EVALUATION OF THE RELATIONSHIP BETWEEN SIZE, FEEDING BEHAVIOR, AND FEED EFFICIENCY IN BEEF CATTLE

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Macie Kaye Mosher

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Program:
Animal Sciences

May 2022

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Dr. Kendall Swanson
Chair

Dr. Lauren Hanna

Dr. Bryon Parman

Approved:

July 5, 2022 — Date

Dr. Guillermo Scaglia — Department Chair

ABSTRACT

Feed efficiency in cow-calf operations can be influenced by multiple environmental and physiological factors. The current study examined the association between body size (weight, frame score, and volume), linear body measurements, and feeding behavior with different measures of feed efficiency in multiparous lactating beef cows. Prediction models for dry matter intake in cows using linear body measurements were also developed. Our findings indicate that body size measurements and feeding behavior may influence measures of efficiency. The inclusion of body measurements in prediction models of intake may serve as accurate and feasible methods for estimating intake of cows on farm. The associations between the traits measured may provide insight for further producing models to measure and predict efficiency traits that are easily accessible on farm. Body measurements and feeding behavior are two traits that should be accounted for when considering efficiency and selection criteria for cow-calf operations.

ACKNOWLEDGMENTS

I would like to start by acknowledging my advisor, Dr. Kendall Swanson. Thank you for pushing me to be a better student, researcher, and writer. I am very grateful for your encouragement, guidance, and endless support during the past two years. I also thank my advisory committee, Dr. Lauren Hanna and Dr. Bryon Parman. I am grateful for the chance to learn from you both. Dr. Hanna, thank you for your patience with me and the learning process of SAS and all your words of wisdom and encouragement with my writing.

Furthermore, I would like to thank the faculty members I had the opportunity to work with during my time at NDSU, Dr. Carl Dahlen, Dr. Gerald Stokka, Dr. Joel Caton, Dr. Mattia Gunkelman, Dr. Carrie Hammer, Dr. Eric Berg, and all of the Animal Science faculty members. Your expertise and dedication to your work has been a great contribution to my research and academic development. Special thanks to Dr. Mustapha Yusuf, who was an immense help with the regression portion of my research analysis. I have learned so much from you and am very grateful for all of your help. Additionally, I thank the staff at the Beef Cattle Research Complex, Sarah Underdahl and Megan Engeseth, and several undergraduates, who took great care of the animals and provided a helping hand during my project when needed.

I need to thank all my lab mates past and present: Dr. Jessica Reiners, Tommy Winders, and Kafi Mia; my office mates and Hultz family; and my partner in crime during graduate school, Layla King. Thank you all for your help during my project, support during these past two years, and for the many shared laughs. Layla, thank you for always being there with me whether it be for words of encouragement, a pair of fresh eyes on a paper, or a Starbucks run, I am forever grateful for your friendship.

I could not have gotten to where I am today without the love and endless support of my close family and friends. My mom, Karen, who has always encouraged me to follow my dreams and has been there by my side every step of the way. My father, Jay, I have come to cherish our early morning talks and am very blessed to have a dad who will support me through anything. My siblings Kiali and Brock, who while they may not always understand what or why I am doing it, always support me anyways in my endeavors and are there for whatever I need. My cousin, Jes Hart who might as well be a sister, and her family, Justin, Braelynn, Zoie, and Jaxon, thank you all for your support, love, and embracing me these past two years in all of your holidays and family events, I don't know what I would do without you. Hannah Bailey, who sparked my interest in graduate school and has been encouraging me every step of the way. Madison Pemberton, you have been with me through all of the ups and downs from undergrad and through graduate school, you have always been there for me for words of support, laughter, or a virtual shoulder to cry on and I am blessed to have a friend like you. Clayton Henningsen and his family: Harvey, Pam, Wyatt, Jocie, and Paige. From the start you treated me like your own and quickly became a second family, I am very grateful for all of your support during this journey and am honored to have you as my North Dakota family. Clayton, the love and support you have provided me through this experience has been nothing short of a blessing. Thank you for being my safe place where I could escape the stress, always pushing me to achieve what I think I can't, and of course your willingness to talk cows. I love you all!

DEDICATION

This thesis is written in dedication to my grandparents, Reginald and Anne Constance Holt, thank you for instilling in me the passion for animals and the importance of chasing my dreams. Your endless support and encouragement have been a blessing and I am forever grateful. Grandma, while you are not here with us today, I know you and our Lord are always looking out for me and for that I am truly blessed. Joshua 1:9

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LIST OF ABBREVIATIONS

ABW ....Average body weight

ADF...Acid detergent fiber

ADG...Average daily gain

AWC ....Average weight change

BL ....Body length

BW...Body weight

Ca ....Calcium

CADG ....Calf average daily gain

CP...Crude protein

CWW ....Calf weaning weight

CWWP ....CWW as a percent of cow body weight

DM ....Dry matter

DMI..Dry matter intake

DMIP..DMI as a percent of cow body weight

FCR ....Feed conversion ratio

FG ....Flank girth

FS ....Frame score

G:F ....Gain to feed ratio

GE ....Gross efficiency

HG..Heart girth

HH..Hip height

HW...Hip width

K...Ridge regression parameter

MPD...Meals per day

NDF..Neutral detergent fiber

NE_m ....Net energy for maintenance

OLS ....Ordinary least square regression

P ....Phosphorus

RFI ....Residual feed intake

RG ....Residual gain

SBW..Shrunk body weight

TPM ....Time per meal

TSEPD ....Time spent eating per day

VIF ....Variance inflation factor

VOL ....Body volume

VPD...Visits per day

WC ....Weight change

WW...Weaning weight

1. INTRODUCTION AND LITERATURE REVIEW

1.1. Introduction

Cattle have been an essential part to enhancing human life for several generations. In North America, the origin of cattle is linked to Christopher Columbus in the 15th Century (Wilson et al., 1965). From use for labor to use for feed purposes, beef cattle have been a key player to agriculture in the United States. Cattle have been an essential tool, used as a source of wealth, food, clothing, and draft power, having since evolved to the symbiotic relationship they have today with humans (Field, 2018). As human population and demands increase, as do the need for cattle. Cattle numbers either need to increase or beef production from one animal needs to increase, thus larger cattle. With this, it is no surprise that cattle size has increased from what it once was. In 1970, the average carcass weight was approximately 278 kg, increased to approximately 288 kg by 1980, increased even more to approximately 340 kg in 2004, and has continued that trend so that the average carcass weight in 2020 was reported to be approximately 376 kg (Field, 2018; USDA, 2020).

The knowledge surrounding beef cattle and how to maximize production has advanced over the years, allowing the beef industry to develop into the highly specialized system it is today. The industry is made up of different operations, known as sectors, designed to meet specific objectives, all contributing to complete a typical beef cycle (Figure 1.1) (Field, 2018; NASEM, 2016). The industry is composed of three main sectors: cow-calf, grower/backgrounder, and finisher/feedlot. Each sector is dependent on the others and the success of one greatly impacts the other. Therefore, for the beef cycle to function properly, it is imperative that each sector is running efficiently and meeting production goals (Field, 2018; NASEM, 2016).

Figure 1.1. Typical beef production cycle.
Adapted from Field (2018).

The typical beef cycle begins with the cow-calf producer. The main objectives for a cow-calf producer are to 1.) maintain a healthy breeding herd, through feeding on pasture, forages, or a mixture of both, and to 2.) maintain the herd through parturition, through weaning, and into breeding again where under ideal conditions a cow is producing one calf a year (Field, 2018). The cow-calf producer is responsible for raising calves to or through weaning and growing them to an ideal weaning weight (WW) to ensure they are ready to move onto the next phase (NASEM, 2016). In cow-calf operations, calves typically graze alongside their dams for up to 6 to 9 months of age, weighing on average around 250 kg (Lalman et al., 2019). At or shortly after the time of weaning, calves will move into the next production stage and move to the backgrounding phase or kept back as a replacement. Calves kept as a replacement are those chosen by the producer that are deemed a good fit and believed will benefit the operation (NASEM, 2016).

Calves are often sold at a sale or directly from farm. From there they are used to the buyer's discretion, which can include as a backgrounder, finisher, or as a replacement heifer (NASEM, 2016). During the background stage, producers feed forage-based diets or graze the calves with the goal of adding frame and weight onto the weaned calves, preparing them for the feedlot phase. Typically, this phase lasts until the calves are yearlings, approximately 12 to 20 months of age (Field, 2018). At the end of this phase, calves typically weigh between 300 to 400 kg and will then be prepared to enter the next phase of the cycle (NASEM, 2016).

The feedlot phase is the next step after backgrounding, however, larger calves may move directly to the feedlot from weaning (Field, 2018). Feedlots consist of confinement feeding operations where the primary diet is a finishing ration to provide high energy. The primary goal during this phase is to maximize growth rate, maintain health, and feed efficiency to ensure carcass quality and maximize profits. A typical goal in this phase is for calves to gain anywhere from 1.2 kg to 1.8 kg a day, often lasting 100 to 200 days (Field, 2018; NASEM, 2016).

A common goal among all sectors is to be as efficient as possible. In cow-calf operations it is important to understand what influences production and profitability as well as methods to improve it. While there is much that goes into each section of the beef industry and the overall agricultural sector, the following topics of this review will focus more so on the cow-calf industry, specifically on efficiency and factors that affect efficiency as well as possible routes to improve efficiency in a cow-calf production.

1.2. Feed efficiency

The term feed efficiency resulted from the need of an index that included feed intake and production. Feed efficiency in the beef industry is a complex topic. The general definition of efficiency is the ratio of output to input (Dickerson, 1970), but can be adapted as it is applied to a specific production setting/goal (Notter, 2002). As the human population and food demands increase, so does the importance of efficiency in livestock productions to ensure demands are met. This can be done through more cattle or more efficient cattle allowing producers to utilize the same resources while producing greater outputs (Kress et al., 1969; USDA, 2021).

Feed cost is an important factor in cow-calf herds accounting for approximately 65 to 85% of overall feed costs and needs immense consideration (Montaño-Bermudez et al., 1990). An increased cost of feed relative to production in an operation decreases the overall profits seen by the producer. To maintain a highly profitable operation, producers need to optimize feed efficiency and production. Feed efficiency is an important and manageable factor. A producer that can maintain feed efficiency while increasing outputs will have an advantage compared to competition. It is critical to understand the factors that influence feed efficiency. Common factors influencing efficiency include: age, sex, breed type, diet, production level, environment and temperature, and other management and environmental variables (NASEM, 2016). Understanding what traits have an effect on feed efficiency for each operation allows for a better understanding of feed utilization.

Research has discovered many factors that influence efficiency. Most feed efficiency studies have focused on production traits such as growth. Studies have shown that there is genetic variation in feed efficiency which suggests that it is heritable. This knowledge leads to the potential of being able to reduce costs through selection for improved efficiency. Feed efficiency has been a growing topic for quite some time with much speculation on the importance of different traits in regulating efficiency (Arthur et al., 2004).

1.3. Measures of efficiency

Feed efficiency is a common factor considered in all sectors of the beef industry, but how efficiency is measured and reported is highly dependent on the sector. Efficiency is not a directly measurable trait and is measured through inputs and outputs (Archer et al., 1999; Dickerson, 1970; Koch et al., 1963). Profitability is a function of outputs and inputs and reducing feed costs is a common avenue to increase profits. There may be potential for selection to improve efficiency through measuring feed intake of growing animals and using relationships that likely exist in efficiency between growing and mature animals (Archer et al., 1999).

An important part of accurately defining efficiency is having a clear understanding of all the biological and economical inputs and outputs. A growing animal's efficiency will be measured differently from that of a mature animal. Therefore, there is a need for different measures based on the operation goals and many measures have been used and are ideal for different production systems (Notter, 2002; Swanson and Miller, 2008). The ideal efficiency measure for an operation will depend on the sector and section of the beef cycle, where the more prioritized on the sector, the more defined the measure (Klosterman, 1972).

