevations but used steeper slopes than the oldest cows in the herd (≥ 8 years old; $P < 0.05$). Also, cows ≥ 8 years of age grazed sites that were ≥ 20 m away from >40% canopy cover compared to 2-3 year old cows ($P < 0.05$) and 2-3 year old cows grazing areas with greater canopy cover than older cows ($P < 0.05$). However, all age classes of cows preferred gentler slopes, westerly aspects, areas further from water, and areas with greater forage production than the averages for the pasture ($P < 0.05$).

An ongoing study by Bailey et al. (2010a) evaluated 377 cows for the effectiveness of determining cow grazing distribution on arid rangeland by her docility score at calving. The results from this study suggest that calving temperament was not an indicator of grazing distribution habits. Furthermore, results from this study are similar to results from previous work. For Hereford and Tarentaise cross cows, breed and number of calves born did have an effect on observed grazing distribution ($P < 0.05$). Cows with 3, 4, or more calves traveled further from water vertically (56 ± 2 m) than cows with only two calves (48 ± 2 m; $P < 0.01$). These results could be directly related to cow age rather than number of calves produced as Bailey et al. (2006) reported that terrain use differed between cows of differing age. Additionally, in Bailey et al. (2010a), cows with a higher percent of Tarentaise breeding (≥ 50% Tarentaise) traveled both further vertically (58 ± 2 m vs. 50 ± 2 m; $P < 0.01$) as well as horizontally from water (652 ± 23 m vs. 615 ± 25 m; $P < 0.05$) than cows with a majority of Hereford breeding.

Previous to this study, Howery et al. (1996) conducted a study to determine habitat and home range differences between 87 cows grazing a Forest Service allotment. Habitat use of the cattle in this study followed the same trend that has been observed in many other studies, preferring riparian areas > upland steppe > upland forests. Out of the 87 cows observed during the two-year study, 78% had similar home range use both years despite drought and management shifts. Thirty-three percent showed total faithfulness to their home range both years. Forty-five percent differed only slightly in home range use the second year as compared with the first. Whereas 18% only moderately remained in the area of the home range they were raised in and 3% differed substantially in home range between the two years. Although home range varied between cows observed, feeding times and time spent loafing were similar between the 87 cows (Howery et al., 1996).

VanWagoner et al. (2006) conducted a study that considered the effect of sire breed on offspring grazing distribution. Angus, Charolais, Piedmontese, and Salers sires were bred to 173 Hereford and Tarentaise cross cows with known classifications as either hill climbers or bottom dwellers. The 96 adult daughters (2-4 years old) resulting from these crosses were observed for grazing distribution differences. Daughters from Piedmontese and Charolais sires traveled further horizontally from water ($P < 0.05$) and daughters from Piedmontese sires had a slight tendency ($P = 0.09$) for higher terrain use ratios than Angus sired cows. Otherwise, breed of sire did not seem to have an effect on the grazing distribution habits or physical performance of their progeny. Daughters born to cows that had previously been recorded to use steeper slopes and travel further from water grazed further vertically from water ($P < 0.05$) and had a higher terrain use ratio ($P < 0.05$) than cows sired from dams that used gentler terrain. Also, cows from Tarentaise dams traveled further both horizontally and vertically ($P < 0.05$) from water than cows from Hereford dams. Additionally, VanWagoner et al. (2006) reported that cow height, weight, and pregnancy status had an effect on grazing distribution in some years, but these effects were not consistent through the experimental period. In years 1998 and 2001, heaver cows traveled further horizontally from water than lighter cows ($P < 0.05$) and in 1998 taller cows traveled further horizontally from water than shorter cows ($P < 0.05$). Pregnant cows used steeper slopes than non-pregnant cows ($P < 0.05$), but this was only observed in 2001. Results from this research also indicated that grazing distribution was not correlated to calving date, actual weaning weight, or age-adjusted weaning weight.

An earlier study also examined the influence of genetic versus learned behavior influence on cow grazing distribution patterns. Howery et al. (1998) observed the habitat patterns of 10 daughters and foster-daughters from cows with known home ranges to analyze if range use is determined by genetics or learned behavior. Results from this study indicated that grazing distribution tended to be influenced by learned behavior as a calf. All 10 offspring observed remained near (mean of 0.5 to 1.2 km from dams' home ranges) the locations they were raised as calves when they were grazed on the same allotment as adults. By the fourth year of the study, most of the cows were observed to stay within 0.7 km from the dams' or foster-dams' home ranges, with all of the monitored daughters and foster-daughters remaining within 1.1 km from the home ranges in which they were raised. Peer influence seemed to be more important in determining grazing distribution when the daughters and foster-daughters were placed back into the same allotment where they were reared as yearling heifers. Data indicated that yearling heifers associated more with their peers than with older cows and this shifted habitat and location use from patterns learned from their dams. A shift in home range use was also observed in drought years and this shift in home range was attributed to the influencing effects of drought weather during those years. However, most cows shifted back to the grazing distribution patterns learned as calves with some exception. Results from this study suggest that grazing distribution is a learned behavior and that selective culling as well as herding and improved abiotic features can improve grazing distribution patterns within a herd (Howery et al., 1998).

Another study that evaluated the possible influence of genetic relationship to observed grazing distribution differences was performed by Bailey et al. (2010b). This study examined the genetic or learned behavior effect on grazing distribution in 108 beef cows. Embryos were collected from 10, previously determined hill climber cows and bottom dweller cows and placed into 98-crossbred-recipient cows also classified as either hill climber or bottom dweller. Adult daughters of the hill climber donor cows used higher elevations than the adult daughters of the bottom dweller cows ($P = 0.04$). Cows raised by recipient hill climber cows also used higher elevations than cows raised by bottom dweller recipient cows ($P = 0.04$). Results from this study suggest that both genetics (donor effect) and early learning (recipient effect) contribute to varied grazing distribution patterns (Bailey et al., 2010b).

In addition to breed differences, genetic influence, and learned behavior differences, it has been suggested that social interactions and hierarchical standing within a cow herd could influence grazing distribution and feeding habits (Sowell et al., 2000). Bennett and Holmes (1987) found that animals with lower ranking within a herd kept a further distance between them and other animals, whereas animals of higher ranking remained relatively close to other animals. They concluded this expression of social behavior could influence access of high quality food, shade, and water sources by low ranking animals (Bennett and Holmes, 1987). Also, Bowman et al. (1999) saw an effect on feeding habits of liquid supplement from herd hierarchical dynamics. Cows 3 years of age tended to dominate feeding bouts of liquid supplement in a rangeland environment. These cows spent more time at the feeders ($P < 0.001$), visited the feeders more times per day ($P < 0.001$), and frequented the feeders more days over the trial period ($P < 0.001$) when compared with 2 year old heifers. All of these studies provide evidence towards the hypothesis that hierarchical standing within a cowherd could influence grazing distribution and habitat use of individual cows.

Currently, there are few studies that have evaluated distribution based on individual cows' natural grazing tendencies without abiotic and biotic influences (Bailey et al., 2006; VanWagoner et al., 2006; Walburger et al., 2009). Research has been conducted on examining grazing distribution differences between cows of differing breeds, age, and terrain use classification (Bailey et al., 2001; Bailey et al., 2004; Walburger et al., 2009). Results from these studies indicate that age has a significant influence on grazing distribution and a possible difference in terrain use between breeds (Bailey et al., 2001; VanWagoner et al., 2006; Walburger et al., 2009). However, studies that have examined breed effect have tended to have poor study design that could have led to exaggerated differences. For a greater understanding of production systems in western environments, additional research is needed that examines cow grazing distribution patterns based on cow characteristics such as cow size and efficiency.

Global Positioning Systems Use in Cattle Research

Poor livestock grazing distribution across western rangeland environments is well documented and understood in the literature (Ganskopp, 2001; Bailey, 2004; Ganskopp and Bohnert, 2009; Anderson, 2010). However, individual cattle attributes that effect grazing distribution are still not thoroughly established (Ganskopp and Bohnert, 2009; Anderson, 2010). The development and recent advances of global positioning systems (GPS) designed for livestock has increased the ability of researchers to examine cattle use across landscapes and possible interactions that influence cattle grazing distribution behavior (Johnson and Ganskopp, 2008; Putfarken et al., 2008; Ganskopp and Bohnert, 2009; Anderson, 2010; Augustine and Derner, 2013).

One study where livestock GPS collars were utilized to monitor cattle grazing distribution was conducted by Ganskopp (2001). At study initiation, the authors placed Lotek GPS collars (Lotek Engineering, Newmarket, Ontario, CA) on 6 randomly selected cows and these cows wore these collars for a 1-month period. For this study, the collars were programed to take a GPS fix every 20 minutes and record activity sensor data for 3-minute periods. In addition, each collared animal was visually observed for 12-13 hours over the study duration. The authors used a Latin-square analysis of variance for data analysis. Forward-stepwise regression models used to identify cattle grazing and resting activities produced mean $R^2 > 0.80$. However, when regression analyses were used to identify standing, walking, and laying activities the mean $R^2 < 0.80$ and the authors considered the variation to be too high to have predictive value. Results reported in this research indicated that cattle spent 11.0 hours grazing, 10.1 hours resting, 1.8 hours walking, 0.3 hours consuming salt, 0.3 hours drinking, and 0.5 hours performing unclassified activities per day. Ganskopp (2001) concluded the GPS collar data was accurate at identifying grazing and resting activity and position of the cattle in the pasture.

However, this author was not satisfied by the accuracy ($R^2 < 0.80$) of resting, standing, and laying activity data.

Ungar et al. (2005) conducted two studies that examined the use of Lotek GPS collar data to identify free-ranging cattle activity for the use of studying cattle-landscape interactions. During the first study, 6 GPS collars were placed on cows. However, one collar failed during this trial and thus the authors were able to collect data from only 5 collars. Over the period of the second study, collar data was collected on 135 cows and collars remained on each animal between 3-7 days. Global positioning system fixes were recorded every 20 minutes in the first study and every 5 minutes during the second study. Activity sensor data was recorded every 6 minutes during the first study and every 4 minutes over the second study. The authors concluded that a 4-split regression tree analysis was the best predictor of cattle grazing activity over the first study period with an $R^2 = 0.84$. When the authors applied the 4-split regression tree analysis to data from the second study they concluded that 22% of data was misclassified. As a result of these two studies, Ungar et al. (2005) summarized that distance traveled data alone was not enough to infer cattle activity from collar data. Additionally, the authors reported that resting was most often misclassified as grazing so grazing hot spots should be verified as non-resting locations. Furthermore, the authors concluded that complete accuracy in determining cattle activity through the use of GPS collar data is difficult to achieve. However, data collected with one sensory fix associated with one GPS fix resulted in the most accurate activity classification.

Data accuracies are dependent on the frequency with which data is recorded (Johnson and Ganskopp, 2008). Johnson and Ganskopp (2008) conducted a study to compare discrepancies in estimated cattle locations and distance traveled between data recording intervals of every 5 minutes to one recording per day. They found that as time between recording intervals increased, estimates of pasture use decreased in accuracy ($P < 0.01$). Furthermore, increased time between recording intervals resulted in increased spatial errors and decreased distance cattle traveled by 10% for each iteration ($P < 0.001$). Additionally, Ganskopp and Johnson (2007) analyzed errors associated with GPS use in free-ranging livestock. With the conclusion of the study, the authors reported that bias of distance measured was inconsequential when cow movements were between 10 to 90 m in length. However, when the cattle, and thus the GPS units were immobile, GPS error generated about 1.7 m (± 0.7 m SE) perceived movement between each stationary iteration ($P < 0.05$). The authors concluded this error could be corrected for with the use of a regression model that included a minimum distance threshold, a motion sensor threshold, or a combined minimum distance/motion sensor threshold. Ganskopp and Johnson (2007) reported that when such a regression model was applied to the recorded GPS data, 81-92% of resting intervals observed in cattle were then correctly classified.

Augustine and Derner (2013) conducted a study examining the calibration and use of models to discriminate between different livestock activities when using Lotek GPS collars to monitor livestock grazing behavior. Lotek 3300LR collar data was collected from 98 yearling steers over 12 deployment periods of 21-30 days that occurred over a 4-year period. Visual observations were also made for 1 day per collar deployment period on 5-9 steers. These visual observations served as a calibration method to determine the ability of models to predict cattle activity through GPS collar data. The authors then developed binary models to discriminate between different livestock activities. Augustine and Derner (2013) concluded that a 9-split model was the most accurate at predicting cattle behavior and that head-down sensory data and distance traveled were the two most important variables when estimating cattle behavior. The 9-split model resulted in reducing cattle activity miscalculation to 13.8% and 12.9% between their training dataset and validation dataset, respectively. These authors concluded that GPS collar data can be used to study cattle distribution and grazing behavior with reasonable accuracy (Augustine and Derner, 2013).