Further understanding efficiency will help with the identification of traits that are less invasive, cheaper, and are easier to measure. Additionally, increased knowledge may provide the potential to reduce costs through selection of efficient cattle (Arthur et al., 2004). Dickerson (1970) introduced a general definition for efficiency as the ratio of total costs to total animal product, where the animal product will change based on the production site. Some common measures of efficiency for cattle are gross efficiency, residual gain, residual feed intake, and cow-calf efficiency. It is important to consider limitations to each measure as these limitations need to be considered for determination of what measure of efficiency is best to utilize for the operation/question at hand (Arthur et al., 2004).

1.3.1. Gross efficiency

Gross efficiency (GE) is a common measure often utilized in feedlots. Gross efficiency is defined as the ratio of dry matter intake (DMI) to gain (live weight), which is further broken down to gain to feed (G:F) (Archer et al., 1999). The inverse of gain to feed is known as the feed conversion ratio (FCR). Gross efficiency provides the potential to be a selection tool to increase performance during growing and finishing stages, however it may not be representative of future efficiency once in mature stages (Arthur et al., 2001). Gross efficiency is often used as a satisfactory index and is used to monitor feedlot cattle performance (Schenkel et al., 2004). The GE measure brings potential for selection of animals with improved GE and may help to improve profitability. An animal is considered to be more feed efficient than its counterparts if it has a higher G:F ratio. A higher G:F indicates a higher amount of gain per unit of required feed. As with any method, this measure can come with implications. When used as a selection tool, it is possible that this measure could affect overall cow efficiency due to selecting for improved gross efficiency, leading to an increase in mature size in turn increasing feed costs (Archer et al., 1999; Swanson and Miller, 2008).

1.3.2. Residual gain

An alternative to measuring feed utilization is residual gain (RG). Residual gain was proposed for cattle by Koch et al. (1963) and measures the difference between actual and predicted gain. Actual gain is defined as ADG in growing animals. Predicted gain is generated through measures such as regression analysis and prediction models. Predicted gain considers body weight, feed intake, body condition score, and other traits. With this measurement, an animal would be defined efficient with a higher RG value, indicating that the animal gained more live body weight then predicted. Selecting for gain can be effective and may contribute to increased efficiency however is only suitable in growing animals and wouldn't be an effective measure with mature animals (Crowley et al., 2010; Koch et al., 1963).

1.3.3. Residual feed intake

Residual feed intake (RFI) is the difference between the actual and expected intake of an animal, most often utilized in growing animals. The expected intake is an estimate calculated considering many factors, such as the animals' body weight (Koch et al., 1963). Residual feed intake is represented as residuals from regressions of intake, and regression models can be developed through methods such as least square regression (Berry and Crowley, 2013). The RFI measure has become increasingly popular, due to its accounting of production traits and potential to be used in selection programs. The measure has been found to be a repeatable measure however is best utilized in the growing animal, with a more negative RFI considered ideal (Arthur et al., 2001; Kelly et al., 2010).

Residual feed intake is a popular tool used to assess efficiency in multiple groups such as yearling heifers (Shaffer et al., 2011), bulls, (Crowley et al., 2010), and steers (Nkrumah et al., 2004). Residual feed intake is used to identify animals which ate different than expected, with efficient animals having a lower or negative RFI (Archer et al., 1999). It has been suggested that RFI may be a useful selection tool for which animals will be efficient in mature stages (Shaffer et al., 2011) but more research is needed to confirm these findings.

1.3.4. Cow-calf efficiency

Many efficiency measures focus on the growing animal. Although efficiency assigned at a growing age may reflect efficiency later in mature stages, there is a need for actual measures of efficiency at the mature stage (Kress et al., 1969). Cow-calf efficiency is a common approach to measuring efficiency in beef herds providing a measure of production efficiency (Jenkins and Ferrell, 1994). The cow-calf measure may provide a better measure of overall production efficiency compared to other biological measures as it is predicted to capture phenotypic variation of feed utilization in beef herds (Archer et al., 1999; Jenkins and Ferrell, 1994).

Total feed intake is measured for the dam and calf throughout a production cycle, often the time of weaning to the next. Cow-calf efficiency is defined as the relation of the weight of the calf weaned (output) to the amount of feed consumed and weight of cow (input) to express total efficiency (Archer et al., 1999; Jenkins and Ferrell, 1994). In cow-calf settings, the goal of the cow is to produce progeny of an ideal weight by the time of weaning (Jenkins and Ferrel, 2002). The weight of the calves is often characterized as a ratio to the weight of the dam or the amount of feed consumed by the dam during lactation (Notter, 2002). Income in cow-calf herds is calculated from costs of inputs and returns from pairs through the selling of calves at or near weaning (Long et al., 1975), increasing income occurs when improving costs received from outputs or reducing input costs.

A common issue with cow/calf efficiency is that the calves' performance isn't fully represented as intake is only measured up until weaning rather than following the calf to slaughter. Additionally, the measurements involved often require large amounts of time, effort, and are costly. Further, the income from sale of cull cows is often not considered when measuring efficiency (Archer et al., 1999; Swanson and Miller, 2008). The cow-calf measure has some limitations and thus a measure that could include an accurate prediction of intake, and be paired with weaning weight may serve as a more representative measure of cow efficiency (Notter, 2002).

1.4. Maintenance requirements and feed efficiency

Understanding the base nutrient requirements of an individual animal is an important aspect to understanding and maximizing efficiency. To achieve optimum feed efficiency an animal's requirements must be met in order to ensure the animal is able to reach maximum production. In cow-calf settings, if a cows' nutritional needs are not met, it is likely that milk production and calf gain will suffer, resulting in reduced revenue as well as decreasing the likelihood of rebreeding (Hall et al., 2009). Maintenance energy represents the nutrients required to keep the animal alive, maintain important metabolic processes of breathing, digestion, thermoregulation, tissue repair, and maintain body weight/composition (Hall et al., 2009; NASEM, 2016).

Maintenance requirements of an individual animal can influence feed efficiency as those with higher requirements for maintenance will likely need to consume more feed for the same outputs as other animals (Herd and Arthur, 2009). Maintenance requirements are related to the animal's size (Klosterman et al., 1968), however, their size is not the only factor influencing requirements. Maintenance requirements are very important in cow herds representing around 60 – 65% of total feed requirements (Arthur et al., 2004). Net energy for maintenance requirements is 0.077 Mcal/SBW$^{0.75}$ (NASEM, 2016), with SBW representing shrunk body weight. The requirement for net energy for maintenance, NEm, is not a constant and varies depending on a number of factors including physiological state and environment (DiCostanzo et al., 1990). Requirements will change based on stage of production. For example, during lactation NEm requirements are greater compared to gestation (NASEM, 2016)

The ability to anticipate needs at different production phases is important to meet production goals and maintaining low feed costs (Hall et al., 2009). Understanding the factors and variation within the maintenance requirements can help to give an understanding of how to improve efficiency (Ferrell and Jenkins, 1985; Montaño-Bermudez et al., 1990).

1.5. Sources of variation in feed efficiency

It is important to identify different factors that can affect the animal's ability to convert feed to weight gain (Jenkins and Ferrel, 2002). Phenotypic variation exists among individual cattle in terms of feed use in the growing and mature stage (Archer et al., 1999). This variation can cause differences in utilization of feed. Understanding which traits affect the variation provides the potential to better understand what impacts efficiency and the potential to decrease feed intake without affecting performance (Archer et al., 1999).

Understanding within herd variation for feed efficiency is important tool for determining net profits (Koch et al., 1963). Understanding relationships between measurable traits and relationships with feed efficiency can help to identify traits that can be used to predict efficiency (Koch et al., 1963). Variation likely differs in growing and mature animals. Variation in utilization of feed has been found to exist in weaning and yearling cattle (Arthur et al., 2001), adult cattle (Archer et al., 1999; DiCostanzo et al., 1990), finishing heifers (Kelly et al., 2010), and steers (Nkrumah et al., 2006).

It can be difficult to fully understand the factors contributing to the variation, even more so due to the relationship between efficiency and production traits. Variation in feed utilization is influenced by processes such as body composition and organ mass (DiCostanzo et al., 1990), intake, activity (Herd and Arthur, 2009), body weight, and metabolism (Herd and Arthur, 2009; Kelly et al., 2010; Nkrumah et al., 2006).

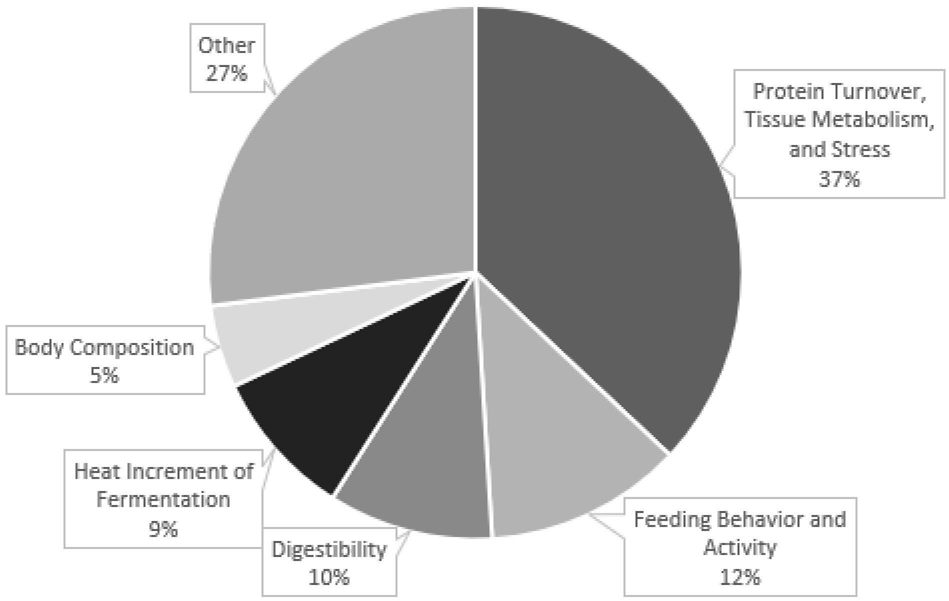

Figure 1.2. Variation in residual feed intake.
Contributions of physiological mechanisms to variation in residual feed intake. Adapted from (Richardson and Herd, 2004).

Richardson and Herd (2004) suggested that 73% of variation in RFI measures of feed efficiency can be explained by different metabolic processes. These processes include protein turnover/tissue metabolism and stress, feeding behaviors, digestibility, heat increment of fermentation, and body composition (Figure 1.2). An increased knowledge of the physiological variation in feed utilization may provide insight into alternative and more attainable measures (Archer et al., 1999). There are multiple processes that may have a direct effect on feed efficiency. The factors associated with variance in feed efficiency discussed below will focus on the factors evaluated in the following chapters (Chapters 2 and 3).

1.5.1. Body size

Body size has both economical and biological effects on efficiency in beef cattle in growing and mature stages. Due to its' effects on maturing rate, weight, and maintenance requirements through various ages, cow size is phenotypically important. Genetically, cow size has effects on growth and maturing rates of progeny (Cartwright, 1979). Biological variables have been identified as important factors in efficiency and in cow-calf operations body weight and weaning weight have been noted to play an integral role (Thompson et al., 2020). The determination of optimal cattle size for efficiency has been a common goal of researchers. Further understanding the relationship between size and efficiency will aid in the determination of the ideal animal and size for different production settings (Holmes, 1973; Klosterman, 1972).

The variability of cattle size may provide a useful resource allowing potential to better understand and improve efficiency (Cartwright, 1979). Selection based off body size may provide the potential to reduce the variation observed in efficiency measures (Yerex et al., 1988). Cow weight can have a direct effect on intake and nutrient requirements, thus proper consideration of the relationship between inputs and outputs need to occur prior to determination of ideal size (Holmes, 1973; Lemenager et al., 1980). The relationship between size and efficiency is complex and determining optimal cow size is complicated as different management systems will have different requirements/types of cattle (Cartwright, 1979; Klosterman, 1972). Differences in nutrient requirements for growth or maintenance contribute to differences in efficiency in mature animals (Long et al., 1975).

Kress et al. (1969) proposed the possibility that a larger heifer may be more efficient later in their production life. Frame size (FS) in heifers is related to different measures of efficiency. Studies show that heifers with a smaller FS eat a smaller amount of DMI and may be more efficient on pastures with limiting resources (Vargas Jurado et al., 2015). Taylor et al. (2008) found heifer FS to be related with subsequent reproductive performance and performance of calves. Heifers with larger FS had greater weaning weights and higher ADG of calves in their first parity, however moderate cows had higher gains in following parities.

There has been controversy that smaller size cows are more efficient (Thompson et al., 2020; Yerex et al., 1988), however others have suggested that larger cows may be more efficient (Morris and Wilton, 1976). It has been argued that larger cows are more efficient as it is predicted they may produce more milk and thus produce larger calves at the time of weaning and may be more profitable as milk yield increases with size (Holmes, 1973; Kress et al., 1969; Morris and Wilton, 1976). Also favorable to the larger mature sizes, bigger cows will bring in a larger income at the time of culling (Doye and Lalman, 2011). Smaller cows have been predicted to be more efficient as it is often postulated they have lower nutrient requirements (Long et al., 1975), eat less overall, and may increase weaning weight ratio (Thompson et al., 2020; Walker, et al., 2015). As cow size increase it is likely that associated income costs will increase as well to account for the increase in feed demands (Long et al., 1975; Walker, et al., 2015). Additionally, larger animals will require greater amounts of supplemental feed. With smaller cows requiring less nutrients, there may be potential to increase stocking rates on pasture (Doye and Lalman, 2011; Long et al., 1975). This brings up the question of where the benefits of increased cow size begin to be outweighed by the associated inputs (Doye and Lalman, 2011)

Size effects efficiency of the cow-calf pair. There is a notable positive relationship between dam weight and calf weaning and yearling weight (Morris and Wilton, 1976). This brings the imperative factor of profits seen and which size is most profitable (Cartwright, 1979). It has been suggested that once expenses are considered, larger cows may be less efficient on a profit standpoint (Doye and Lalman, 2011).

Also to be considered, an increase in mature size may come with the potential of increased calf birth weights and related calving difficulty. Larger mature size may come with the consequence of greater the risk for dystocia and other calving problems, if the increase in mature size results in too large of an increase in calf birth weight (Cartwright, 1979; Holmes, 1973). Body weight (BW) at maturity and calf birth weight have been noted to be genetically correlated which calving problems and can have effects on reproductive performance through increased risk of dystocia, longer time to rebreeding, etc. (Jenkins and Ferrel, 2002).

Research has suggested that there are associations with differing phenotypes of efficiency and differences in animal size characterized by linear body measurements. It has been suggested that linear body measurements might give a clearer understanding or measure of skeletal growth compared to other measures (Holmes, 1973). Calf weaning weight as a percentage of cow body weight has been a common method to examine efficiency among different sizes in beef herds (Thompson et al., 2020), with a trend for a negative relationship between the ratio and cow girths and body weight (Scasta et al., 2015). Positive relationships with body weight and DMI with hip width, body length, heart and middle girth exist in mature pregnant cattle (Wood et al., 2014). Heart girth has been identified as a parameter highly correlated with body weight and thus a possible predictor of animal size (Heinrichs et al., 2007). The ratio of weight to height at the withers were found to have a correlation with maintenance requirements of mature cows, suggesting a negative relationship with measures of efficiency (Klosterman et al., 1968; Kress et al., 1969). Body measurements have the potential of allowing easier access as these measurements can be taken at a low cost with a generic tape measure while still providing accurate and consistent results (Lukuyu et al., 2016).

1.5.2. Feeding behavior

Behavioral habits relating to feed can alter an animals' physical activity and thus influence the amount of energy expended and ultimately the utilization of feed (Kelly et al., 2010). Eating behavior can have a direct effect on the animal's physical activity which effects energy use and requirements. As noted previously, Richardson and Herd (2004), noted that approximately 12% of the variation in residual feed intake may be accounted for by feeding behavior and activity. Feeding behavior assessment may be one tool available to identify an animal's performance (Montanholi et al., 2010). Associations with feeding behavior and efficiency has been evaluated in steers (Golden et al., 2008; Kelly et al., 2010; Nkrumah et al., 2006), heifers (Kelly et al., 2010), mature dairy (Xi et al., 2016), and beef cows (Fitzsimons et al., 2014). Feed efficient cattle, measured through RFI, tend to engage in less feeding activity (Golden et al., 2008; Kelly et al., 2010), eat at a slower rate (Kelly et al., 2010; Montanholi et al., 2010), eat smaller meals (Montanholi et al., 2010), and eat less overall (Xi et al., 2016). The observed relationships with feeding patterns provide the opportunity of including feeding behavior traits into efficiency models and indirectly assessing feed efficiency.

1.6. Predicting intake

Intake represents the largest input cost in cow-calf and other production settings making it an important factor to focus on developing prediction models. Tools to identify which cows are more efficient can help to improve overall efficiency and profitability. Assessing feed intake to give insight into which cows are more efficient is an available tool (Klosterman, 1972). Having an effective model to predict DMI can aid producers in evaluating measures of efficiency to help select which animals to keep and which to cull (Archer et al., 1999; Yerex et al., 1988). If a measure is able to explain an adequate proportion of variance of an individual animal's intake, producers may be able to reduce feed waste and time associated with monitoring for efficiency. There is a need for accurate measures of assessing feed intake on pasture on an individual basis (Arthur et al., 2004).

Intake can be estimated through monitoring of body weight, use of the RFI method, feeding behavior, use of thermal imaging, and marker techniques (Koch et al., 1963; Wright et al., 2019). Current models have limitations due to cost, time, and labor requirements. Additionally, certain models don't measure the intake on an individual basis (Herd et al., 2003; Lukuyu et al., 2016). There is a need for further development of cost-effective methods for identification of which animals are feed efficient (Arthur et al., 2004). Residual feed intake is a common method to assess the difference between predicted and actual intake, however, focuses on the growing animal. There is a need for efficient methods to estimate intake in the mature animal (Koch et al., 1963).

Body weight has been found to be an accurate representation of requirements such as DMI, however the inclusion of other variables may provide greater accuracy (Lemenager et al., 1980). Body measurements have been identified to be correlated with varying efficiency characteristics including intake and may serve as predictive measures for DMI (Enevoldsen and Kristensen, 1997). Body measurements are an alternative to predict intake as they are relatively easy to collect and are representative of BW (Heinrichs et al., 1992). Body measurements have been evaluated to serve as predictors for several characteristics including BW of cows (Enevoldsen and Kristensen, 1997; Lukuyu et al., 2016), weaning weight, and yearling weight (Gunawan and Jakaria, 2010). Positive relationships between cow girths, width at pins, and rump width with DMI have been reported (Williams et al., 2019).

Models to predict DMI with body measurements may be done through regression modelling, however there could be complications using these methods. Multicollinearity is a common issue with developing models with multiple parameters that are related. Multicollinearity is the occurrence of high correlation between two or more explanatory variables in a prediction model (Bonate, 1999). Correlation within the covariates in a model can affect the precision of parameter estimates and inaccurate representation of the predicted variable (Bonate, 1999; Shieh and Fouladi, 2003). There are different ways to assess and combat the issue of collinearity, however emphasis will be placed on the measure used in this thesis (Chapter 2). Variance inflation factors (VIF) are one tool for monitoring and detecting collinearity in models. The VIF gives a representation of the multicollinearity present between individual parameters, with a value over 10 indicating high multicollinearity (O'Brien, 2007). If multicollinearity is an issue, ridge regression is one approach commonly utilized (Bonate, 1999; Hoerl and Kennard, 1970). Ridge regression was introduced as an alternative approach for when high amounts of multicollinearity are present among parameters included in a model (Hoerl and Kennard, 1970). Ridge regression has been used to address the issue of collinearity in models for predicting performance in crossbred calves (Pimentel et al., 2007), weaning weights (Bergmann and Hohenboken, 1995), and milk quality traits (Frizzarin et al., 2021).

1.7. Research hypothesis and objectives

It is hypothesized that animal size and feeding behaviors are related with efficiency traits in cow-calf operations. Animal size characterized through body measurements, weight, frame score, and volume are all associated with cow-calf traits. Thus, there may be potential for body measurements and other size characteristics to represent the variation in efficiency traits such as DMI and WW. The evaluation of body measurements, size characteristics, and feeding behaviors may provide additional options for measuring and predicting efficiency. Additionally, body measurements may serve as an alternative and cheaper model for predicting DMI.

To evaluate the hypothesis an experiment was conducted with the objectives to:

1.) Evaluate relationships between cow size characterized by average body weight (ABW), volume (VOL), and frame score (FS) with efficiency traits such as DMI and WW (Chapter 2);

2.) Examine the relationship between feeding behaviors and measures of efficiency in cow-calf herds (Chapter 2);

3.) Evaluate the potential of body measurements to serve as predictor models for DMI of cows in cow-calf herds (Chapter 3).

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2. EVALUATING RELATIONSHIPS AMONG MEASURES OF EFFICIENCY WITH COW SIZE AND FEEDING BEHAVIORS IN LACTATING MULTIPAROUS CROSSBRED BEEF CATTLE

2.1. Introduction

Having an efficient cow-calf operation is a vital part to reaching production goals and maximizing profits. As feed costs represent one of the largest expenses in any cattle operation, understanding feed efficiency and how to improve it is an essential component. Efficiency has a general definition of the ratio of total costs to total products, inputs:outputs (Dickerson, 1970). The definition of efficiency gets more complex as it gets applied to a specific operation. Both the inputs and outputs play important roles in efficiency. To achieve optimal efficiency, it is important to understand the outputs and inputs that affect the operation and how they interact with each other. In a cow-calf production setting, the calf is the output as opposed to the growth of the animal itself. As calves are often sold at weaning, achieving a high weaning weight often results in increased revenue. Costs that can be overlooked are those associated with the production of the calf, specifically feed intake of the dam, as this is often the largest cost within a cow-calf operation (Klosterman, 1972; Wood et al., 2014).

While many new discoveries have been made about feed efficiency over the past years, there is still much to be investigated to better understand feed efficiency in beef cattle. Much of the research on feed efficiency has been centered around growing animals (Wood et al., 2014) rather than mature cows. Determining optimal cow size has been a common goal among researchers for quite some time (Klosterman, 1972). A common perception is that larger cows will wean larger calves, which has in turn lead to larger cows being more favorable. While it is perceived that larger cows are more efficient, after all outputs and inputs are considered, it is often questioned if smaller cows are in fact more efficient when it comes to weaning a calf and profitability (Doye and Lalman, 2011; Klosterman, 1972). This has resulted in increased interest to investigate the effect of cow size on efficiency. Improving efficiency would not only bring with it the potential of decreasing nutrient excretion and losses, but also would result in an increase in profitability for producers (Swanson and Miller, 2008). A more defined understanding of feed efficiency may equip farmers with more information when choosing efficient breeding females (Wood et al., 2014).