Another study that was performed with the objective of developing a method for accurately identifying cattle activity based on data collected by GPS collars was conducted by González et al. (2015). The authors performed two trials; one was conducted to develop an activity classification algorithm and one to evaluate the accuracy of the algorithm developed. One CSIRO GPS collar (Commonwealth Scientific and Industrial Research Organization, Canberra, Australia) was placed on each of 11 steers, which were broken into 4 groups for the first study, and 14 steers with a GPS collar per steer was used for the second study. Data from each collar was aggregated into 10-second intervals for analysis. Additionally, direct visual observations were recorded on the 14 steers used for the second study. To classify activity data, the authors used a 4-step decision tree, which resulted in classifying cattle activity data into 5 groups, resting, ruminating, foraging, traveling, and other activities. González et al. (2015) concluded that GSP collar data can be used to identify fine-scale cattle activities throughout a daily period. Although the authors reported the high frequency data collection needed to produce fine scale cattle activity results is taxing on battery life and thus such data can only be collected over short durations of time.

The use of GPS collar systems to study free-ranging cattle grazing distribution and daily behavior is agreed upon as an important new tool to broaden the understanding of cattle behavior (Johnson and Ganskopp, 2008; Putfarken et al., 2008; Ganskopp and Bohnert, 2009; Anderson, 2010; Augustine and Derner, 2013). However, it is also agreed that not all cattle activities can accurately be classified (Turner et al., 2000; Ganskopp, 2001; Ungar et al., 2005; Ganskopp and Johnson, 2007; Augustine and Derner, 2013). Cattle activities that can be identified with acceptable misclassification (12-14%) accuracy are time spent grazing per day and distance traveled per day (Ganskopp, 2001; Ungar et al., 2005; Augustine and Derner, 2013). Therefore, the use of GPS collar data to identify activities performed by cattle with different efficiency classifications could exceedingly expand the understanding of grazing behavior for different cow types.

Rational for Research

Metrics of cow efficiency that are easily implemented on ranch and are accurate in identifying animals that produce more calf weight weaned per kilogram of feed consumed has long been desired (Dinkel and Brown, 1978; Scasta et al., 2015; Beck et al., 2016). Techniques that can be used to identify which animals are more efficient have long been searched for both in beef cattle production settings and through research (Dinkel and Brown, 1978; Scasta et al., 2015; Beck et al., 2016). The ability of researchers and producers to identify which animals are best adapted to producing the most calf weight weaned on limited, western rangeland environments has evolved from the need for producers to be profitable and produce on a decreasing land base. Also, the continuously expanding human population has placed pressure on cattle producers to produce more high quality protein on a continuously decreasing land base (FAO, 2009; USDA National Agricultural Statistic Service, 2014; Beck et al., 2017). However, research is limited relative to cattle selection metrics that can be used to easily and accurately identify which cattle are best suited to extensive grazing production systems based in arid, western rangeland ecosystems.

There has been continued discussion within the beef cattle industry that explores whether small or large cows, based on body-weight and body condition score, are more suited for arid, western rangeland based production systems (Hammond et al., 1947; Dickerson, 1978; Stewart and Martin, 1983; Scasta et al., 2015). Previous research, conducted by Dinkel and Brown (1978) and Scasta et al. (2015), has indicated that cow size does influence cow production efficiency. However, previous research has not thoroughly agreed what sized cow is best suited to western rangeland environments (Dinkel and Brown, 1978; Stewart and Martin, 1983; Scasta et al., 2015; Beck et al., 2016). Much of this previous research tends to agree that small cows achieve more returns and are more efficient than large cows in pasture and rangeland settings (Kress et al., 1969; Dinkel and Brown, 1978; Stewart and Martin, 1983; Scasta et al., 2015; Beck et al., 2016). However, most research that has examined the effect of cow size on cow efficiency has used estimated cow intake rather than actual cow intake in rangeland settings. This has resulted in the current belief that smaller cows require less feed and that producers can increase herd numbers by decreasing cow size because of the perceived reduced intake need of each individual cow (Scasta et al., 2015; (Dinkel and Brown, 1978; Scasta et al., 2015; Beck et al., 2016). However, since the interaction between cow size and cow efficiency is not thoroughly established, more research is needed comparing cow size and efficiency in rangeland environments.

In addition, the ratio of calf weight weaned to cow weight, termed weaning weight ratio, is currently considered an accurate estimate of cow efficiency (Dinkel and Brown, 1978; Kirkpatrick et al., 1985; Kress et al., 2001; Scasta et al., 2015). When compared with other techniques for estimating cow efficiency, Dinkel and Brown (1978), Kirkpatrick et al. (1985), and Kress et al. (2001) all concluded that weaning weight ratio was the best predictor of cow efficiency out of the efficiency metrics examined in their studies. Dinkel and Brown (1978) and Scholljegerdes and Summers (2016) both concluded that weaning weight ratio was biased towards smaller and younger cattle when unadjusted cow and calf weights were utilized. Additionally, previous research examining the effectiveness of weaning weight ratio as a metric of cow efficiency either considered direct cow-calf weaning weight ratio or considered the ratio with the addition of cow intake. However, this research assumed that cows consume 2-2.5% body weight daily, individual feed bunks with limited feeding times, or fecal markers to estimate cow intake (Davis et al., 1983; Kirkpatrick et al., 1985; Kress et al., 2001). Furthermore, there is little recent research that examines the use of cow-calf weaning weight ratio as an accurate metric of cow efficiency. With modern technology (e.g. automated feed bunks and EID tags) there is now the ability to acquire accurate individual feed intake data that also includes feed intake behavior attributes (e.g. time spent feeding, number of feeding visits per day, and intake per visit) not previously reported in the literature. This technology can produce precise data that can be used to accurately measure individual cow intake that can then be used to confirm if cow-calf weaning weight ratio is an accurate and effective determinant of cow efficiency (Mendes et al., 2011).

Cattle feed efficiency highly influences cattle productivity and profitability (Koch et al., 1963; Arthur et al., 2001; Nkrumah et al., 2006; Berry and Crowley, 2013). The current definition of cattle feed efficiency is the ability of an animal to convert feed to meat and is measured as a ratio between the two (Berry and Crowley, 2013; Scholljegerdes and Summers, 2016). Although animal feed efficiency is not synonymous with production efficiency, it plays a large role in the ability to increase livestock production on a decreasing land base (Berry and Crowley, 2013). Cow feed efficiency also relates back to cow production efficiency (Dinkel and Brown, 1978; Scasta et al., 2015; Beck et al., 2016; Scholljegerdes and Summers, 2016). The current preferred method of estimating and predicting cow feed efficiency is through the use of residual feed intake (Hegarty et al., 2007; Herd and Arthur, 2009; Bolormaa et al., 2013). However, research conducted by Meyer et al. (2008) and Lawrence et al. (2012) both indicated that RFI classification determined in heifers was not an adequate predictor of cow DMI while grazing in pasture settings. Therefore, an alternative method needs to be found and used for predicting beef cow feed efficiency in pasture and rangeland environments.

Furthermore, few studies have examined the relationship between cow size, cow efficiency, and grazing behavior in western rangeland environments. Extensive grazing systems are embedded in western rangeland beef cattle systems and thus attaining uniform distribution across landscapes is vitally important for the success of beef cattle production systems based in the western United States. Considerable research has been conducted on biotic and abiotic features that can be used by cattle producers to alter grazing distribution of beef cattle in rangeland environments (Ganskopp, 2001; Bailey, 2005; Stephenson et al., 2016). It is also well documented in the literature that increasing livestock water sources and strategically placing salt, mineral, and protein supplement aid in increasing grazing distribution into areas less naturally preferred by cattle (Ganskopp, 2001; Bailey, 2004; Rawluk et al., 2014; Stephenson et al., 2016).

However, few studies have evaluated how individual cow type or cow characteristics influence inherent grazing distribution behavior on native western landscapes (Bailey et al., 2006; VanWagoner et al., 2006; Walburger et al., 2009). What research has been conducted on this subject has focused on grazing distribution differences between cows of differing breeds, age, and terrain use classification (Bailey et al., 2001; Bailey et al., 2004; Walburger et al., 2009). The influence of cow size and cow-calf weaning weight ratio on winter grazing behavior and individual supplement intake has not been previously examined. The use of global positioning systems now allow researchers the ability to examine the interaction between different classes of livestock with the environment and should be utilized when studying the effects of cow size and cow efficiency as determined by cow-calf weaning weight ratio (Putfarken et al., 2008; Ganskopp and Bohnert, 2009; Augustine and Derner, 2013).

Milk production in beef cows has long been attributed to have a major influence on the weight gain of calves, which is an important contributor to beef cattle efficiency

(Totusek et al., 1973; Mondragon et al., 1983; Beal et al., 1990). However, when Williams et al. (1979b) analyzed cow physical measurements to determine the correlation between physical attributes such as body height, weight, weight to height ratio, and body condition score of the cow to milk production, none were significantly correlated. Furthermore, the effects of cow weaning weight ratio and milk production has on pre-weaning calf growth and the influence of cow feed intake on cow efficiency has not been jointly considered. Therefore, there is a need for research to examine the interaction of cow-calf weaning weight ratio and cow size with cow milk production and calf pre-weaning average daily gain.

Although there has been individual research examining the effects of cow size, cow weaning weight ratio, cow feed efficiency, grazing distribution, and cow milk production, very few studies have been conducted evaluating more than two to three of these factors together. Therefore, there is a need for research to examine the influence of cow size on feed intake, grazing behavior, milk production, and the use of cow-calf weaning weight ratio as an accurate metric of cow efficiency. Both in a controlled, dry-lot setting and in a more realistic, rangeland based system, with the objective of identifying methods that could be applied to beef cattle production environments and practiced on ranch by beef cattle producers. To address this need in the literature, these studies were designed to assess how cow body weight and weaning weight ratio effect feed intake, milk production, calf pre-weaning performance, grazing behavior, and supplement consumption.

Western rangeland based beef cattle producers are currently encouraged to reduce cow size because of the belief that smaller cows have lower feed intake and the belief that by reducing cow size, producers are able to increase herd numbers. However, producers are being encouraged to reduce cow size without relinquishing calf weaning weight performance. There is also the belief that all cows should be able to wean a calf that weighs 50% of their own body weight at weaning. Additionally, there is currently little to no research examining the differences in feed intake and grazing behavior between cows of varying size that are expected to wean similar sized calves. Therefore, the objectives of this research were to assess the influence of cow-calf weaning weight ratio and cow size on cow feed intake, milk production, and cow grazing behavior.

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CHAPTER THREE

THE INFLUENCE OF WEANING WEIGHT RATIO AND COW SIZE ON FEED INTAKE BEHAVIOR, MILK YIELD, AND MILK CONSTITUENTS

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ABSTRACT

Metrics that identify beef cow productivity and efficiency in extensive rangeland environments has long been sought in both beef cattle research and production settings. Previous research and applied practice has suggested the ratio of calf weight weaned to cow weight, or weaning weight ratio (WWR), is an accurate estimate of cow efficiency. Furthermore, milk yield and constituents influence calf pre-weaning ADG and milk production influences cow feed requirements. Therefore, the objective of this study was to evaluate the influence of cow-calf WWR and within WWR, cow BW on feed intake and milk production. Forty Angus cow-calf pairs (≥ 4 year-old; cow initial BW = 575 kg ± 9.4 SE) were randomly allotted to high and low WWR groups (whole plot; ± 0.75 SD from herd mean) based on lifetime average WWR and within WWR classification groups were classified as light or heavy weight (sub-plot; > or < group mean) in a randomized split-plot design. Cow-calf pairs were contained in a dry-lot and provided *ad-libitum* access to a commercially available, 18% protein, pelleted alfalfa based total mixed ration in eight SmartFeedPro feeders for a 22-d period, which consisted of a 14-d adaption period and 7-d intake data collection period. Individual cow average daily feed consumption, average daily feeding bout duration, number of visits per day, and total time spent eating per day was collected. On the final day of the feed trial, a weigh-suckle-weigh procedure was conducted and 50 mL milk samples were collected from each cow. Milk was analyzed for fat, solids not fat, total solids, protein, and lactose content, and milk yield was calculated as the change in calf weight following the weigh-suckle-weigh procedure. High WWR cows consumed 6.3 g/kg (± 1.6 SE) more feed per kg BW than low WWR cows (P < 0.001). High WWR cows produced 2.96 g milk/kg BW (± 1.1 SE; P < 0.001) and 1.16 kg (± 0.6 SE) total milk more than low WWR cows (P < 0.03). Heavy cows within the two WWR groups tended to consume an average of 1.5 kg (± 0.8 SE) more feed than light cows per day (P < 0.09). Results indicate that high WWR cows were lighter but consumed more feed and produced more milk when both were expressed on a g/kg BW bases and that cow size alone was not an accurate indicator of cow efficiency.