Understanding what affects feed efficiency first begins at understanding how to measure feed efficiency. Several methods have been identified, including gross efficiency, maintenance efficiency, and residual feed intake. A common measure of efficiency for mature cows is cow/calf efficiency, the ratio of the weight of the calf weaned to the amount of feed consumed by the cow (Archer et al., 1999; Swanson and Miller, 2008). Recent studies on factors influencing feed efficiency have found that body size, linear body measures, metabolic blood markers, and eating behaviors are all likely important contributors to feed efficiency (Walker, et al., 2015; Wood et al., 2014; Xi et al., 2016). While there are currently multiple measures and tools available to assess cow characteristics to determine efficiency, these are not always readily available to farmers either due to time, labor, and/or cost. Linear body measurements are one alternative to measure efficiency. Body measurements have the potential of allowing easier access as these measurements can be taken at a low cost with a generic tape measure while still providing accurate and consistent results (Lukuyu et al., 2016). Research has been done to further investigate the relationship with body measurements by identifying which measurements are best to identify, such as heart girth, which has been identified as a parameter highly correlated with body weight and thus a possible predictor of animal size (Heinrichs et al., 2007).

The objectives of this study were to 1.) evaluate relationships between cow size characterized by average body weight (ABW), volume (VOL), and frame score (FS) and efficiency traits (feed intake of the cow and calf weaning weight) in cow-calf operations, 2.) evaluate the relationship between feeding behavior and measures of efficiency, and 3.) investigate the potential of developing prediction equations for different efficiency measures with body size characteristics. We hypothesized that animal size characterized through body measurements, weight, frame score, and volume are associated with different cow-calf efficiency traits and that there is potential for prediction equations based on cow size for efficiency traits such as dry matter intake (DMI) and calf weaning weight (CWW).

2.2. Materials and methods

2.2.1. Animals, experimental conditions, and dietary treatments

All procedures were approved by the North Dakota State University Institutional Animal Care and Use Committee. During the summer of 2020, 60 crossbred mature cows (ages 5 to 6 years) weighing 662 ± 93.3 kg and their calves (aged 2 weeks or greater) were housed at the North Dakota State University (NDSU) Beef Cattle Research Center (BCRC). All cows in the current study were previously involved in a study that included the extraction of blood and DNA samples to determine their genomic breed (Bhowmik, 2021). Prior to and following the study, cows and calves resided at NDSU’s Dickinson Research Extension Center (DREC) in Dickinson, North Dakota. Cows and calves arrived two weeks before the start date of the experiment to allow the animals to train and acclimate to the feeders. The trial began on July 20, 2020 and lasted 64 days. Cows had a range of frame scores assigned as heifers (FS: 2.34 to 7.42), which was calculated based on the Beef Improvement Federation (BIF) equation for heifers measured at their hip height between 5 and 24 months of age. Hip height at weaning age (approximately

6.5 months) was used to calculate frame score. Cows and their calves were divided into groups of 15 pairs across 4 pens. Access to a separate pen for calves was shared between 2 sets of 2 pens where only calves could access to consume grass hay as they aged (Figure 2.1).

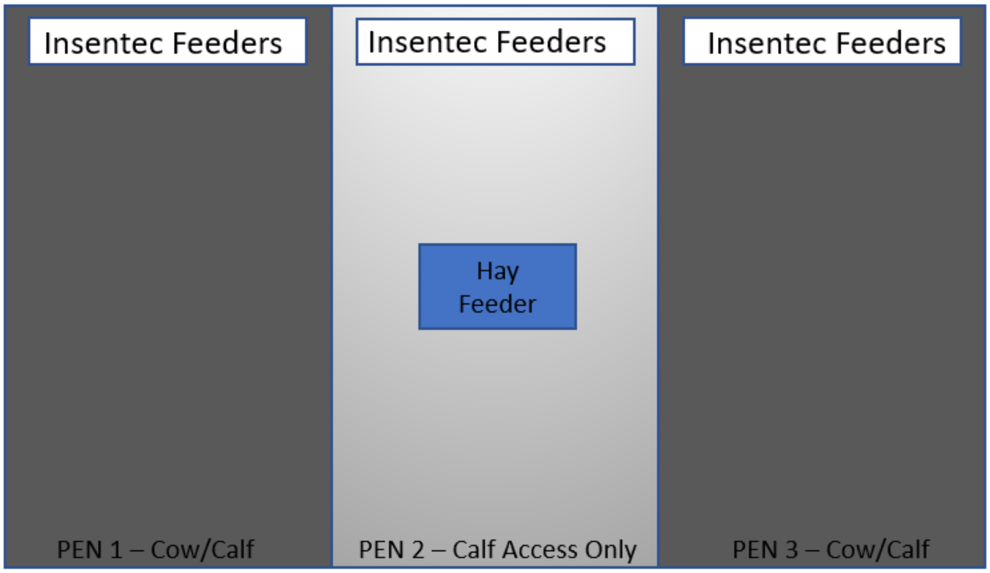

Figure 2.1. Cow and calf pen set up at the Beef Cattle Research Center.
A Cow/Calf pen consisted of 15 pairs with a subsequent pen where only calves could access to be provided grass hay.

Cows and calves had free access to an outdoor yard as well as an indoor feeding system with ad libitum access. All cows received a radio frequency identification (RFID) tag placed in their right ear which allowed recording of feed intake as well as behavioral assessments. Behavioral assessments included meals per day (MPD), time spent eating per day (TSEPD), visits per day (VPD), and average time spent per meal (TPM). Cows were fed a forage-based diet (Table 2.1), and feeding behavior was monitored throughout the feeding period via the Insentec feeding systems (Hokofarm Group B.V., Marknesse, Netherlands).

2.2.2. Productive performance and feed efficiency assessments

Individual feed intake was determined using the Insentec feeding system. Following the end of the experiment, feed intake data were summarized per day. Intake data was filtered to exclude outliers (negative numbers below -0.2 kg/feeding event or highly unlikely numbers above 20 kg/feeding event) and days missed due to mechanical problems. Efficiency was characterized by each cows intake in kg (DMI) and as a percent of average body weight (DMIP), CWW, and the ratio of calf weaning weight to cow average body weight (CWWP). Feeding behavior traits were calculated and summarized as number of bunk visits and meals per day, eating time in minutes (per visit, meal, and day), and eating rate (grams of dry matter per visit and meal). A visit to the feed bunk was defined as each time the feeder detected an animal. To minimize risk of mislabeling a meal, a meal was defined as eating periods including short breaks separated by intervals (less than 7 minutes per break). Following the experiment, data were summarized as the average for each event for each individual animal per day over the feeding period.

2.2.3. Feed analysis

Similar to Swanson et al. (2014), diet samples were collected weekly and samples were analyzed at the Nutrition Laboratory at NDSU. Samples were dried in a 55°C oven and ground to pass a 1-mm screen. Samples were analyzed for dry matter (DM), ash, N (Kjehldahl method), Ca, and P by standard procedures (AOAC, 1990). The samples were also analyzed for NDF (assayed with heat stable and amylase and sodium sulfate and expressed inclusive of residual ash) and ADF (expressed inclusive of residual ash) concentration by the method of Roberston and Van Soest (1981) using a fiber analyzer (Ankom Technology Corp., Fairport, NY). Percent crude protein (CP) was calculated by multiply N concentration x 6.25 (Table 2.1).

Table 2.1. Ingredient and nutrient composition for total mixed ration in multiparous cows.

Item	% DM
Ingredient[1]	
Hay	68.5
Corn Silage	15.0
DDGS[2]	11.5
Fine Ground Corn	4.72
Salt	0.20
Vitamin Premix	0.01
Trace Mineral Premix	0.05
Monensin Premix	0.02
Chemical Composition	
DM	71.43
CP	11.29
NDF	63.18
ADF	36.34
Ca	0.56
P	0.29

[1]Diet components as percent of total diet in a dry matter (DM) basis.
[2]Dried distiller's grains with solubles.

2.2.4. Body parameter measures

Body weights were collected for two consecutive days at the beginning and end of the experiment, and every 14 days throughout the experiment. Following the end of the trial, cows and calves returned to the DREC location where calf weights were collected at the time of weaning. Body measurements were collected at the beginning and end of the experiment. Body measurements were recorded similar to as described by Wood et al. (2014). Body measurements were collected using a generic fabric measuring tape. The measuring tape was used to measure body length, hip width (HW), and girth at the heart, mid, and flank. Hip height (HH) was recorded using a livestock height measuring stick. Body length (BL) was defined as the distance from the point of the shoulder to the end of the rump. Hip height was defined as the distance from ground to the base of the tail head. Heart girth (HG) was defined as the circumference around the midsection caudal to shoulder. Mid-girth (MG) was defined as the circumference around the middle, over the navel. Flank girth (FG) was defined as the circumference around the middle at the flank and cranially to the udder. Body measurements were used to calculate body volume of each cow by using the BL, HG, MG, and FG. Body volume was calculated using the equation for the volume of a barrel: $\frac{\pi H(r^2+2R^2)}{3}$ with H representing body length, r^2 representing the radius of the end girths (average of heart and flank girth) and R^2 representing the radius of the middle girth.

2.2.5. Statistical analysis

Data were analyzed using SAS 9.4 (SAS Institute, Inc., Cary, NC). Pearson correlation coefficients were analyzed in Proc GLM for each variable with measures of feed efficiency. Descriptive statistics were calculated for body size and measures of efficiency. Pearson correlations were analyzed using Proc Corr. Correlations were examined between the dependent variables (feed efficiency descriptors) and independent variables (body characteristics, feeding behaviors, etc.) along with the significance of the correlation coefficients. After examining the correlation coefficients, Proc Reg was used to evaluate individual relationships between efficiency descriptors and body characteristics prior to developing regression equations. Proc GLM was utilized to create regression equations for dry matter intake prediction.

2.3. Results

Descriptive statistics for body size characteristics and measures of efficiency are presented in Table 2.2. Genomic data were available to identify specific breed compositions of the cows for improved breed grouping. Breed counts and descriptive statistics for ABW and FS were generated for each breed (Table 2.3). A cow was denoted as a specific breed if it had more than 51% of that breed present and was denoted mixed if not one breed made up 51% or greater.

Relationships between individual breeds were not examined as that is beyond the scope of this project.

Table 2.2. Descriptive statistics for ABW, VOL, FS, and measures of efficiency of crossbred mature cows.

item[1]	Mean ± SD	Median	Minimum	Maximum
ABW, kg	662 ± 93.3	673	429	814
VOL, cm^3	628 ± 96.4	644	407	857
FS	5.17 ± 1.38	5.47	2.34	7.42
WC, kg	14.1 ± 20.49	12.5	-35.2	68.04
ADG, kg/d	0.22 ± 0.32	0.19	-0.55	1.06
DMI, kg/d	16.2 ± 2.38	16.2	10.2	22.5
DMIP, %	2.45 ± 0.2	2.45	1.81	2.95
CWW, kg	258 ± 35.2	254	181	332
CWWP, %	39.00 ± 6.00	40.00	28.00	50.00
CADG, kg/d	1.07 ± 0.15	1.05	0.73	1.35

[1]Descriptive statistics of variables representing body size: average body weight (ABW), volume (VOL), and frame score (FS), and measures of cow efficiency: weight change (WC), average weight change per day (ADG), dry matter intake (DMI) and as percent of body weight (DMIP), calf weaning weight (CWW) and as a percent of cow body weight (CWWP), and calf average daily gain (CADG). Sample size for all measures was 60.

Table 2.3. Breed counts and descriptive statistics per breed for average body weight (ABW) and frame score (FS).

Breed[1]	N	ABW Mean ± SD	ABW Range	FS Mean ± SD	FS Range
AA	4	484 ± 40.7	429 – 523	3.17 ± 0.62	2.34 – 3.84
ANR	28	656 ± 82.5	529 – 814	5.04 ± 1.26	2.83 – 7.25
SH	10	713 ± 62.1	611 – 797	6.16 ± 0.60	5.37 – 7.00
SM	5	765 ± 32.3	709 – 790	6.28 ± 0.83	5.21 – 7.42
MIX	13	649 ± 80.1	505 – 735	4.91 ± 1.55	2.47 – 6.51

[1]Breeds included: American Aberdeen (AA), Angus/Red Angus (ANR), Shorthorn (SH), Simmental (SM), and mixed breed (MIX). Cows with no single breed greater than 51% were categorized as MIX.

2.3.1. Body size relationships

Dry matter intake was positively correlated ($P < 0.001$) with ABW, VOL, and FS (r = 0.84, 0.80, 0.74, respectively). Dry matter intake measured as a percent of cow body weight (DMIP) was negatively correlated ($P = 0.05$) with ABW ($r = -0.25$) and had a tendency for negative correlation ($P = 0.09$) with VOL ($r = -0.22$). Calf weaning weight was significantly correlated ($P \leq 0.01$) with ABW, VOL, and FS (r = 0.47, 0.37, 0.44, respectively). When measured as a percent of cow body weight, calf weaning weight (CWWP) was negatively correlated ($P < 0.001$) with ABW, VOL, and FS (r = -0.59, -0.62, -0.49, respectively). Calf average daily gain (CADG) was positively correlated ($P < 0.01$) with ABW, VOL, and FS (r = 0.46, 0.34, 0.42, respectively) (Table 2.4).

Table 2.4. Pearson correlation coefficients between ABW, VOL, and FS and measures of efficiency.[1]

	ABW	VOL	FS
DMI	0.839; <0.001	0.803; <0.001	0.743; <0.001
DMIP	-0.25; 0.05	-0.223; 0.09	-0.209; 0.11
CWW	0.471; 0.0001	0.37; 0.0036	0.436; 0.0005
CWWP	-0.587; <0.0001	-0.617; <0.001	-0.491; <0.001
CADG	0.456; 0.0003	0.344; 0.007	0.415; 0.001

[1]Pearson correlation coefficients are followed by P-value (correlations; P-value) between average body weight (ABW), volume (VOL), and frame score (FS) with measures of efficiency: dry matter intake (DMI), dry matter intake as percent of body weight (DMIP), calf weaning weight (CWW), calf weaning weight as a percent of cow body weight (CWWP), and calf average daily gain (CADG).

2.3.2. Regression analysis

To determine if body measurements and other size characteristics were associated with efficiency traits, several regression equations were examined to analyze individual relationships between body size characteristics and measures of efficiency. Regressions were analyzed on efficiency measures: DMI, DMIP, WC, CWW, and CWWP. Individual relationships were analyzed between each efficiency variable and several different body measurements: ABW, VOL, HH, BL, HG, MG, FG, and HW.

Absolute DMI (kg/d) was positively associated ($P < 0.0001$) with all body measurement parameters (Table 2.5). The variables with the largest F-values were ABW, VOL, and FG, all having values over 100, further validating significance of the relationships. Each relationship had R^2 and R_a^2 that were similar in value, with five of the eight parameters having a R_a^2 value greater than 0.5. Dry matter intake (% of intake) was negatively associated ($P > 0.05$) with ABW, HG, MG, and HW and tended ($P = 0.09$) to be negatively associated with VOL (Table 2.5). Generally, the F-values and R_a^2 were less for DMIP than observed for DMI. Weight change (WC) was not associated with any of the parameters (Table 2.5). Calf weaning weight (kg) was positively associated ($P < 0.02$) with ABW ($R_a^2 = 0.21$), VOL ($R_a^2 = 0.12$), HH ($R_a^2 = 0.20$), BL ($R_a^2 = 0.11$), HG ($R_a^2 = 0.10$), MG ($R_a^2 = 0.08$), and FG ($R_a^2 = 0.15$) (Table 2.5). Calf weaning weight (% of cow weight) was negatively associated ($P < 0.0001$) with ABW ($R_a^2 = 0.33$), VOL ($R_a^2 = 0.37$), HH ($R_a^2 = 0.21$), BL ($R_a^2 = 0.24$), HG ($R_a^2 = 0.36$), MG ($R_a^2 = 0.36$), FG ($R_a^2 = 0.26$), and HW ($R_a^2 = 0.45$) (Table 2.5).

2.3.3. Feeding behavior

Meals per day was negatively correlated ($P < 0.001$) with FS, ABW, VOL, DMI (r = -0.46; -0.60; -0.53; -0.55 respectively), positively correlated ($P = 0.0002$) with CWWP (r = 0.48) and a tendency for negative correlation ($P = 0.97$) with CWW (r = -0.22). Time spent eating per day was positively correlated ($P < 0.05$) with FS, ABW, DMI, DMIP, CWW, and CADG (r = 0.30; 0.27; 0.48; 0.41; 0.34; 0.34 respectively). Time spent eating per day had a tendency for positive correlation (P = 0.06; 0.08) with VOL and WC (r = 0.25; 0.24). Average visits per day was negatively correlated ($P = 0.015$) with VOL (r = -0.32) and tended to be negatively correlated (P = 0.067; 0.055) with FS and ABW (r = -0.25; -0.26). Average time per meal was positively correlated ($P < 0.05$) with FS, ABW, VOL, DMI, DMIP, CWW, and CADG (r = 0.44; 0.47; 0.43; 0.61; 0.29; 0.31; 0.30 respectively) and tended to be correlated ($P = 0.068$) with CWWP (r = -0.24) (Table 2.6).

Table 2.5. Parameter estimates ± SD and associated statistics of the regression analysis for differing predicted efficiency characteristic measures.[1]

Y	X	Intercept	X Estimate	P-Value	F-Value	R^2	R_a^2
DMI							
	ABW	2.01 ± 1.22	0.02 ± 0.002	<0.0001	138	0.70	0.70
	VOL	3.74 ± 1.23	0.02 ± 0.002	<0.0001	105	0.64	0.64
	HH	-17.3 ± 3.63	0.25 ± 0.027	<0.0001	85.3	0.60	0.59
	BL	-8.36 ± 3.16	0.18 ± 0.02	<0.0001	60.5	0.51	0.50
	HG	-15.5 ± 4.57	0.15 ± 0.02	<0.0001	47.9	0.45	0.44
	MG	-14.4 ± 4.07	0.12 ± 0.02	<0.0001	56.8	0.50	0.49
	FG	-23.5 ± 3.91	0.17 ± 0.02	<0.0001	103	0.64	0.63
	HW	-4.65 ± 3.88	0.37 ± 0.07	<0.0001	28.9	0.33	0.32
DMIP							
	ABW	2.81 ± 0.19	-0.0006 ± 0.0003	0.05	3.88	0.06	0.05
	VOL	2.75 ± 0.17	-0.0005 ± 0.0003	0.09	3.04	0.05	0.03
	HH	2.96 ± 0.48	-0.0038 ± 0.0036	0.3	1.11	0.019	0.0019
	BL	2.89 ± 0.38	-0.003 ± 0.003	0.25	1.33	0.02	0.01
	HG	4.01 ± 0.49	-0.007 ± 0.002	0.002	10.2	0.15	0.14
	MG	3.44 ± 0.47	-0.004 ± 0.002	0.04	4.41	0.07	0.06
	FG	2.8 ± 0.56	-0.002 ± 0.002	0.54	0.39	0.007	-0.01
	HW	3.45 ± 0.39	-0.018 ± 0.007	0.01	6.76	0.10	0.09
WC							
	ABW	12 ± 19.3	0.003 ± 0.029	0.91	0.01	0.0002	-0.017
	VOL	5.93 ± 17.7	0.01 ± 0.027	0.64	0.22	0.004	-0.01
	HH	20.2 ± 49.05	-0.05 ± 0.37	0.90	0.02	0.0003	-0.02
	BL	16.2 ± 38.9	-0.02 ± .28	0.96	0.00	0.00	-0.02
	HG	7.62 ± 53.2	0.03 ± 0.25	0.90	0.01	0.0003	-0.02
	MG	-17.6 ± 49.1	0.13 ± 0.2	0.52	0.42	0.007	-0.01
	FG	-23.2 ± 55.9	0.16 ± 0.24	0.51	0.45	0.008	-0.01
	HW	-8.21 ± 40.8	0.39 ± 0.72	0.59	0.30	0.005	-0.01
CWW							
	ABW	140 ± 29.2	0.18 ± 0.04	0.0001	16.5	0.22	0.21
	VOL	173 ± 28.3	0.14 ± 0.04	0.0036	9.21	0.14	0.12
	HH	-39.9 ± 74.7	2.22 ± 0.56	0.0002	15.9	0.22	0.2
	BL	79.7 ± 62.7	1.29 ± 0.45	0.006	8.11	0.12	0.11
	HG	26 ± 86.3	1.11 ± 0.41	0.009	7.23	0.11	0.1
	MG	60.8 ± 80.7	0.8 ± 0.33	0.018	5.97	0.09	0.08
	FG	-37.4 ± 88.3	1.29 ± 0.38	0.001	11.19	0.16	0.15
	HW	191 ± 69.8	1.18 ± 1.23	0.34	0.92	0.02	-0.001
CWWP							
	ABW	0.63 ± 0.04	-0.0004 ± 0.00006	<0.0001	30.5	0.34	0.33
	VOL	0.62 ± 0.04	-0.0004 ± 0.00006	<0.0001	35.7	0.38	0.37
	HH	0.88 ± 0.12	-0.0036 ± 0.0009	<0.0001	16.6	0.22	0.21
	BL	0.81 ± 0.09	-0.003 ± 0.0007	<0.0001	20.0	0.26	0.24
	HG	1.08 ± 0.12	-0.003 ± 0.0006	<0.0001	34.4	0.37	0.36
	MG	1.02 ±0.11	-0.003 ± 0.0004	<0.0001	33.5	0.37	0.36
	FG	1.01 ± 0.13	-0.003 ± 0.0006	<0.0001	21.2	0.27	0.26
	HW	0.98 ± 0.08	-0.01 ± 0.002	<0.0001	49.0	0.46	0.45

[1]Estimates for predicted measures: dry matter intake (DMI), dry matter intake expressed as a percent of cow body weight (DMIP), weight change (WC), calf weaning weight (CWW), and calf weaning weight expressed as a percent of cow body weight (CWWP) with different body measure parameters. Parameters include average body weight (ABW), volume (VOL), hip height (HH), body length (BL), heart girth (HG), middle girth (MG), flank girth (FG), and hip width (HW). Associated statistics, P-value, F-value, R^2, and R_a^2 are shown.

Table 2.6. Correlations (and P-values) between feeding behavior and body size and measures of efficiency.[1]

	MPD	TSEPD	VPD	TPM
FS	-0.457; 0.0004	0.297; 0.025	-0.245; 0.067	0.443; 0.0006
ABW	-0.60; <0.0001	0.267; 0.045	-0.256; 0.055	0.472;0.0002
VOL	-0.532; <0.0001	0.248;0.062	-0.32;0.015	0.434;0.0008
WC	0.135; 0.316	0.235;0.078	-0.151; 0.26	0.121;0.369
DMI	-0.551; <0.0001	0.479;0.0002	-0.134;0.32	0.6128; <0.0001
DMIP	0.043; 0.751	0.412;0.0015	0.208;0.12	0.289; 0.03
CWW	-0.222; 0.097	0.339; 0.001	-0.129; 0.34	0.305; 0.021
CWWP	0.476; 0.0002	0.017; 0.90	0.153; 0.257	-0.243; 0.0681
CADG	-0.203; 0.129	0.337; 0.01	-0.094; 0.485	0.295; 0.026

[1]Correlations between feeding behaviors: meals per day (MPD), time spent eating per day (TSEPD), visits per day (VPD) and average time per meal (TPM) and body sizes and measures of efficiency. Frame score (FS), average body weight (ABW), and body volume (VOL) represented body size. Measures of efficiency included weight change (WC), dry matter intake in kilograms (DMI) and as a percent of cow body weight (DMIP), calf weaning weight in kilograms (CWW), as a percent of cow body weight (CWWP) and calf average daily gain (CADG). P-values follow each correlation (correlations; P-value).