Key words: Beef, cattle, efficiency, feed-intake, milk-production

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INTRODUCTION

Metrics that identify which beef cows in production settings will produce more calf weight weaned per kilogram of feed consumed, often termed cow efficiency, has long been sought in both beef cattle production settings and research (Dinkel and Brown, 1978; Beck et al., 2016). Previous research and applied practice has suggested the ratio of calf weight weaned to cow weight, or weaning weight ratio (WWR), is a potential metric to estimate cow efficiency (Dinkel and Brown, 1978; Kirkpatrick et al., 1985; Scasta et al., 2015). In addition, cow body size has been attributed to influence calf weight weaned, feed intake, and as a result, cow efficiency (Scasta et al., 2015; Beck et al., 2016). However, previous research that has examined the effectiveness of WWR as a metric of cow efficiency and what sized cow performs best in western rangeland environments has utilized feed intake estimates, limited individual feeding times, or fecal markers to calculate cow intake (Davis et al., 1983; Kirkpatrick et al., 1985; Scasta et al., 2015). Modern technology can provide accurate individual feed intake data that also includes feed intake behavior attributes not previously reported in the literature (Mendes et al. 2011). Milk yield and constituents have also been attributed to influence calf pre-weaning ADG but have not been revisited in recent years (Mondragon et al., 1983; Beal et al., 1990). Furthermore, as defined by WWR, the effects milk production has on pre-weaning calf growth and the influence of cow feed intake on cow efficiency has not been considered. Therefore, the objective of this study was to evaluate cow-calf WWR and within WWR, cow size influences on feed intake, milk production, and milk composition to evaluate WWR and cow size as accurate metrics of cow efficiency. The hypothesis was that high WWR cows would have lower feed intake while producing heavier calves than low WWR and that small BW cows would have lower feed intake and produce less milk than heavy BW cows.

MATERIALS AND METHODS

Protocols for this research were approved by the Montana State University Agricultural Animal Care and Use Committee (#2018-AA02). Lifetime production records from cows with a minimum of 3 calf crops and bred with the forth calf from the Montana State University Northern Agriculture Research Center predominantly Angus cowherd were used to identify high and low WWR groups the fall previous to trial year (Table 1).

Cows with ≥ 3 previous calves were used to insure cows examined in this research had already proved reproductive efficiency and to insure a representative calf weight and weaning weight ratio average. All calf data was corrected for age of dam, sex of calf, and equalized to a 205-d adjusted weaning weight. Likewise, cow weights were adjusted to a standardized body condition (5 on a scale of 1–9) before calculating weaning weight ratios. Dinkel and Brown (1978) and Scholljegerdes and Summers (2016) recommended adjusting both calf and cow weights to remove bias towards younger and smaller animals in future research. All of the multiparous (minimum of 3 weaned calves), Angus cow-calf pairs were stratified by WWR and randomly allotted to high and low WWR groups (whole plot; ± 0.75 SD from herd mean of 49%) and, within WWR classification groups, allotted to light and heavy weight groups (sub-plot; > or < group mean). Because WWR was negatively correlated (R^2 = 0.56) to cow size with smaller cows typically having higher WWR, cow size was evaluated within WWR groups (Figure 1).

This resulted in a randomized split-plot design with the following four classification groups: 1) High WWR-Light BW, 2) High WWR-Heavy BW, 3) Low WWR-Light BW, and 4) Low WWR-Heavy BW (Table 1; Zoby and Holmes, 1983; Brandyberry et al., 1991). Once cows were stratified into the four classification groups, actual cow and calf weights were utilized for trial analyses. This technique was repeated both years of the trial and 40 cow-calf pairs (cow initial BW = 574.7 kg ± 9.4 SE; calf initial BW = 89.8 kg ± 3.7 SE) were randomly selected per year (*n* = 10 per classification group) of the trial. Additionally, only cows that had calved within the first four-weeks of calving were used and mean calf age at trial initiation was 42.0 d (± 2.2 SE) postpartum (Table 1).

Furthermore, calf birth weight (43.5 kg ± 1.3 SE) did not differ between classification groups either year (*P* > 0.10; Table 1). As was expected, cow weights were statically different between the two WWR classification groups and between BW classification groups (Table 1).

Cow-calf pairs were contained in a dry-lot May 2, 2017 to May 23, 2017 (year one) and May 1, 2018 to May 22, 2018 (year two) and fed *ad-libitum* a commercially available pelleted alfalfa diet designed to meet NRC requirements for lactating cows when consumed at 2.5% of BW per day (Table 2; CHS Nutrition, Sioux Falls, SD). Random grab samples of the pelleted diet were collected once daily over the 7-d intake data collection period and combined before being sent to Dairy One Laboratory (Ithaca, NY) for forage analysis including, DM (Goering and Van Soest, 1970), NDF (Van Soest et al., 1991), ADF (AOAC, 2000), CP (AOAC, 2000), TDN, and net energy during lactation (NEL). Cow diets were provided in eight SmartFeedPro feeders, which were fully contained within two portable trailers (C-Lock Inc., Rapid City, SD). Calves had *ad-libitum* access to the same feed, which was provided in a creep feeder and cow-calf pairs had continuous access to water throughout the study period. Body weights were recorded for the cows and calves, and BCS were taken following a 16 h shrink prior to the start of the trial (Table 1). The trial consisted of a 14-d adaption period followed by a 7-d intake data collection period.

Individual cow average daily dry mater intake (DMI), average feeding bout duration, number of visits per day, and total time spent eating per day were collected. On day 23 of the feed trial, a weigh-suckle-weigh procedure was conducted following the methods detailed by Williams et al. (1979). In addition to the weigh-suckle-weigh protocol, a 50 mL milk sample was collected from each cow, immediately placed on ice, and transported to the Montana Central Milk Laboratory (Montana Veterinary Diagnostic Laboratory, Montana Department of Livestock, Bozeman, MT) where the samples were analyzed for percent fat, solids not fat, total solids, protein, and lactose content. Milk yield was calculated using calf weight differences from the weigh-suckle-weigh protocol.

Statistical Analysis

Feed trial and milk data were analyzed as a split-plot analysis of variance using the PROC MIXED procedure in SAS (v. 9.4; SAS Inst. Inc., Cary, NC). Weaning weight ratio classification was treated as the whole-plot, body weight classification was treated as the sub-plot, and a WWRxBW interaction was included in each analysis. Individual cow was the experimental unit. Dependent variables were DMI, average feeding bout duration, number of visits per day, total time spent eating per day, milk yield, % fat, % solids not fat, % total solids, % protein, and % lactose. Three cows were removed from this analysis due to either EID tag failure and/or unacceptable feed intake variation (CV > 30%). A year by treatment interaction was not indicated between DMI, number of visits per day, total time spent eating per day, milk yield, % fat, % solids not fat, % total solids, % protein, and % lactose and therefore data means from both years were combined and analyzed together. However, a year by treatment interaction was indicated in average feeding bout duration and therefore data was analyzed and represented by individual year. When WWR interacted with BW, means were separated using the LSMEANS procedure of SAS and a

Tukey-Kramer test was included in all MIXED procedures. Statistical significance was considered when *p*-values were ≤ 0.05 and a trend towards significance was considered when *p*-values were > 0.05 but ≤ 0.10.

RESULTS AND DISCUSSION

Although there was a year effect ($P < 0.05$) indicated in DMI, total time spent eating per day, milk yield, and milk constituents, there was no treatment by year interaction ($P > 0.10$) except with average feeding bout duration. Thus, data from both years were combined and averaged for all results except average feeding bout duration. Even though cow and calf weights were adjusted following the recommendations of Dinkel and Brown (1978) and Scholljegerdes and Summers (2016), cow age was different between WWR classification groups. Cows classified as high WWR animals were 1.5 yr younger on average than cows classified as low WWR ($P = 0.002$; Table 1). This suggests that cow WWR may be confounded by age, despite the use of cows ≥ 5 years of age, as well as 205-d adjusted calf weaning weights, and cow weights standardized to a common body condition score of 5 (on a 1-9 BCS scale) before selection of cows. Both the current research and previous research indicates a bias towards younger and smaller cows, regardless of the use of actual or adjusted cow and calf weights.

Feed Intake and Behavior

Cow weight tended to influence daily feed consumption when data from both years of the trial were averaged together ($P = 0.086$), with heavy cows consuming 1.5 kg (± 0.8 SE) more than light cows, which was 8.5% more on average (Figure 2a; Table 3). Similar results were reported by Walker et al. (2015) in lactating cows with Walker et al. (2015) reporting that heavy cows (573 ± 39 kg) had 4.8% higher daily DMI compared to light cows (488 ± 30 kg; $P = 0.03$). Additionally Zoby and Holmes (1983) reported that feed intake for 631 kg non-lactating cows was 4.2% higher than the intake of 439 kg non-lactating cows. Cow WWR classification did not influence ($P = 0.223$) feed intake expressed as total kg per d (Figure 2a; Table 3). However, when expressed on a g feed/kg cow BW basis, cow WWR classification had an effect on g feed consumed per kg cow BW ($P < 0.001$). High WWR cows consumed 6.4 g (± 1.6 SE) of feed per kg of BW more, which is 23% more, than low WWR classified cows (Figure 2b; Table 3). Although high WWR cows consumed more feed per kg of BW than low WWR, their calves were heavier at weaning (Table 1). Possibly suggesting these cows transfer the additional feed energy to their calf.

Kleiber (1961) suggested that cow energy demands are proportional to 0.75 power of cow body weight and the National Academies of Science (2016) have used this power in many of their feed intake estimation equations. Following these equations, smaller cows would have higher energy demand per unit of body weight than larger cows. The high WWR cows in this study consumed 23% more feed than the low WWR classified cows and were also 83.3 kg lighter. Therefore, the difference observed in g intake per kg BW may be explained by this relationship. Furthermore, Zoby and Holmes (1983) also reported that smaller cows consumed more feed per kg $BW^{0.75}$ than larger cows with an intake difference of 19.3%. However, when Coleman et al. (2014) evaluated intake prediction calculations used by the National Research Council in the 1996-2000 *Nutrient Requirements of Beef Cattle*, the authors reported that cow milk yield and calf pre-weaning gain influenced cow intake greater than cow size. Therefore, the additional intake observed in the high WWR cows when intake was expressed on a g/kg BW basis may also be due to milk production and calf performance (Coleman et al., 2014).

Cows classified as high WWR tended to frequent feed 3.7 (± 2.1 SE) more times per day than cows classified as low WWR (P = 0.078; Table 3). Additionally, light BW cows spent an average of 26 s longer per visit to feed than heavy BW cows in the first year of the trial (P = 0.019; Table 3). However, in the second year of the trial, cow body weight did not have an effect on AFD, but cow WWR classification did tend to influence average time spent eating per visit with high WWR cows spending an average of 31 s longer per visit than low WWR cows (P = 0.099). Because of the reversal of effects indicated in AFD between years, TSE was not significantly different between any of the cow groups (Table 3).

Milk Yield and Composition

Total kg milk yield following the 8 h separation period during the weigh-suckle-weigh protocol indicated a difference between high and low WWR classified cows (*P* = 0.029; Figure 3a; Table 4). High WWR cows produced 1.16 kg (± 0.6 SE) more milk following the 8 h separation period, which equated to a 31% difference, than low WWR cows (Figure 3a; Table 4). Additionally, when milk yield was represented on a g milk yield/kg cow BW basis, high WWR cows produced 2.96 g (± 1.1 SE) milk/kg BW more than low WWR cows, which was 50% more milk/kg BW (*P* = 0.0006; Figure 3b; Table 4). Previous research has indicated that cow milk yield is correlated (R^2 = 0.55-0.77) to calf pre-weaning ADG (Gleddie and Berg, 1968; Jeffery and Berg, 1971; Beal et al., 1990). Additionally, Davis et al. (1983) reported results that indicated a positive correlation between milk yield and cow efficiency when cow feed intake was compared with calf weight weaned. Therefore, the higher milk yield produced by the high WWR classified cows may explain why these cows wean heavier calves than cows classified as low WWR. The greater milk yield may also explain why these animals consume more feed per kg BW. Milk yield reported in this research was comparable to milk yield reported by Melton et al. (1967), Jeffery and Berg (1971), and Totusek et al. (1973). Melton et al. (1967) reported that older cows produced more milk than younger cows and this research indicated opposite results. However, cows examined by Melton et al. (1967) were 2, 3 and 4 year old cows compared to 5 through 10 year old cows. Whereas cows used for this research were > 5 years of age.

An interaction between cow WWR and cow BW was observed in respect to milk lactose content (*P* = 0.018; Table 4). As cow BW increased in the high WWR cows, so too did percent milk lactose content, however, as cow BW increased in the low WWR cows, percent milk lactose decreased. A trend towards a similar interaction between cow WWR classification and BW classification was also indicated in percent milk fat and percent milk protein content (*P* = 0.098 and *P* = 0.062, respectively; Table 4). However, for these two variables, as BW increased in high WWR classified cows, percent fat and protein decreased, and as BW increased in low WWR classified cows, so too did percent fat and protein content. Percent milk lactose (mean 4.9% ± 0.1 SE) and percent fat (3.7% ± 0.2 SE) were comparable to percent milk lactose and milk fat reported by Mondragon et al. (1983). Total solids (10.6% ± 0.2 SE) and SNF (9.3% ± 0.1 SE) were comparable to results reported by Melton et al. (1967). Previous studies have reported that milk constituents were not correlated to calf ADG or pre-weaning growth (Jeffery and Berg, 1971; Totusek et al., 1973; Mondragon et al., 1983). Results from this research agree with the literature, with milk constituents not influenced by cow weaning weight ratio or cow weight.

Implications

Results from this research provide additional information on how cow size, cow-calf weaning weight ratio, and milk production affect cow and production efficiency. In this study, cows that had consistently weaned a greater percent of body weight over at least three calf croups were smaller (*P* < 0.0001) but consumed more feed (6.4 ± 1.6 g/kg; *P* =

0.0002) and produced more milk (2.96 ± 1.1 g/kg; $P = 0.0006$) when both feed intake and milk yield were expressed on a g/kg BW basis. This increased feed consumption and milk production may explain why these animals are able to consistently wean a greater percent of BW. The use of cow-calf weaning weight ratio as a selection metric for beef cows may incidentally select for animals that are heavier milk producers and require additional feed. In addition, cows that were classified as consistently weaning > 50% of body weight were younger (7.2 ± 0.5 yr) than cows classified as consistently weaning < 50% body weight (8.7 ± 0.5 yr; $P = 0.002$). Thus, the use of cow-calf weaning weight ratio may select against older animals that are still productive in the cowherd. As a result, the use of cow-calf weaning weight ratio as a method for selecting animals within a cowherd should be practiced with some caution because of the potential increases in feed intake, milk production, and bias to younger cows.

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Table 1. Cow and calf data at the start of the feed trial period and lifetime cow and calf weaning weight averages when cows were classificed by weaning weight ratio and body weight (*n* = 10 cows per group; 22-d intake study; 2017-2018).

	High WWR[1]		Low WWR[2]			WWR[3]	BW[4]	WWR*BW[5]
Item	Light BW	Heavy BW	Light BW	Heavy BW	SE	*P*-value	*P*-value	*P*-value
Lifetime averages								
Cow BW, kg	502.9	542.7	590.3	631.8	4.20	<0.0001	<0.0001	0.847
Calf wt., kg	283.4[a]	292.0[a]	248.8[b]	270.3[c]	3.19	<0.0001	<0.0001	0.047
WWR[6], %	56.4[a]	53.8[b]	42.2[c]	42.8[c]	0.52	<0.0001	0.067	0.004
Start trial								
Cow BW, kg	517.6	548.6	604.1	628.7	9.39	<0.0001	0.004	0.732
Cow BCS	4.8	4.8	5.1	5.0	0.12	0.053	0.665	0.388
Cow age, yr	6.9	7.5	8.5	8.9	0.47	0.002	0.286	0.830
Calf wt., kg	92.3	93.8	86.5	86.7	3.71	0.082	0.822	0.864
Calf birth wt., kg	41.9	43.1	45.9	42.7	1.28	0.140	0.477	0.097
Calf age, d	43.9	43.1	40.4	40.7	2.15	0.164	0.917	0.784
WR[6], %	17.8	17.1	14.3	13.8	0.84	<0.0001	0.373	0.869

[1] High WWR = high weaning weight ratio group
[2] Low WWR = low weaning weight ratio group
[3] WWR = main plot analysis associated with cow weaning weight ratio classification
[4] BW = sub plot analysis associated with cow body weight classification
[5] WWR*BW = interaction between whole and sub plot analysis associated with the interaction of weaning weight ratio and cow body weight
[6] WR = weight ratio between calf and cow weights
P-values were considered significant at ≤ 0.05 and were considered as a trend towards significance at > 0.05 but ≤ 0.1
[a,b,c] Means within a row with different superscripts differ ($P \leq 0.05$)

Table 2. Ingredients and nutrient composition (DM basis) of the pelleted, total mixed ration provided *ad-libitum* to cows on trial (22-d intake study; 2017-2018).

Item	%
Ingredients	
Alfalfa, hay	79.3
Corn, ground	20.0
Ultramin. 12-6[1]	0.75
Nutrient value	
NEL, MJ/kg	7.45
DM	89.7
CP	17.9
NDF	36.6
ADF	28.4
	75.5
K	1.74
Ca	1.48
S	0.29
P	0.27
Mg	0.24
Na	0.13

[1] Ultramin 12-6: 12% Ca, 6% P, 4.5% salt, 2.75% Mg, 25 ppm Co, 200 ppm I, 3500 ppm Mn, 2500 ppm Cu, 7500 ppm Zn, 36 ppm Se, 661,385 IU/kg vitamin A, 66,139 IU/kg vitamin D, and 1,102 IU/k vitamin E.

Table 3. The influence of cow weaning weight ratio and cow body weight classification on feed intake (DM basis) and feeding behavior while in a 22-d dry-lot setting with *ad-libitum* access to a pelleted, alfalfa based, total mixed ration (2017-2018).

	High WWR[1]		Low WWR[2]			WWR[3]	BW[4]	WWR*BW[5]
Item	Light BW	Heavy BW	Light BW	Heavy BW	SE	*P*-value	*P*-value	*P*-value
Intake								
Daily, kg	16.7	19.2	16.7	17.1	0.84	0.223	0.086	0.227
g/kg cow BW	32.4	35.4	27.9	27.1	1.64	<0.001	0.518	0.246
Feeding bouts								
Number/day	30.3	34.5	29.3	28.0	2.10	0.078	0.482	0.192
Per day, min	104.2	113.1	103.4	90.2	9.49	0.222	0.818	0.249
Visit duration, min								
Year 1	2.77	2.49	2.65	2.07	0.18	0.128	0.019	0.390
Year 2	4.31	4.14	4.38	5.06	0.27	0.099	0.340	0.125

[1] High WWR = high weaning weight ratio group
[2] Low WWR = low weaning weight ratio group
[3] WWR = main plot analysis associated with cow weaning weight ratio classification
[4] BW = sub plot analysis associated with cow body weight classification
[5] WWR*BW = interaction between whole and sub plot analysis associated with the interaction of weaning weight ratio and cow body weight
P-values were considered significant at ≤ 0.05 and were considered as a trend towards significance at > 0.05 but ≤ 0.1

Table 4. The influence of cow weaning weight ratio and cow body weight classification on cow milk yield and milk composition following an 8 hr cow-calf separation period using the weigh-suckle-weigh technique (2017-2018).

	High WWR[1]		Low WWR[2]			WWR[3]	BW[4]	WWR*BW[5]
Item	Light BW	Heavy BW	Light BW	Heavy BW	SE	*P*-value	*P*-value	*P*-value
Days postpartum	67.3	63.5	64.2	61.6	2.76	0.164	0.254	0.829
Milk yield								
Yield, kg	4.63	5.18	3.00	4.50	0.62	0.029	0.110	0.449
g/kg cow BW	8.64	9.01	4.72	7.01	1.09	<0.001	0.231	0.385
Milk constituents								
Fat, %	1.23	0.87	0.94	1.24	0.20	0.874	0.856	0.098
SNF[6], %	9.29	9.33	9.22	9.27	0.09	0.459	0.625	0.914
TS[7], %	10.54	10.21	10.17	10.52	0.22	0.875	0.970	0.123
Protein, %	3.86	3.75	3.65	3.92	0.10	0.782	0.414	0.062
Lactose, %	4.69	4.85	4.86	4.60	0.09	0.660	0.571	0.018

[1] High WWR = high weaning weight ratio group
[2] Low WWR = low weaning weight ratio group
[3] WWR = main plot analysis associated with cow weaning weight ratio classification
[4] BW = sub plot analysis associated with cow body weight classification
[5] WWR*BW = interaction between whole and sub plot analysis associated with the interaction of weaning weight
[6] SNF = solids not fat
[7] TS = total solids
P-values were considered significant at ≤ 0.05 and were considered as a trend towards significance at > 0.05 but ≤ 0.1

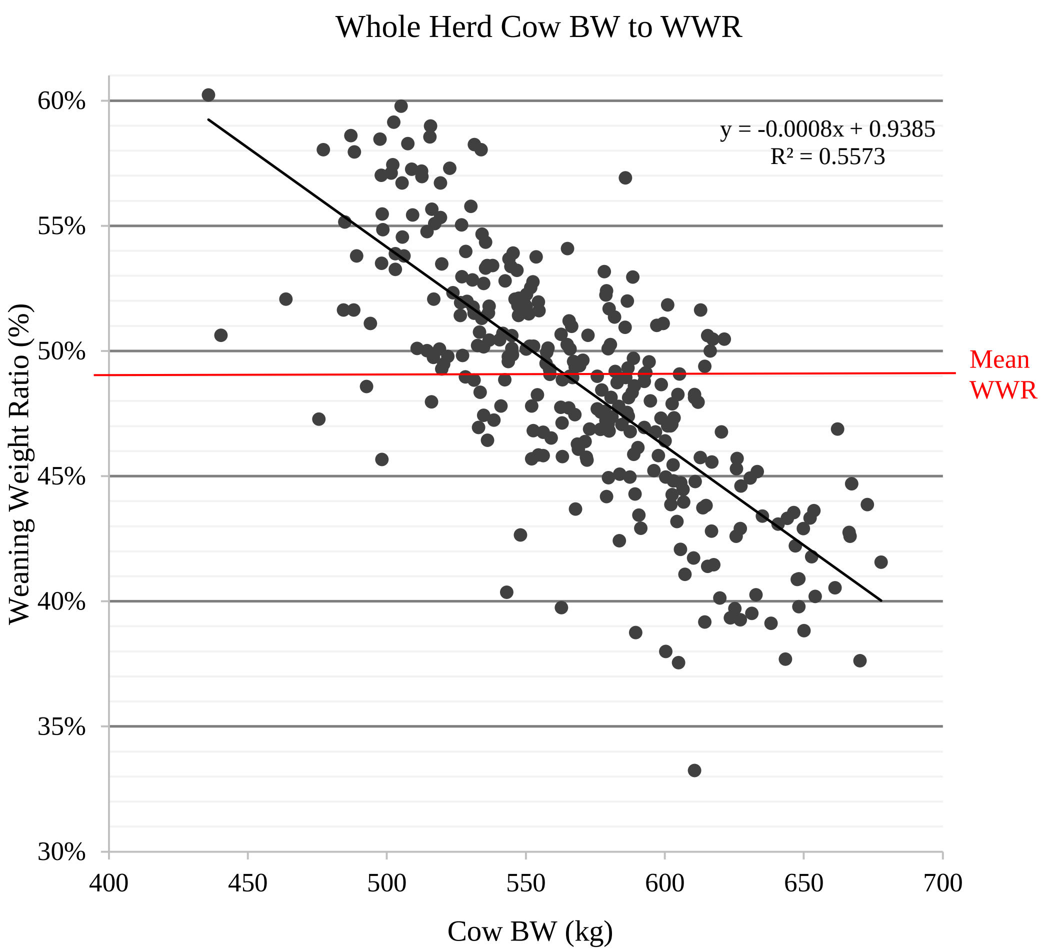

Figure 1. The relationship between cow body weight (BW) and weaning weight ratio (WWR) indicated in the Northern Agricultural Research Center Angus cow herd (*n* = 300, 2016-2018).