2.3.4. Predicting dry matter intake

Multiple regression models were formed to predict DMI with differing combinations of ABW, average weight change (AWC), and CWW (Table 2.7). The first model included only ABW (R^2 = 0.70), then one other parameter was added to the model, either AWC (R^2 = 0.71) or CWW (R^2 = 0.74). The final model contained ABW, AWC and CWW (R^2 = 0.75). All models were significant (P < 0.0001).

Table 2.7. Parameter estimates ± SD and associated statistics of the regression analysis for predicted DMI adjusted for weight change and calf weaning weight.[1]

	Parameter estimate					
Y	Intercept	ABW	AWC	CWW	R^2	P-value
DMI	2.01 ± 1.22	0.021 ± 0.002	-	-	0.70	<0.0001
DMI adj. for AWC	1.90 ± 1.22	0.021 ± 0.002	0.62 ± 0.53	-	0.71	<0.0001
DMI adj. for CWW	-0.086 ± 1.35	0.019 ± 0.002	-	0.015 ± 0.005	0.74	<0.0001
DMI adj. for AWC & CWW	-0.33 ± 1.35	0.019 ± 0.002	0.759 ± 0.5	0.016 ± 0.005	0.75	<0.0001

[1]Parameter estimates along with standard deviation values for different equations to predict cow dry matter intake (DMI). DMI was analyzed with average body weight (ABW) as a predictor and further adjusted (adj.) for average weight change (AWC) and calf weaning weight (CWW).

2.4. Discussion

2.4.1. Body size relationships

Body size was related to multiple measures of efficiency. Compared to smaller cows, larger cows (ABW, VOL, and FS) consumed a greater amount of feed. However, as a percent of body weight, smaller cows consumed a greater amount of feed. In relation to calf weight, larger cows weaned calves with larger weaning weights compared to calves from smaller cows. On the contrary, smaller cows weaned a greater percent of body weight compared to larger cows. Additionally, larger cows (ABW, VOL, and FS) had calves that had greater average daily gain.

Associations between CWW and DMI with ABW and FS were similar to findings in past research. Thompson et al. (2020) and Scasta et al. (2015) also observed negative relationships between cow body weight and calf weaning weight as a proportion of body weight. Furthermore, similar to the current study, Walker et al. (2015) found that DMI was greater for heavier cows compared to lighter cows. Also, similar to this current study, Taylor et al. (2008) examined the relationship between FS assigned as heifers and cow performance. They reported that heifers with greater FS tended to produce calves with greater weaning weights both as a heifer and with subsequent parities. Also observed was a trend for CADG to increase with larger framed cows (Taylor et al., 2008).

2.4.2. Regression analysis

Compared to the other efficiency measures analyzed, dry matter intake when expressed as kg (DMI), had the most significant relationships with the body characteristic parameters. Similar to Wood et al. (2014), the current study found positive relationships between body measurements: BL, HW, and FG, with DMI, while Williams et al. (2019) also observed positive relationships between cow girths, width at pins, and rump width with DMI. Two of the strongest relationships with DMI were ABW and VOL, suggesting that DMI is highly related to cow size. When leaving VOL out and focusing on body measurements, all body measurements showed strong relationships with DMI; however, FG had the strongest relationship as it had a higher F-value and R^2 value compared to the other measurements, suggesting that flank girth may be an influencer of DMI.

Cow weight change was not associated with body measurements suggesting that using body parameters may not be an appropriate approach to predict weight change. However, this may differ from growing cattle, as mature cows are not growing, but rather maintaining BW. While DMIP was associated with some of the body parameters, it's prediction may be more difficult using the body measurement variables used in the current experiment because R^2 values were relatively low indicating that much of the variation was not explained by the prediction equations.

Although associations were observed between CWW and all body parameters aside from HW, the relationships were relatively low indicating body measurements may not be the most accurate predictor for CWW. Similar to the findings in Thompson et al. (2020), the regression analyses in the current experiment showed a negative relationship between CWWP and ABW, agreeing with the correlation results, suggesting that larger cows wean calves weighing less on a percentage basis than smaller cows. While CWWP was associated with all parameters tested, most of the relationships had low R^2 values, indicating they might not serve as the best fit for predictive measures alone. Hip width had a moderately strong relationship with CWWP indicated by the F-value (58.1) and R^2 value (0.5). These results suggest that there may be potential for a predictive equation for CWWP with multiple body measures.

2.4.3. Feeding behavior

Our results indicate that feeding behavior may influence different measurements of efficiency in cow-calf herds. Cows in the current study classified as large (ABW, VOL, and FS) engaged in less meals but spent more time eating overall. As expected, larger cows ate more (kg) per day which aligns with the relationship observed of larger cows having a greater DMI throughout the trial. Interestingly, smaller cows (ABW, VOL, and FS) ate less DMI compared to larger cows however engaged in more frequent visits to the feed bunk. Cows that spent more time eating had calves with a larger ADG and tended to wean a lower percent of body weight. These results indicate that cows with a larger CWWP tend to eat shorter meals and eat more frequently throughout the day. The results of this data are similar with Golden et al. (2008), who reported that steers with lower residual feed intake (RFI) engage in less feeding activity in a day, and Montanholi et al. (2009) who demonstrated that steers with lower RFI consumed smaller meals. Cows in our study who demonstrated increased CWWP and decreased DMIP spent less time eating in a day and engaged in less time eating per meal. Further evaluation with the current data is warranted to better understand the relationship between efficiency and feeding behavior that occurred in this study.

2.4.4. Prediction equations

Average body weight could be an important factor influencing dry matter intake. However, including additional size variables, such as those measured in this experiment, could improve prediction models. The prediction model for DMI was improved when adding either weight change of the cow or calf weaning weight. These parameters were chosen to be tested for the prediction model as they are important factors that could influence intake in cow-calf production settings. The best-fit prediction equation is as follows: DMI = -0.33 + 0.019(ABW) +

0.759(AWC) + 0.016(CWW). There may be potential for the development of equations utilizing body measurements. Further analysis is warranted to investigate other models to predict DMI incorporating more size characteristics and to test models in different test populations.

2.4.5. Future work

Further regression analyses will be conducted to improve prediction equations for DMI and other measures important in determining efficiency of cow-calf production. The regression analysis in the current study demonstrated several relationships between individual size characteristics and efficiency measures which suggests that prediction models with body measurement characteristics could be used to improve prediction models. The results suggest that body size and measurements may be useful in predicting DMI and CWW. Upon further investigating regression models, multiple factors will be evaluated to define models that best fit the data and serve as reliable prediction models.

2.5. Conclusion

The analyses done in this study demonstrated that cow body size is associated with different measures of efficiency in multiparous lactating beef cattle. The results indicate that larger cows wean larger calves but at smaller percentages of cow body weight. Larger cows consumed a greater amount of feed while eating less in proportion to body weight. Feeding behavior was also shown to have relationships with efficiency measures suggesting that further investigation is warranted to better understand the relationship between eating patterns and cow efficiency. In conclusion, body measurements and other body size characteristics may be good tools to use for predictive measures of DMI and other measures of efficiency, such as CWW, in cow-calf operations. Developing improved prediction equations using body measurements could lead to more convenient and precise methods to predict efficiency traits without substantial costs.

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3. UTILIZATION OF LINEAR BODY MEASUREMENTS TO PREDICT DRY MATTER INTAKE IN LACTATING MULTIPAROUS CROSSBRED BEEF CATTLE

3.1. Introduction

As mentioned in chapter 2, having an efficient operation is a critical component of maximizing profits. The ability to identify which cows are more efficient can help improve overall efficiency and profitability. An integral part to understanding efficiency and maximizing profits is understanding the factors that contribute to efficiency and how they relate with one another. Efficiency can be defined as the ratio of outputs to inputs (Dickerson, 1970) with the outputs and inputs becoming more defined as they get applied to a specific production. Achieving profitability can be done through improving associated outputs such as weaning weights, or decreasing costs with inputs such as feed intake (Archer et al., 1999). Profitability is a function of outputs and inputs, and as feed costs represent a major expense, dry matter intake (DMI) is a major factor affecting efficiency in cow-calf herds.

As an efficient cow-calf herd is important for maximizing profits, developing models to examine factors that play key roles in influencing efficiency can be useful. Examining feed intake is one tool available for producers to determine if a cow is efficient (Klosterman, 1972). Animal selection based on feed efficiency has been considered for quite some time. However, approaches are continually being updated and further researched to better understand and identify the best methods to implement into production systems. As a measure of profitability, feed efficiency is a potential tool available to producers when making selection decisions of what cows to keep (Archer et al., 1999; Yerex et al., 1988).

Estimating DMI provides producers the potential to minimize feed waste as well as identify efficient animals through selection. Reducing costs associated with feed intake involves having a clear understanding of individual intake and what cows are eating more than others. Residual feed intake (RFI) is a common measure that compares the differences between observed intake and predicted intake. A negative RFI indicates a more efficient animal indicating that the animal ate less than anticipated. There are many models designed to predict DMI when developing RFI models, however, many of these approaches are better suited for growing animals rather than mature animals. Additionally, current models to estimate DMI aren't ideal for routine use by producers (Koch et al., 1963). Having a better understanding of DMI as well as developing a practical approach to predict DMI can help to not only prevent feed waste but also identify more efficient cows.

Predicting DMI can be challenging as a representative model needs to predict intake accurately and consistently. Efficiency of feed use is not a directly measurable trait and models are continuing to be developed and improved to find the best models that capture a strong percentage of variation of DMI and are practical for on-farm use. Prior to recommendations about individual feed intake, the relationship between intake and other measurable traits needs to be identified and understood (Koch et al., 1963). Additionally, an ideal model would be suitable for on pasture prediction rather than confinement. Current techniques to predict DMI are not always practical for on farm use due to either being impractical on pasture, invasive, time consuming, or expensive. Models for predicting measures such as DMI are often based off varied factors such as nutrition, physiology, or environment. Current models for estimating DMI include monitoring changes in body weight (BW), feeding behavior, and use of thermal imaging or digesta marker techniques. One problem with some of these models is that the measurements are made as group averages from estimations of pre and post grazing pasture masses and do not capture variation in intake that occurs between individual animals. Indigestible markers are one method for estimating intake of grazing animals on an individual basis, a common one being the N-alkane technique. While this measure brings the potential to provide accurate and independent estimation of intake, there are still implications such as time constraints and costs (Wright et al., 2019).

As weight and size will impact maintenance requirements, BW is a measure commonly utilized for monitoring factors such as feed efficiency (Koch et al., 1963). Body weight may not always be readily available to measure due to lack of equipment or time and the development of other measures to represent BW are needed. There are measures and tools available for measuring weight however they are not always readily available to producers (Lukuyu et al., 2016). Studies have been conducted to evaluate measures that may serve as representors for body weight. Different body measurements have been identified as traits that may serve as a reliable replacement for BW (Lukuyu et al., 2016). Girth measurements, such as heart girth have been used as a proxy for BW. However, heart girth may be difficult to consistently measure uniformly due to placement or positioning of the animal during the measurement. Wither height, hip height, and hip width have all been identified as possible traits as they are indicative of body size as well as may be easier to measure (Enevoldsen and Kristensen, 1997; Koch et al., 1963).