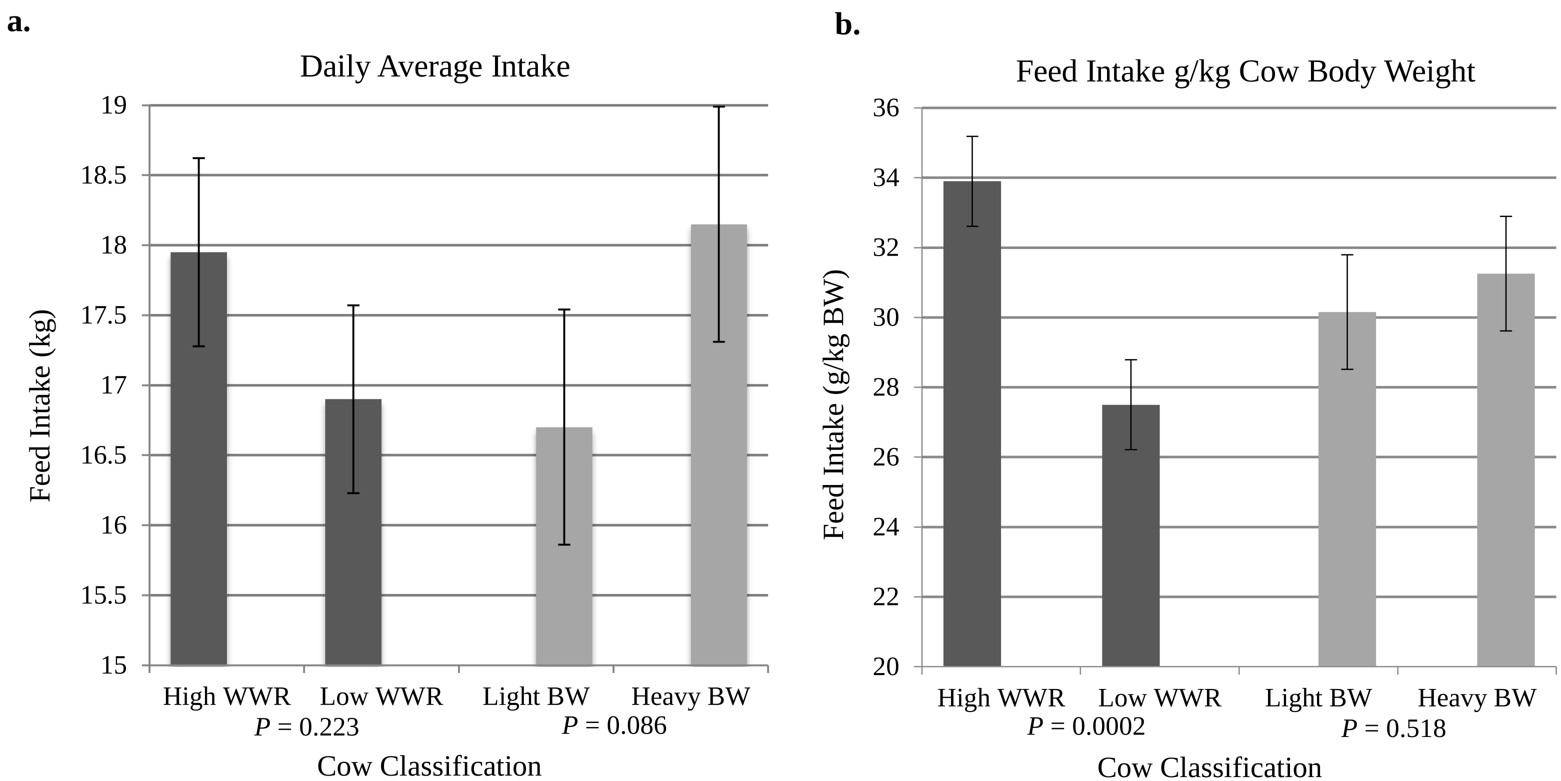

Figure 2. Average daily total feed intake (kg; DM basis, part **a.**) and average daily g/kg BW intake (DM basis; part **b.**) between cows classified as either high or low weaning weight ratio (WWR) or classified as light or heavy body weight (BW) when provided *ad-libitum* access to a pelleted, alfalfa, total mixed ration (22-d trial 2017 and 2018).

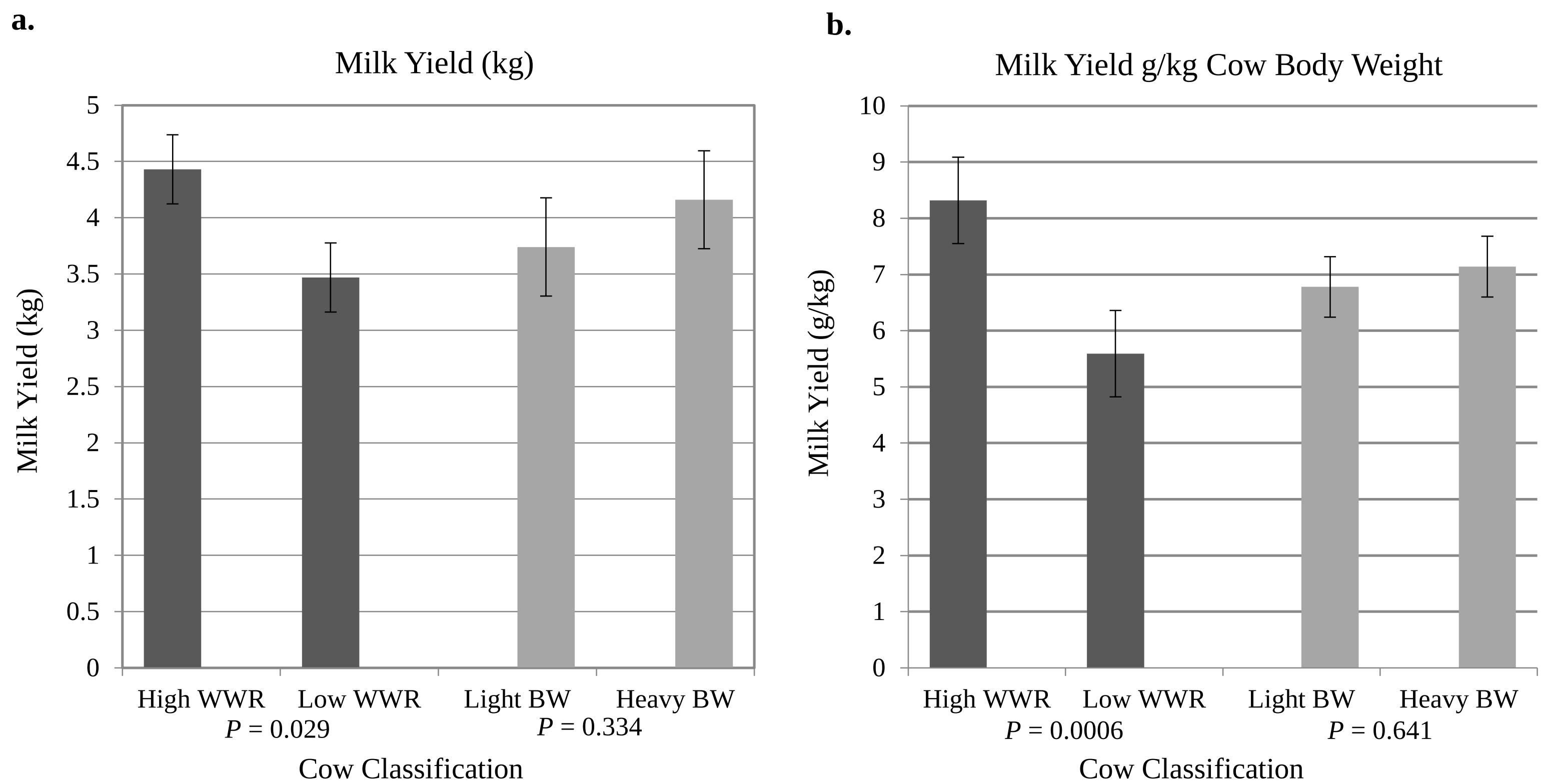

Figure 3. Total milk kg yield (part **a.**) and g milk/kg BW (part **b.**) differences between cows classified as either high or low weaning weight ratio (WWR) or classified as light or heavy body weight (BW) following an 8 hr cow-calf separation period using the weigh-suckle-weigh technique (2017 and 2018).

CHAPTER FOUR

THE INFLUENCE OF WEANING WEIGHT RATIO AND COW SIZE ON WINTER GRAZING AND SUPPLEMENT INTAKE BEHAVIOR

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ABSTRACT

The ideal cow for extensive western rangeland beef cattle production systems would convert forage consumed to more kilograms calf weaned and optimize use of rangeland forage resources. However, research is limited relative to matching cattle metrics to western rangeland production systems. Few studies have evaluated how cow type or cow characteristics influence grazing distribution and supplement consumption on native landscapes. The objectives of this study were to assess cow grazing behavior, resource use, and supplement intake when cows were classified by weaning weight ratio (WWR) and within WWR, body weight (BW), in a winter, native rangeland, grazing system. Forty Angus cows (≥ 4 year-old; cow initial BW = 635.4 kg ± 9.7 SE) were stratified by WWR and randomly allotted to high and low WWR groups (whole plot; ± 0.75 SD from herd mean) and, within WWR classification groups, allotted to light and heavy BW groups (sub-plots; > or < group mean) in a randomized split-plot design. Cows were located in a 329 ha pasture located at the Thackeray Ranch, Havre, Montana for 45-d (year one) and 60-d (year two) grazing periods. Average forage production at study initiation was 2,456-kg/ha and 3,156-kg/ha, for 2016 and 2017, respectively. Fifty-percent of the cows were fitted with Lotek 3300LR GPS collars per group (n = 20). A commercially available, 36% crude protein, salt-limited, pelleted supplement was provided *ad-libitum* in eight SmartFeedPro feeders. Total distance traveled and time spent grazing were collected on individual cows with GPS collars. Individual cow daily supplement consumption, daily feeding bout duration, number of visits per day, and time of day feeding bouts occurred were collected

for all cows. High WWR cows spent 23% more time grazing per day than low WWR classified cows ($P < 0.02$). However, total distance traveled per day did not differ between high and low WWR classified cows or light and heavy BW cows ($P > 0.10$) with the mean distance traveled per day of 3.2 km (± 0.11 SE). Supplement intake and supplement intake behavior was not different between either high or low WWR classified cows or light and heavy BW cows ($P > 0.10$). The time of day most visits to supplement occurred at was between 0900 to 1300 h. Results indicated that winter supplement intake did not differ between WWR or BW classification groups and neither did total distance traveled, but high WWR cows spent more time grazing per day.

Key words: Beef cattle, winter grazing, supplement intake

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INTRODUCTION

An ongoing discussion in the beef cattle industry explores if small or large cows, based on body weight (BW) and body condition score (BCS), are more suited for western rangeland environments (Dickerson, 1978; Stewart and Martin, 1983; Scasta et al., 2015). This discussion is based on what cow type converts forage consumed to more kilograms calf weaned, often referred to as cow efficiency, while optimizing the use of diverse, extensive rangeland environments (Scasta et al., 2015; Beck et al., 2016). Previous research has suggested that cow-calf weaning weight ratio (WWR) is a potential metric to estimate cow efficiency (Dinkel and Brown, 1978; Kirkpatrick et al., 1985). Since extensive grazing systems are embedded in western rangeland beef cattle systems, attaining uniform distribution across landscapes is vitally important for the success of these production systems. Considerable research has been conducted on biotic and abiotic features that alter grazing distribution in beef cattle in rangeland environments (Ganskopp, 2001; Bailey, 2005; Stephenson et al., 2016). However, very little research has evaluated how cow type or cow characteristics influence grazing distribution (VanWagoner et al., 2006; Walburger et al., 2009). What research has been conducted on this subject has focused on grazing distribution differences between cows of differing breeds, age, and terrain use classification (Bailey et al., 2001; Bailey et al., 2004; Walburger et al., 2009). The influence of cow WWR and cow BW on supplement intake in a winter rangeland setting has not previously been examined. Therefore, the objective of this study was to assess how cow WWR and within WWR, cow BW, effects grazing behavior and supplement consumption in a winter rangeland environment. The research hypothesis was that high WWR cows would consume more supplement and have different grazing behavior than low WWR cows and that light cows would eat less supplement but travel further than heavy cows.