While estimating efficiency can be a useful tool to identify efficient animals and improve profits, costs with current methods can often exceed benefits making some producers hesitant to examine efficiency. Measurements aimed to determine individual feed intake can be difficult, costly, interrupt normal grazing behavior, and interfere with intake. Costs for estimating feed efficiency can often be cost restrictive, making there a need for identification of traits that can represent feed intake and are easily measurable (Koch et al., 1963; Yerex et al., 1988).

Alternatives to predicting intake have been investigated to identify measurements that will be representative and are easier for producers to collect (Williams et al., 2019). Body measurements have been examined for their potential of traits related to efficiency (Yerex et al., 1988). Body measurements have been identified as a potential alternative to predict DMI as they are easier to measure and are highly representative of BW (Heinrichs et al., 1992; Lukuyu et al., 2016). As discussed in chapter 2, relationships between DMI and body measurements have been identified. Different body measurements such as hip width, hip height, body length, and girth measures have been noted to be correlated with DMI suggesting there may be a potential for prediction equations for intake based off body measurements (Enevoldsen and Kristensen, 1997; Wood et al., 2014).

While current techniques for predicting DMI are well developed and have high accuracy results, there is a need for cheaper, faster, and ultimately more convenient methods that can be utilized on farm. The idea of body measurements being incorporated to prediction models could meet those goals, as the material needed to conduct the measurements are easily attainable and low in cost. Additionally, body measurements can be taken rather quickly and thus don't require much time compared to other techniques. The objective of this study was to evaluate the potential of body measurements to serve as predictor variables for dry matter intake. We hypothesized that body measurements would serve as an alternative model for predicting intake in cow-calf herds. With addition of parameters, there is increased chance of collinearity between variables, which needs to be monitored and adjusted as needed to reduce variance inflation between parameters.

3.2. Materials and methods

3.2.1. Animals, experimental conditions, and dietary treatments

All procedures were approved by the North Dakota State University Animal Care and Use Committee. During the summer of 2020, 60 crossbred mature cows (ages 5 to 6 years) weighing 662 ± 93.3 kg and their calves (aged 2 weeks or greater) were housed at the North Dakota State University (NDSU) Beef Cattle Research Center (BCRC). All cows in the current study were previously involved in a study that included the extraction of blood and DNA samples to determine their genomic breed (Bhowmik, 2021). Cows and calves arrived two weeks before the start date of the experiment to allow the animals to train and acclimate to the feeders. The trial began on July 20, 2020 and lasted 64 days. Cows had a range of frame scores assigned as heifers (FS: 2.34 to 7.42), which was calculated based on the Beef Improvement Federation (BIF) equation for heifers measured at their hip height between 5 and 24 months of age. Hip height at weaning age (approximately 6.5 months) was used to calculate frame score. Cows and their calves were divided into groups of 15 pairs across 4 pens. Access to a separate pen for calves was shared between 2 sets of 2 pens where only calves could access to consume grass hay as they aged. Cows and calves had free access to an outdoor yard as well as an indoor feeding system with ad libitum access. All cows received a radio frequency Identification (RFID) tag placed in their right ear which allowed recording of feed intake as well as behavioral assessments. Cows were fed a forage-based diet (Table 3.1), and feeding behavior was monitored throughout the feeding period via the Insentec feeding systems (Hokofarm Group B.V., Marknesse, Netherlands).

3.2.2. Feed analysis

Similar to Swanson et al. (2014), diet samples were collected weekly and samples were analyzed at the Nutrition Laboratory at NDSU. Samples were dried in a 55°C oven and ground to pass a 1-mm screen. Samples were analyzed for dry matter (DM), ash, N (Kjehldahl method), Ca, and P by standard procedures (AOAC, 1990). The samples were also analyzed for NDF (assayed with heat stable and amylase and sodium sulfate and expressed inclusive of residual ash) and ADF (expressed inclusive of residual ash) concentration by the method of Roberston and Van Soest (1981) using a fiber analyzer (Ankom Technology Corp., Fairport, NY). Percent crude protein (CP) was calculated by multiply N concentration x 6.25 (Table 3.1).

Table 3.1. Ingredient and nutrient composition for TMR in multiparous cows.

Item	% DM
Ingredient[1]	
Hay	68.5
Corn Silage	15.0
DDGS[2]	11.5
Fine Ground Corn	4.72
Salt	0.20
Vitamin Premix	0.01
Trace Mineral Premix	0.05
Monensin Premix	0.02
Chemical Composition	
CP	11.29
NDF	63.18
ADF	36.34
Ca	0.56
P	0.29

[1]Diet components as percent of total diet in a dry matter (DM) basis.
[2]Dried distiller's grains with solubles.

3.2.3. Body parameter measures

Body weights were collected for two consecutive days at the beginning and end of the experiment, and every 14 days throughout the experiment. Body measurements were collected at the beginning and end of the experiment. Body measurements were recorded similar to as described by Wood et al. (2014). Body measurements were collected using a generic fabric measuring tape. The measuring tape was used to measure body length, hip width (HW), and girth at the heart, mid, and flank. Hip height (HH) was recorded using a livestock height measuring stick. Body length (BL) was defined as the distance from the point of the shoulder to the end of the rump. Hip height was defined as the distance from ground to the base of the tail head. Heart girth (HG) was defined as the circumference around the midsection caudal to shoulder. Mid-girth (MG) was defined as the circumference around the middle, over the navel. Flank girth (FG) was defined as the circumference around the middle at the flank and cranially to the udder. Body measurements were used to calculate body volume of each cow by using the BL, HG, MG, and FG. Body volume (VOL) was calculated using the equation for the volume of a barrel: $\frac{\pi H(r^2+2R^2)}{3}$ with H representing body length, r^2 representing the radius of the end girths (average of heart and flank girth) and R^2 representing the radius of the middle girth.

3.2.4. Productive performance

Individual feed intake was determined using the Insentec feeding system. Following the end of the experiment, feed intake data were summarized per day. Intake data was filtered to exclude outliers (negative numbers below -0.2 kg/feeding event or highly unlikely numbers above 20 kg/feeding event) and days missed due to mechanical problems. Data was used to determine a cow’s individual dry matter intake in kg (DMI) averaged over the whole experimental period.

3.2.5. Statistical analysis

Data were analyzed using SAS 9.4 (SAS Institute, Inc., Cary, NC). *Proc GLMselect* was utilized to examine which variables should be included in the model. *Proc Reg* was used to analyze several different regression models through ordinary least square (OLS) or ridge regression. To monitor collinearity, variance inflation factors (VIF) were generated in SAS for parameters in each regression model. Several models were analyzed, and collinearity was assessed in all models to determine if OLS or ridge regression should be utilized. If multicollinearity appeared to be a problem, indicated by VIF, the ridge model that decreased the maximum VIF below 5 was selected as the best fit model.

3.3. Results

Upon initial analysis, HW was noted to be insignificant for predicting DMI and thus was removed from the analysis and not included in any of the models discussed below. Frame score (FS) was also not included in this portion of the analysis because FS was collected when the animals were heifers and thus was hypothesized to be less representative of their current body size compared to other measures examined in the analysis.

Several ridge regression models were examined to assess the adequacy of different possible models and the best model was selected. Collinearity was assessed in all models. Two models had large variance inflation factors (VIF > 10) and were modified through ridge regression. If ridge regression was utilized, the model at which the max VIF was ≤ 5 was chosen.

Two base models were created to explore the potential of a model with average body weight (ABW) and body measurements and to help identify which parameters might be best to use in the model and which parameters could be removed. The base models represented ABW, BL, HG, MG, FG, and HH. Body length and girth measurements were included individually (model 2) or represented by VOL (model 1). As an OLS regression, base model 1 with ABW, VOL, and HH had high collinearity between the parameters (Max VIF = 12.27), which decreased (Max VIF = 5) using a ridge parameter (K) of 0.03 (Table 3.2).

Table 3.2. *Model 1*. Parameter estimates ± SD of the ridge regression analysis compared to the ordinary least square regression analysis for predicted dry matter intake (DMI), adjusted for body weight (ABW), volume (VOL), and hip height (HH).[1]

Parameter Estimates					
Intercept	ABW	VOL	HH	K	Max VIF
-3.74 ± 3.722	0.012 ± 0.0041	0.005 ± 0.0004	0.068 ± 0.0386	0.03	5
-3.27 ± 4.291	0.014 ± 0.0064	0.01 ± 0.005	0.06 ± 0.046	0	12.27

[1]Parameter estimates with standard deviations are shown [estimate ± SD] through ridge regression (K = 0.03) and ordinary least square regression (K = 0). The maximum variance inflation factor (VIF) is displayed for each model.

As an OLS regression, base model 2 with ABW, BL, HG, MG, FG, and HH also had high collinearity between the parameters (Max VIF = 18.29), which decreased (Max VIF = 4.9) using a ridge parameter (K) of 0.041 (Table 3.3).

Table 3.3. *Model 2.* Parameter estimates ± SD of the ridge regression analysis compared to the ordinary least square regression analysis for predicted DMI adjusted for body weight and linear body measurements.[1]

Parameter Estimates								
Intercept	ABW	BL	HG	MG	FG	HH	K	Max VIF
-8.6 ± 5.46	0.013 ± 0.0037	0.035 ± 0.0238	-0.063 ± 0.0263	-0.0005 ± 0.0197	0.07 ± 0.024	0.065 ± 0.0344	0.041	4.9
1.8 ± 9.26	0.022 ± 0.0071	0.021 ± 0.0282	-0.102 ± 0.0355	-0.012 ± 0.0245	0.07 ± 0.03	0.048 ± 0.0424	0	18.29

[1]Parameter estimates with standard deviations are shown [estimate ± SD] for predicting dry matter intake (DMI) through ridge regression and ordinary least square regression (K = 0). DMI was analyzed with average body weight (ABW) and linear body measurements: body length (BL), heart girth (HG), middle girth (MG), flank girth (FG), and hip height (HH). The ridge parameter (K) and maximum variance inflation factor (VIF) is displayed for each model.

After analyzing the base models, ABW was removed from both models to test the models with only body measurements. The overall p-value for the model with VOL and HH (model 3) was significant ($P < 0.0001$) and both parameters were significant in the model (VOL: $P < 0.0001$; HH: $P = 0.0048$; Table 3.4). Model 4 represents all body measurements initially included in the prediction model for DMI (BL, HG, MG, FG, and HH). The overall p-value for the model was significant ($P < 0.0001$), and three parameters were significant in the model, BL ($P = 0.032$), FG ($P = 0.001$), and HH ($P = 0.0086$) (Table 3.5).

Table 3.4. *Model 3.* Parameter estimates ± SD of the ordinary least square regression analysis for predicted DMI adjusted for volume and hip height.[1]

Parameter Estimates				
Intercept	VOL	HH	R_a^2	F-Value
-7.4 ± 3.96 (0.067)	0.01 ± 0.003 (<0.0001)	0.1 ± 0.04 (0.0048)	0.68	63.75

[1]Parameter estimates with standard deviations are shown along with respective P-values [estimate ± SD (P-value)] for predicting dry matter intake (DMI). DMI was analyzed with volume (VOL) and hip height (HH). The adjusted R-squared (R_a^2) and F-value for the model are also displayed. The model had a P-value of <0.0001.

Table 3.5. *Model 4*. Parameter estimates ± SD of the ordinary least square regression analysis for predicted DMI adjusted for linear body measurements.[1]

Parameter Estimates							
Intercept	BL	HG	MG	FG	HH	R_a^2	F-Value
-24.6 ± 3.623 (<0.0001)	0.06 ± 0.027 (0.032)	-0.04 ± 0.032 (0.19)	0.01 ± 0.025 (0.6)	0.1 ± 0.03 (0.001)	0.1 ± 0.04 (0.0086)	0.71	30.4

[1]Parameter estimates with standard deviations are shown along with respective P-values [estimate ± SD (P-value)] for predicting dry matter intake (DMI). DMI was analyzed with linear body measurements: body length (BL), heart girth (HG), middle girth (MG), flank girth (FG), and hip height (HH). The adjusted R-squared (R_a^2) and F-value for the model are also displayed. The model had a P-value of <0.0001.