MATERIALS AND METHODS

Protocols for this research were approved by the Montana State University Agricultural Animal Care and Use Committee (#2015-AA04). Lifetime production records from cows with a minimum of 3 calf crops and bred with the forth calf from the Montana State University Northern Agriculture Research Center Angus cowherd were used to identify high and low WWR groups (Table 1). Cows with ≥ 3 previous calves were used to insure cows examined in this research had already proved reproductive efficiency and to insure a representative calf weight and weaning weight ratio averages. All calf data was corrected for age of dam, sex of calf, and equalized to a 205 day adjusted weaning weight. Likewise, cow weights were adjusted to a standardized body condition (5 on a scale of 1–9) before calculating weaning weight ratios. Dinkel and Brown (1978) and Scholljegerdes and Summers (2016) recommended adjusting both calf and cow weights to remove bias towards younger and smaller animals in future research. All of the multiparous (minimum of 3 weaned calves), Angus cows were stratified by WWR and randomly allotted to high and low WWR groups (whole plot; ± 0.75 SD from herd mean of 49%) and, within WWR classification groups, allotted to light and heavy weight groups (sub-plot; > or < group mean). Because WWR was negatively correlated ($R^2 = 0.56$) to cow size with smaller cows typically having higher WWR, cow size was evaluated within WWR groups.

This resulted in a randomized split-plot design with the following four classification groups: 1) High WWR-Light BW, 2) High WWR-Heavy BW, 3) Low WWR-Light BW, and 4) Low WWR-Heavy BW (Table 1; Brandyberry et al., 1991). This technique was repeated both years of the trial and 40 cows (cow initial BW = 635.4 ± 9.7 kg) were randomly selected per year (*n* = 10 per classification group) of the trial. As was expected, cow weights were significantly different between the two WWR classification groups and between BW classification groups (Table 1).

Cows were located in a 329 ha pasture at the Thackeray Ranch, 21 km south of Havre, Montana (48.377236, -109.632802) for 45-days from December 1, 2016 to January 15, 2017 (year one) and 60-days from November 1 to December 31, 2017 (year two) with the rest of the 300 head cowherd. Average temperature at the study site was -9.6°C year one and -2.0°C year two (Wyffels et al. unpublished data). Total precipitation received between December 1, 2016 and January 15, 2017 was 2.57 cm and between November 1 and December 31, 2017 was 3.60 cm (U.S. Climate Data, Havre, Montana, usclimatedata.com, Accessed August 15, 2018). Dominant vegetation in the pasture was Kentucky bluegrass (*Poa pratensis*), rough fescue (*Festuca campestris*), bluebunch wheatgrass (*Pseudoroegneria spicata*), and western wheatgrass (*Pascopyrum smithii*). Average forage production at study initiation was 2,456 and 3,156-kg/ha for 2016 and 2017, respectively. Pasture forage quality at the start of year one was 6.9% CP, 70.5% NDF, 43.9% ADF, and at the start of year two was 7.1% CP, 70.1% NDF, and 44.5% ADF (Wyffels et al. unpublished data).

Twenty cows (*n* = 5 per classification group) were randomly assigned to wear a Lotek 3300LR GPS collar (Lotek Engineering, Newmarket, ON, Canada) for the duration of the grazing period. Collars were programed to record a GPS fix every 15 min and an activity sensor period every 5 min. The 3 left-right and fore-aft motion sensor counts that were recorded between every 15 min GPS fix were averaged together and linked with the associated GPS fix record. Collars were placed on, and removed from, the randomly assigned cows at the time of cow weight and BCS data collection pre and post grazing period. A commercially available, 36% crude protein, pelleted supplement with 25% salt as the intake limiting factor (CHS Nutrition, Sioux Falls, SD) was provided to the cowherd in eight SmartFeedPro feeders that were fully contained within two portable trailers (C-Lock Inc., Rapid City, SD) and were centrally located in the pasture (Table 2). The supplement target intake was 0.9 kg per d per cow. Cows had continuous access to water throughout the study period. Individual cow average daily supplement consumption, average daily feeding bout duration, number of visits per day, total daily time spent consuming supplement per day, and time of day feeding bouts occurred, were collected for all cows. Additionally, total distance traveled and time spent grazing were calculated from GPS collar data for individual cows assigned to GPS collars (n = 20). Modified R code (v. 3.3.1; R Core Team, Foundation for Statistical Computing, Vienna, Austria) written by Jameson Brennan (South Dakota State University, Brookings, SD) based on work conducted by Augustine and Derner (2013) was used to calculate distance traveled per day and time spent grazing per day.

Statistical Analysis

Data were analyzed as a split-plot analysis of variance using the PROC MIXED procedure in SAS (v. 9.4; SAS Inst. Inc., Cary, NC). Weaning weight ratio classification was considered as the whole-plot, body weight classification was the sub-plot, and a WWRxBW interaction was included in each analysis. Dependent variables were average daily supplement consumption, average daily feeding bout duration, number of visits per day, total daily time spent consuming supplement per day, time of day feeding bouts occurred, total distance traveled, and time spent grazing. The PROC FREQ procedure in SAS was used to determine time of day feeding bouts occurred. The LSMEANS procedure and a Tukey-Kramer test were included in each analysis. A year by treatment interaction was not indicated between average daily feeding bout duration, number of visits per day, total daily time spent consuming supplement per day, time of day feeding bouts occurred, total distance traveled, and time spent grazing, and therefore data means from both years were combined and analyzed together. Three cows were removed from year one due to either EID tag failure or non-supplement consumer. No cows were removed from year two analyses. P-values ≤ 0.05 were considered significant and p-values > 0.05 and ≤ 0.10 were considered as a trend toward significance.

RESULTS AND DISCUSSION

Although there was a year effect ($P < 0.05$) indicated in supplement intake, intake behavior, and grazing behavior data, a treatment by year interaction was not indicated ($P > 0.10$). Therefore, data from both years were combined and averaged, and results were represented as a single mean. Even though cow and calf weights were adjusted following the recommendations of Dinkel and Brown (1978) and Scholljegerdes and Summers

(2016), cow age was different between WWR classification groups. Cows classified as high WWR animals were 1.5 yr younger than cows classified as low WWR animals on average ($P = 0.003$; Table 1). These results suggest that cow WWR may be confounded by age, despite the use of cows > 4 years of age, 205-d adjusted calf weaning weights, and cow weights standardized to a common body condition score of 5 (on a 1-9 BCS scale). Both the current research and previous research indicates a bias towards younger and smaller cows, suggesting that cow-calf WWR may inherently be biased towards these cows, regardless of the use of actual or adjusted cow and calf weights. Cow BCS at the start of the trial was different ($P = 0.023$) between high and low WWR cows with low WWR cows having an average of 0.25 more body condition than high WWR cows (Table 1). However, by the end of the trial period, there was no significant difference in cow BCS between the two WWR groups (Table 1). Results reported by Kirkpatrick et al. (1985) indicated that cow progeny weights were positively correlated with cow efficiency, whereas cow BW and BCS were negatively correlated to cow efficiency.

Supplement Intake and Behavior

Cow classification did not affect daily supplement intake when expressed as total kg consumed per d ($P > 0.10$; Figure 1a; Table 3). Average supplement consumption per d over the four cow groups was 1.13 kg (± 0.17 SE). Salt was included in the protein supplement at 25% to limit cow intake to 0.9 kg per d. However, cows from each classification group averaged above the target intake daily (Figure 1a; Table 3).

Additionally, when average daily supplement intake was expressed on a g supplement/kg cow BW basis, there was no difference in amount of supplement consumed between the four cow groups ($P > 0.10$; Figure 1b; Table 3).

Number of visits made to supplement each day did not differ between classification groups (3.5 ± 0.55 SE; $P > 0.10$; Table 3). Average time spent consuming supplement per visit tended to differ between high and low WWR cows ($P = 0.077$), with low WWR tending to spend 16% longer per visit to supplement than high WWR cows (Table 3). However, this trend towards significance in average feed duration did not result in a significant difference in time spent eating per day between any of the cow groups ($P > 0.10$; Table 3). Total number of feeding visits made to supplement also did not differ between the four cow groups ($P > 0.10$; Table 3). Most visits to supplement occurred between 0900 and 1300 h over both years of the study (Figure 2; Table 4). Times trailers were filled with supplement varied between 0800 to 1400 h every day to every other day. However, since the supplement provided was a self-fed supplement, cattle had continuous access to supplement and feeding frequency was dependent on keeping an unlimited supply of supplement to the cattle. Time of day cattle frequented supplement in this study differed from the results of another winter grazing trial conducted by Garossino et al. (2003). In the study conducted by Garossino et al. (2003), cattle visited supplement most between 0200-0300 h and then in the evening between 1600-1800 h. However, in a study conducted by Manzano et al. (2012), the authors reported that cattle frequented supplement the most between 1000 and 1500 h during a late fall supplement study, which was more comparable to the results of this study.

Grazing Behavior

There was no difference in total distance traveled per day between cows classified by weaning weight ratio or body weight (*P* > 0.10) with the mean distance traveled of 3.2 km (± 0.11 SE) per day (Figure 3a). A difference was indicated in total time spent grazing per day between the high WWR and the low WWR cows (*P* = 0.015). High WWR grazed for 1 h (± 0.40 SE) longer per day than low WWR cows, which equated to a 23% increase in time spent grazing compared to low WWR cows (Figure 3b). Previous research that has examined distance traveled and time spent grazing by cattle in winter rangeland systems have reported similar results to this research. DelCurto et al. (1990) reported that cattle grazed for 7.4 h per day when different protein supplement sources were provided in the tallgrass prairie. In another winter grazing study performed in the tallgrass prairie, Brandyberry et al. (1991) reported that cattle spent 7.94 h grazing and traveled 2.83 km per day. Further research performed by Brandyberry et al. (1992) reported cattle traveled 6.14 km and grazed for 5.93 h per day when winter grazing Great Basin native rangeland. Barton et al. (1992) reported cattle spent an average of 7. 2 h grazing per day when grazing native sagebrush-steppe rangeland December to February. A fall grazing study performed in eastern Montana reported cattle grazed for 8.4 h per day and traveled 3.9 km (Adams, 1985). The differing results in time spent grazing and distance traveled per day reported between this research and that of previous winter grazing research may be due to pasture size, forage availability, and climate differences between research locations. In environments with lower forage production, cattle may have to travel further per day to meet daily DMI requirements. Similarly, in environments with lower forage CP, cattle may have to spend more time grazing per day to meet nutrient needs.

Implications

Results from this research provide additional information on how cow size and cow-calf weaning weight ratio affect grazing distribution and supplement intake while winter grazing native rangeland. Total distance traveled did not differ between cows of differing weaning weight ratio history and differing body size ($P > 0.10$). However, time animals spent grazing per day did differ between cows that had a history of weaning > 50% of BW compared to cows that had a history of weaning < 50% of BW, with high WWR cows spending 23% more time grazing per day than low WWR cows ($P < 0.01$). Supplement intake did not statistically differ when reported as total kg consumed per day or on a per body weight basis and this may be due to high variability observed in supplement intake between cows. However, the added time high WWR cows spent grazing may have resulted in higher forage intake by these cows. As reported in the previous chapter, high WWR classified cows consumed more feed when feed intake was expressed on a g/kg BW basis. Therefore, the increased grazing time reported in high WWR cows may relate to the total mixed ration data reported in the previous chapter. Additionally, high WWR cows were 1.5 years younger than low WWR cows ($P < 0.01$). Thus, the cow-calf weaning weight ratio calculation appears to be bias towards younger animals and may incidentally discredit older cows that are still productive in the cowherd. As a result, the use of cow-calf weaning weight ratio as a selection metric for beef cows should be practiced with caution because of the potential increases in feed intake and a bias towards younger cows.

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Table 1. Cow and calf performance at the start and end of the trial period, lifetime averages, and at weaning prior to trial start when cows were classificed by weaning weight ratio and body weight (*n* = 10 cows per group; 45-d 2016 and 60-d 2017).

Item	High WWR[1]		Low WWR[2]		SE	WWR[3] *P*-value	BW[4] *P*-value	WWR*BW[5] *P*-value
	Light BW	Heavy BW	Light BW	Heavy BW				
Lifetime averages								
Cow BW, kg	499.8	542.0	590.3	634.5	4.26	<0.0001	<0.0001	0.810
Calf wt., kg	281.9	290.4	249.6	267.5	3.41	<0.0001	<0.001	0.169
WWR[6], %	56.4[a]	53.6[b]	42.3[c]	42.2[c]	0.53	<0.0001	0.006	0.013
Weaning								
Calf wean wt., kg	300.9	300.8	263.7	285.8	6.26	<0.0001	0.083	0.081
WWR[6], %	52.6	49.7	40.0	41.0	1.10	<0.0001	0.375	0.068
Trial start								
Cow BW, kg	572.2	610.2	661.9	697.4	9.72	<0.0001	<0.001	0.901
Cow BCS	5.4	5.5	5.7	5.7	0.11	0.023	0.744	0.328
Cow age, yr	5.6	6.5	7.2	7.9	0.48	0.003	0.121	0.835
Trial end								
Cow BW, kg	557.2	611.5	648.3	670.2	8.39	<0.0001	<0.0001	0.057
Cow BCS	5.2	5.2	5.4	5.6	0.16	0.112	0.526	0.526

[1] High WWR = high weaning weight ratio group
[2] Low WWR = low weaning weight ratio group
[3] WWR = main plot analysis associated with cow weaning weight ratio classification
[4] BW = sub plot analysis associated with cow body weight classification
[5] WWR*BW = interaction between whole and sub plot analysis associated with the interaction of weaning weight ratio and cow body weight
[6] WWR = weaning weight ratio (calf weaning weight/cow weight at weaning)
P-values were considered significant at ≤ 0.05 and were considered as a trend towards significance at > 0.05 but ≤ 0.1
[a,b,c] Means within a row with different superscripts differ ($P \leq 0.05$)

Table 2. Ingredients and nutrient composition (DM basis) of the commercially available, 36% crude protein, salt-limited, pelleted supplement provided *ad-libitum* to cows winter razing northern Montana rangeland (2016-2018).

Item	%
Ingredients	
Canola meal	35.0
Salt	25.0
Malt sprouts	15.0
Cane molasses	5.00
Dried distillers grain	5.00
Bentonite powder	4.00
Urea 281	3.45
Calcium carbonate	2.95
Wheat middlings	2.25
Trace mineral mix[1]	0.20
Talcum powder	0.10
Nutrient composition	
NEM, MJ/kg	8.41
DM	89.4
CP	36.2
NDF	19.5
ADF	13.3
TDN	81.0
Na	10.8
Ca	1.92
P	1.18
K	1.07
S	0.60
Mg	0.44

[1] Trace mineral mix: 854.0 ppm Fe, 249.0 ppm Zn, 143.0 ppm Mn, 67.0 ppm Cu, 5.7 ppm I, 2.1 ppm Se, 9.1 IU/kg vitamin A, 0.9 IU/kg vitamin D, 9.1 IU/kg vitamin E.

Table 3. The influence of cow weaning weight ratio and cow body weight classification on daily cow supplement intake (DM basis) and supplement intake behavior while winter grazing northern Montana rangeland (45-d 2016 and 60-d 2017).

	High WWR[1]		Low WWR[2]			WWR[3]	BW[4]	WWR*BW[5]
Item	Light BW	Heavy BW	Light BW	Heavy BW	SE	*P*-value	*P*-value	*P*-value
Intake								
Daily, kg	1.00	1.32	1.15	1.05	0.17	0.733	0.490	0.217
g/kg cow BW	1.74	2.18	1.73	1.51	0.27	0.215	0.687	0.223
Feeding bouts								
Number/day	3.3	4.4	3.8	3.1	0.55	0.401	0.734	0.109
Duration, min	1.18	1.32	1.38	1.50	0.11	0.077	0.245	0.945
Per day, min	4.21	5.99	5.09	4.47	0.76	0.673	0.447	0.116

[1] High WWR = high weaning weight ratio group

[2] Low WWR = low weaning weight ratio group

[3] WWR = main plot analysis associated with cow weaning weight ratio classification

[4] BW = sub plot analysis associated with cow body weight classification

[5] WWR*BW = interaction between whole and sub plot analysis associated with the interaction of weaning weight ratio and cow body weight

P-values were considered significant at ≤ 0.05 and were considered as a trend towards significance at > 0.05 but ≤ 0.1

Table 4. Total number of visits to supplement per day and time of day feeding events occurred, categorized by six, four-hour periods: early morning (0100-0500 h), morning (0500-0900 h), late morning (0900-1300 h), afternoon (1300-1700 h), evening (1700-2100 h), and night (2100-0100 h), by cows classified weaning weight ratio and body weight while winter grazing northern Montana rangeland (45-d 2016 and 60-d 2017).

	High WWR[1]		Low WWR[2]			WWR[3]	BW[4]	WWR*BW[5]
Item	Light BW	Heavy BW	Light BW	Heavy BW	SE	*P*-value	*P*-value	*P*-value
Time of day								
Early morning	4.4	4.5	3.5	2.5	1.91	0.442	0.820	0.770
Morning	138.0	104.9	145.5	105.1	83.8	0.962	0.664	0.966
Late morning	327.8	310.3	272.5	217.3	84.3	0.372	0.669	0.824
Afternoon	71.1	84.6	81.0	69.5	18.2	0.884	0.957	0.499
Evening	8.8	10.5	10.9	9.5	4.04	0.887	0.963	0.702
Night	10	9.4	9.9	6.6	3.09	0.638	0.536	0.675

[1] High WWR = high weaning weight ratio group
[2] Low WWR = low weaning weight ratio group
[3] WWR = main plot analysis associated with cow weaning weight ratio classification
[4] BW = sub plot analysis associated with cow body weight classification
[5] WWR*BW = interaction between whole and sub plot analysis associated with the interaction of weaning weight ratio and cow body weight
P-values were considered significant at ≤ 0.05 and were considered as a trend towards significance at > 0.05 but ≤ 0.1

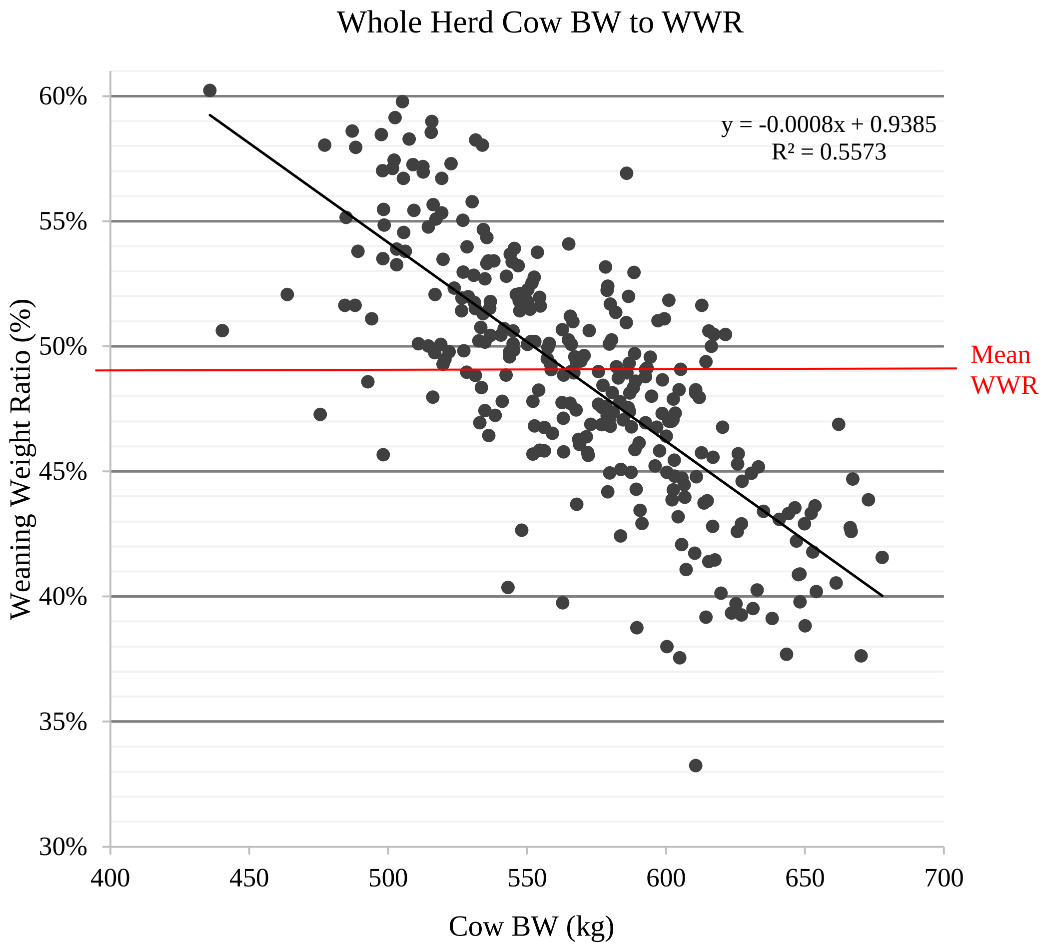

Figure 1. The relationship between cow body weight (BW) and weaning weight ratio (WWR) indicated in the Northern Agricultural Research Center Angus cow herd (n = 300; 2016-2018).

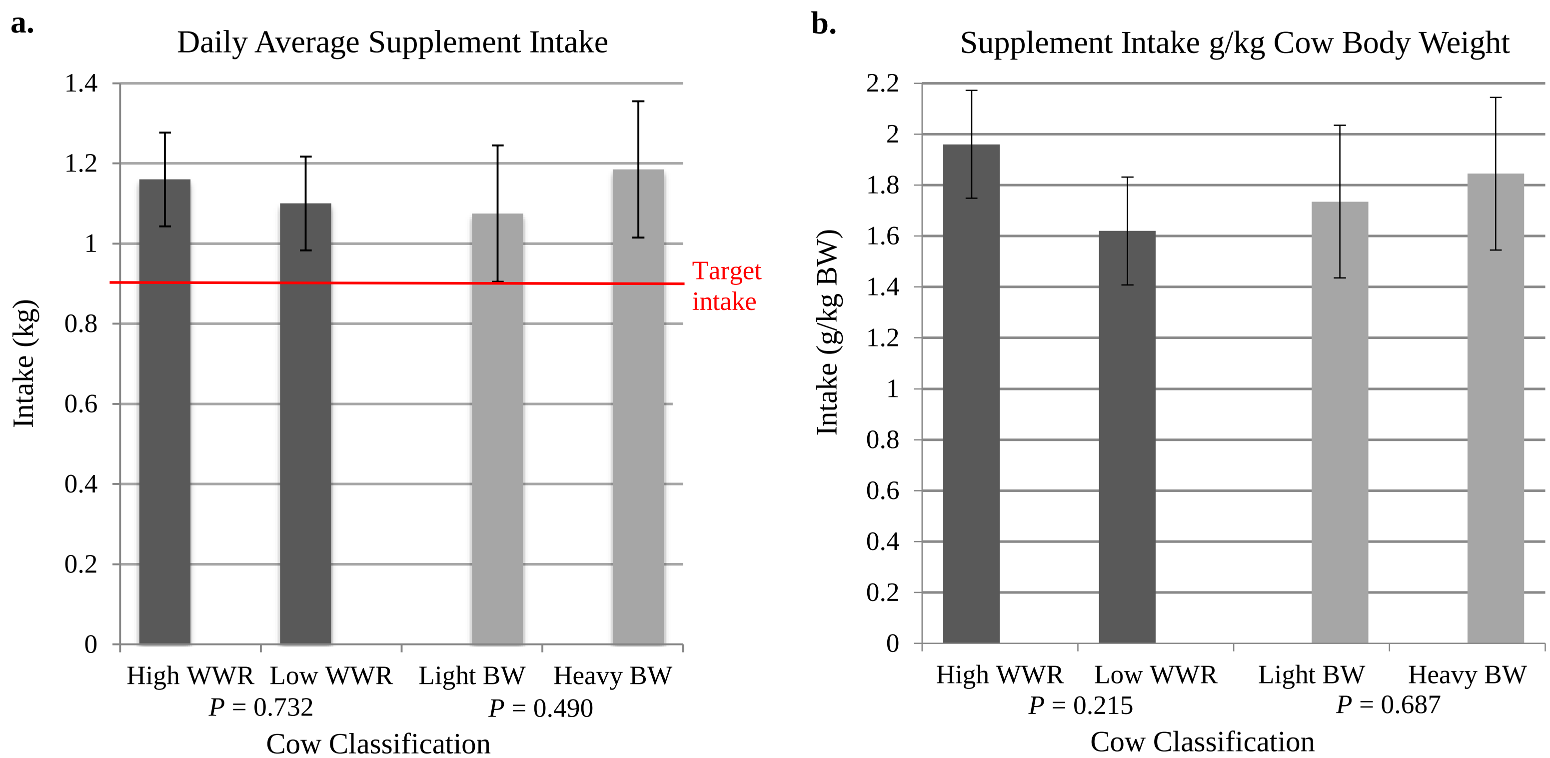

Figure 2. Average daily total supplement intake (kg; DM basis; part **a.**) and g supplement/kg BW (part **b.**) intake between cows classified as either high or low weaning weight ratio (WWR) or classified as light or heavy BW when these cows were provided *ad-libitum* access to a pelleted, 36% protein, salt limiting supplement while winter grazing northern Montana rangeland (45-d 2016 and 60-d 2017).

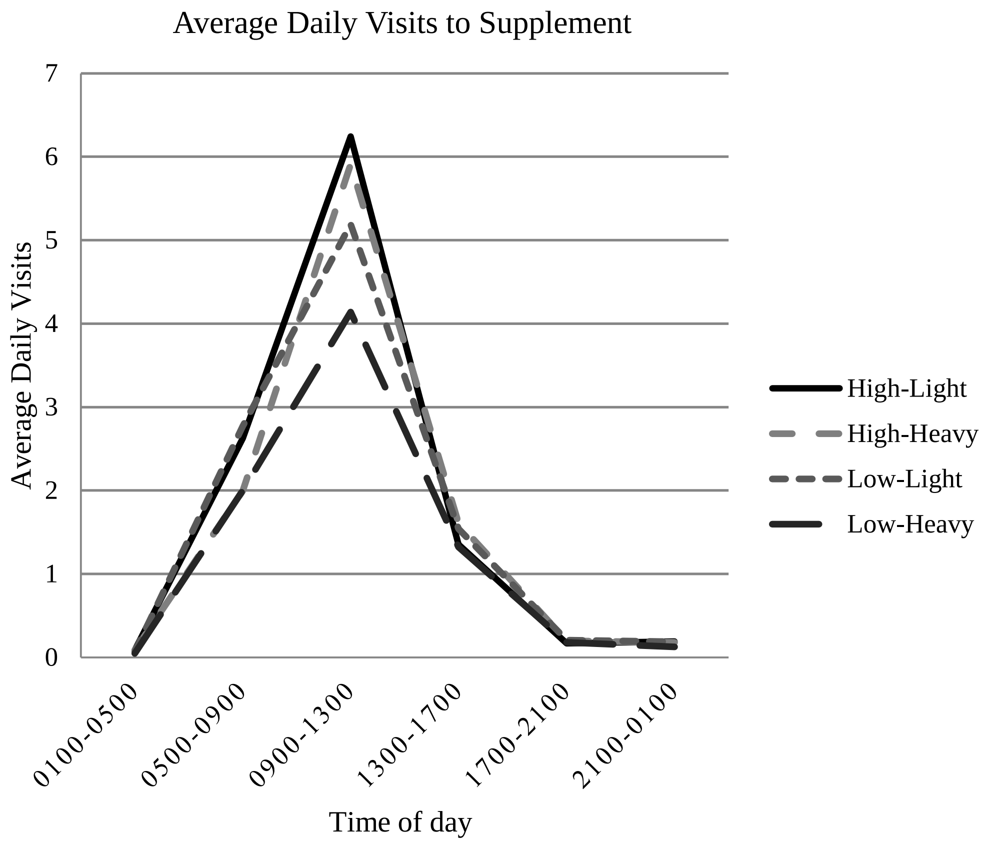

Figure 3. Time of day visits to supplement occurred, categorized by six, four-hour periods: early morning (0100-0500 h), morning (0500-0900 h), late morning (0900-1300 h), afternoon (1300-1700 h), evening (1700-2100 h), and night (2100-0100 h), by cows classified as either high or low weaning weight ratio (WWR) or classified as light or heavy body weight (BW) while winter grazing northern Montana rangeland (45-d 2016 and 60-d 2017).

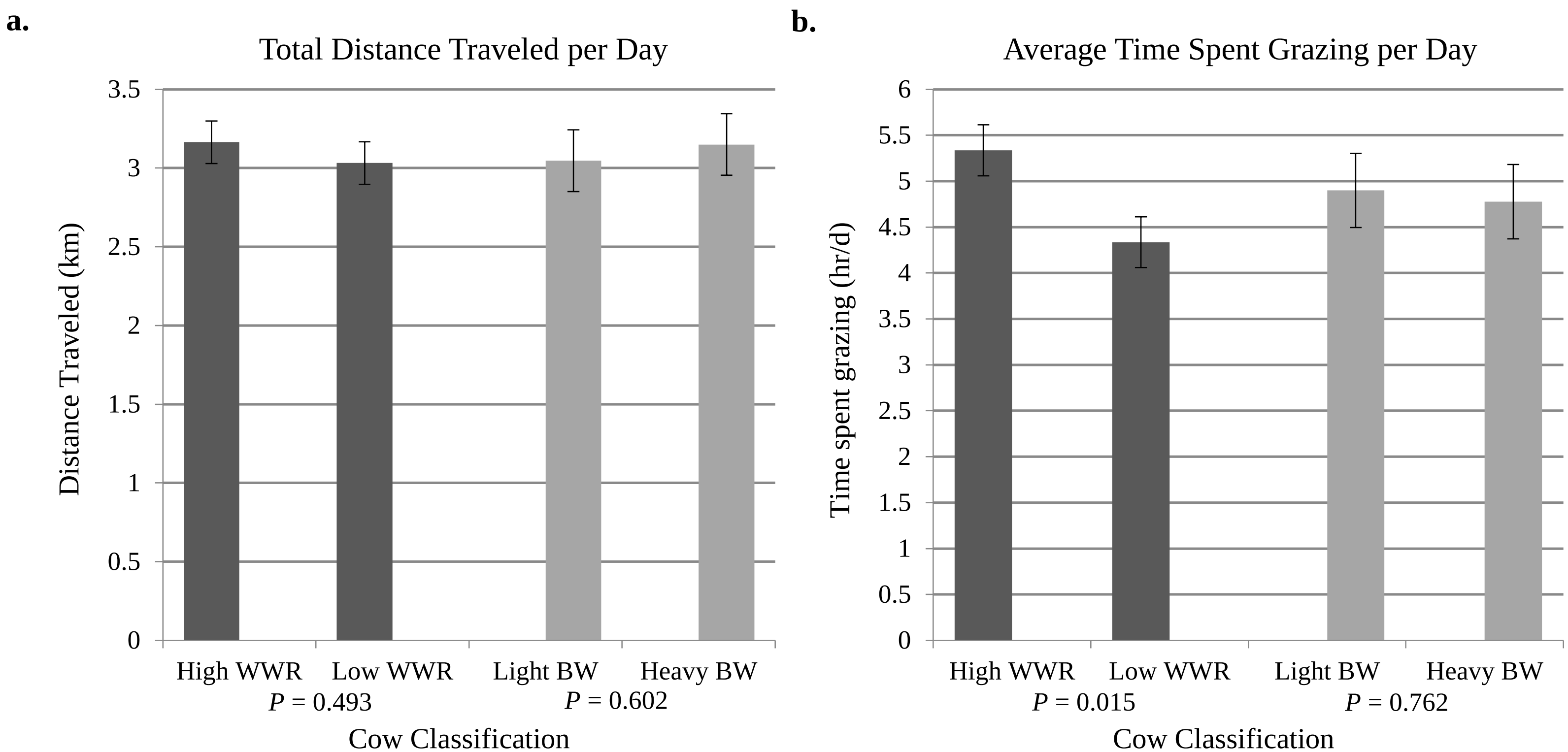

Figure 4. Distance traveled (km; part **a.**) and average time spent grazing per day (part **b.**) between cows classified as either high or low weaning weight ratio (WWR) or classified as light or heavy body weight (BW) while winter grazing northern Montana rangeland (45-d 2016 and 60-d 2017).

CHAPTER FIVE

CONCLUSIONS

Results from this research provide additional information on how cow size and cow-calf weaning weight ratio effect cow and production efficiency as related to cow feed and supplement intake, milk production, and grazing behavior. The objective of the first study was to evaluate how cow-calf weaning weight ratio and cow size influenced feed intake, milk production and composition, and subsequent calf pre-weaning performance. In this study, cows that had consistently weaned a greater percent of body weight were smaller ($P < 0.0001$) but consumed more feed ($P < 0.001$) and produced more milk ($P < 0.001$) when both feed intake and milk yield were expressed on a grams/kilogram BW basis. Thus indicating that small cows that are expected to wean heavy calves may not be as efficient as previous research has reported. Additionally, heavy cows tended to consume more feed per day than light cows when feed intake was expressed on a total kilograms per day basis ($P < 0.09$).

Overall for both years of the study, feeding behavior did not differ between high and low weaning weight ratio or light and heavy weight cows ($P > 0.10$). Cows that were classified as consistently weaning > 50% of body weight were younger than cows classified as consistently weaning < 50% body weight ($P < 0.01$). Cow weight alone did not influence cow milk yield ($P > 0.10$) and milk constituents did not differ between the cow groups ($P > 0.10$). The increased feed consumption and milk production of the high weaning weight ratio cows may explain why these animals are able to consistently wean a greater percent of their bodyweight than the heavy cows used for this research. Additionally, the use of cow-calf weaning weight ratio as a selection metric for beef cows may indirectly select for animals that produce more milk and have higher nutritional requirements. Furthermore, the use of cow-calf weaning weight ratio may be biased towards younger cows and disfavor older animals that are still productive in the cowherd.

The objective of the second study was to assess how cow-calf weaning weight ratio and cow bodyweight effected grazing behavior and supplement consumption in a winter grazing environment. In this study, cow weights and weaning weight ratio were different between the four cow classification groups ($P < 0.01$). Even though cow weights differed between the four cow groups, supplement intake did not differ between the cow groups ($P > 0.10$). Additionally, supplement intake behavior did not differ between the cow groups ($P > 0.10$). Most visits to supplement occurred between 0900 and 1300 h, which is comparable to results reported in other research. The results from this research contradict the research hypothesis that high weaning weight ratio classified cows would have higher supplement intake than low weaning weight ratio cows and that heavy body weight cows would consume more than light body weight cows. Based on previous research, it was expected that as cow weight increased, supplement intake would increase, especially when represented on a per body weight basis.

Total distance traveled per day also did not differ between cows of differing weaning weight ratio history and differing body size ($P > 0.10$). However, time cows spent grazing per day differed between cows that had a history of weaning > 50% of body weight compared to cows that had a history of weaning < 50% of body weight ($P < 0.02$). High weaning weight ratio cows spent 23% more time grazing per day than low weaning weight ratio cows. Because of the increased grazing time, forage intake by high weaning weight ratio classified cows was possibly greater than that of low weaning weight ratio cows if high and low weaning weight ratio cows have similar intake rates while grazing. These results further the understanding of cattle grazing behavior and resource use in winter native rangeland systems and thus adds to the discussion of what type of cow is more suited to western rangeland based production environments. Other recent research has indicated that small cows are better suited to western rangeland environments. However, data from this research indicates while although small cows may have a slight advantage in these production environments, when producer expect heavy calf weaning weights, small cows may not be that superior when compared with large cows. In conclusion, the use of cow-calf weaning weight ratio as a method for selecting animals within a cowherd should be practiced with some caution because of the potential increases in feed intake, milk production, bias to younger cows, and no difference in winter supplement intake. Results from this research also indicate that cow size alone is not an adequate indicator of cow efficiency. This research indicated that both the use of cow-calf weaning weight ratio and cow size may have inherent limitations that restrict their usefulness as applied selection metrics for cow efficiency in western rangeland based production systems.

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