Model 5 consisted of 3 measurements, FG, BL, and HH. The overall p-value for the model was significant ($P < 0.0001$) and the model accounted for a high amount of variation (Ra2 = 0.72). Flank girth and HH were significant in the model ($P = 0.0001$; 0.014 respectively), and BL had a tendency for significance ($P = 0.059$) (Table 3.6). To investigate if a model with HH and any one girth measurement would yield significance a model with MG and HH only was analyzed (model 6). The overall p-value for the model was significant (P < 0.0001) and both parameters were significant in the model (P < 0.01), however the model accounted for the lowest amount of variation of all the models (R_a^2 = 0.63) (Table 3.6). Model 7 was the final model analyzed and consisted of FG and HH. The overall p-value of the model was significant (P < 0.0001) and a large amount of variance was accounted for in the prediction of DMI (R_a^2 = 0.7). Both parameters were significant in the model (FG: P < 0.0001; HH: P = 0.0004; Table 3.6).

Table 3.6. *Models 5, 6, and 7.* Parameter estimates ± SD of the ordinary least square regression analysis for predicted DMI adjusted for different parameters.[1]

Parameter Estimates						
Intercept	MG	FG	BL	HH	R_a^2	F-Value
Model 5						
-25.7 ± 3.525 (<0.0001)	-	0.096 ± 0.0233 (0.0001)	0.05 ± 0.026 (0.059)	0.10 ± 0.04 (0.014)	0.72	50.30
Model 6						
-21.1 ± 3.721 (<0.0001)	0.05 ± 0.020 (0.0084)	-	-	0.18 ± 0.037 (<0.0001)	0.63	51.11
Model 7						
-26.1 ± 3.601 (<0.0001)	-	0.11 ± 0.023 (<0.0001)	-	0.13 ± 0.034 (0.0004)	0.70	70.23

[1]Parameter estimates with standard deviations are shown along with respective P-values [estimate ± SD (P-value)] for predicting dry matter intake (DMI). Models were analyzed with hip height (HH) and adjusted for body length (BL), flank girth (FG), and middle girth (MG). The adjusted R-squared (R_a^2) and F-value for the model are also displayed. All models had a P-value of <0.0001.

3.4. Discussion

There has been an increasing interest in utilizing body measurements for predicting efficiency characteristics. Body measurements have been evaluated to serve as predictors for several characteristics including BW of cows (Enevoldsen and Kristensen, 1997; Lukuyu et al., 2016), weaning weight, and yearling weight (Gunawan and Jakaria, 2010). Body weight is a common factor contributing to changes in feed efficiency in cattle, however. BW may not always be a readily available measure. The current study was conducted to examine the potential of prediction models that may be more convenient to use for producers compared to other methods. Body measurements appeared to be an accurate representation of DMI in lactating beef cows.

Characteristics to help determine which model may be the best for prediction of DMI were collinearity, variance, and the p-value of the model and individual variables.

Model 1 and 2 included ABW and body measurements to determine the benefit of including body measurements along with BW to predict DMI. Models 3 through 7 only included body measurements to assess the potential of body measurements alone to predict DMI. Model 1 and 2 served as base models including either ABW and all body measurements, or ABW, HH and VOL as VOL represented BL, MG, HG, and FG.

As body measurements are all associated with one another, we expected that collinearity may be a problem and thus tested for collinearity between the tested variables. Upon initial analysis, models 1 and 2 had higher than ideal multicollinearity. Multicollinearity is defined as the occurrence of high correlation between two or more of the explanatory variables and is a common complication in regression models with variables that are related. Correlation among variables within a regression model can affect the precision of the model leading to inaccurate estimates or models with significance but no significance among individual parameters (Bonate, 1999; Shieh and Fouladi, 2003). A common way to assess multicollinearity is through the examination of variance inflation factors (VIF) with each parameter. O'Brien (2007), explained that VIF can help to provide a representation of the multicollinearity that is present within the model. The VIF is a means to diagnose multicollinearity with a common agreement that a VIF greater than 10 indicates high multicollinearity. Model 1 had a maximum VIF of 12.27 and model 2 had a maximum VIF of 18.29, both indicating there was high multicollinearity in the model. A method to address the issue of multicollinearity was introduced by Hoerl and Kennard (1970) and is known as ridge regression. Ridge regression addresses the issue of collinearity through the addition of a ridge parameter (K) which reduces VIF. In our study ridge regression was utilized for two models. Using ridge regression decreased multicollinearity (VIF ≤ 5). Pimentel et al. (2007) also utilized ridge regression to overcome the occurrence of multicollinearity in models for predicting growth performance in crossbred calves and was successful in decreasing multicollinearity using this approach. In the current study, the use of ridge regression helped to decrease multicollinearity. The parameter estimates changed minimally while the standard errors of parameters decreased in the ridge models compared to OLS. Multicollinearity was not a concern for all other models evaluated (VIF ≤ 5) and therefore OLS regression was utilized.

Model 3 represented all body measurements, with BL and the girth measurements represented by VOL and HH. The overall p-value of the model was significant and both VOL and HH were significant in the model. The model had a moderate R_a^2 value and the model was investigated further to improve the prediction model. Additionally, models were evaluated to examine the inclusion of individual body measurements. Body volume is an estimate rather than a direct measure and requires calculation. We expected that model fit may increase with body measurements represented individually in the model.

Model 4, with BL, HG, MG, and FG represented individually, improved the R_a^2 by 0.03 compared to model 3 suggesting that model 4 may account for greater proportion of the variation when predicting DMI. Although the overall model p-value was significant, not all variables included in the model were significant suggesting they may not be improving model fit. Heart girth has been shown to be associated with DMI by Lukuyu et al. (2016) who found that HG is associated with body weight suggesting that it may also be a good predictor of DMI as BW and DMI are highly correlated. Heinrichs et al. (2007) is one of many researchers to study the relationship between HG and BW concluding that HG can be used as a good predictor of BW.

Interestingly, HG was not significant in model 4, suggesting it was not improving model fit for predicting DMI although FG was significant. In Chapter 2, individual relationships between body measurements and DMI were evaluated. All girths had significant relationships with DMI, however FG had the highest correlation, which agrees with the results reported here suggesting FG was the best predictor for DMI. It is likely that FG was our most consistent measure out of all the girths as this measure was taken consistently in the same location whereas HG and MG likely changed some from cow to cow as it is more difficult to be consistent in measuring heart and middle circumference. Along with FG, BL and HH were also noted to be significant in the model. These results indicate that although a model with body measures represented individually rather than within the calculated VOL may be more ideal, the best model may only need to include a few select measurements with BL, FG, and HH being the most important variables when predicting DMI. In model 5, FG and HH were significant (P = 0.0001; 0.014 respectively) in the model and BL tended (P = 0.059) to be significant. To see if the model could be further improved BL was removed. From here two models were examined both including HH and one girth measurement. As girth measurements have been predicted to serve as a reliable predictor, a model with only MG and HH was examined to evaluate the potential of models with HH and any one girth measurement. Although both variables were significant, the model p-value had the lowest R_a^2 value of all the models examined suggesting that a model with MG should not be included in the DMI prediction model compared to the other models.

The final and best fit model ($R_a^2 = 0.70$) tested was the model with only FG and HH (model 7). The model was significant (P < 0.0001), as were FG and HH (P = <0.001) (Table 3.6). In a study evaluating relationships with linear body measurements and measures of feed efficiency in mature pregnant beef cows, Wood et al. (2014), observed significant correlations with HW, BL, HG, and MG. Interestingly HH and FG were not correlated with DMI however in the current study those were the most representative and included in the final model. Model 7 was selected as the best model due to the overall variance as well as both parameters in the model having individual significance. Williams et al. (2019) also studied the use of several measures to develop a model to predict DMI in grazing lactating beef cows. Different from the current study they examined two models, a primary and final, where they were adding measures to the final model where in the current study, measures were removed to find the most simple and representative model. Compared to the model developed in Williams et al. (2019), our final model accounted for a greater proportion of variance as represented by R_a^2. Furthermore, their model included many parameters (maternal origin, BW, milk yield, calving day, parity, width at pins, full body depth, ruminating mastication's, rump width, and central ligament) some which are hard to directly measure and milk yield was represented by estimates, where the final model in this study only includes measures that are easily directly measured. Enevoldsen and Kristensen (1997) demonstrated that HH and HW may be used as accurate predictors of BW which may suggest that they may also serve as a predictive measure for DMI. This is supported by HH being included in the final model in our study although HW was removed from the analysis. In chapter 2, HW was correlated with DMI but it had the lowest F-value of all the measures. Additionally, due to results from initial analyses and because HW is likely more subjective in its measurement, HW was not included in the models. Our results suggest the best model tested in the current study is: DMI = -26.1 + 0.11 (FG) + 0.13 (HH).

3.4.1. Future work

Further regression analyses should be conducted to explore the potential of body measurements to predict several efficiency characteristics in cow calf herds, such as weaning weight. Gunawan and Jakaria (2010) demonstrated that the body measurements HG, BL, and height at the wither can be used to estimate weaning and yearling weights. Future studies could further evaluate this concept to examine the potential of accurate prediction models for weaning and yearling weights in beef cattle using body measurements. Additionally, the final model selected for DMI should be further evaluated and applied using data sets with larger sample sizes to further validate the model.

3.5. Conclusion

Our findings suggest that body measurements may serve as an alternative to measuring and predicting dry matter intake in lactating cows. Approaches that use body measurements to predict DMI may provide more readily available practices for producers to better characterize DMI and feed/pasture use. Further research is warranted to better understand the relationship among body measurements and DMI as well as other commonly measured efficiency traits in cow calf herds, such as calf weaning weight. The best model from this analysis resulted from including FG and HH in the prediction model. However, further evaluation is needed to validate the findings in more studies and with larger sample sizes.

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4. SUMMARY AND CONCLUSIONS

Feed efficiency in beef cattle has been a topic of interest in research for many years. Improving efficiency is accompanied with many economic and environmental benefits. A more defined understanding of feed efficiency will aid producers in the selection of cattle. A significant amount of research has focused on the growing animal; however, considerations of the mature animal are also important to maximizing efficiency (Wood et al., 2014). Among the complexity of feed efficiency is the topic of size and how animal size interacts with efficiency. Determining optimal cow size and having a clearer understanding of how cow size interacts with efficiency is an important and common goal among researchers (Klosterman, 1972). An understanding of how different characteristics influence efficiency will provide insight to what an 'ideal' cow is for specific productions.

Feed intake of the dam is the largest cost within a cow calf operation, however costs can often be overlooked (Klosterman, 1972; Wood et al., 2014). Having a feasible method to estimate efficiency on farm could provide as an essential tool for evaluating and optimizing efficiency. Current measures of efficiency are not always readily available due to time, labor, or cost demands or not capturing much variance. Various body measurements have been identified as representative of body size and intake including girth measurements, wither height, and hip height and width (Enevoldsen and Kristensen, 1997; Koch et al., 1963). Body measurements may contribute to prediction models through added variation captured and may serve as an alternative to estimating intake (Heinrichs et al., 1992; Lukuyu et al., 2016).

In the current study, the objectives were to examine the relationship of body size and feeding behavior with various efficiency measures and to evaluate the potential of body measurements to serve as an alternative for predicting intake in beef cows. The study conducted and presented in this thesis have provided the opportunity to evaluate the relationship between body measurements and feeding behavior with efficiency measures in beef cattle.

Cow body size and feeding behavior were associated with measures of efficiency in multiparous lactating beef cattle. Based on the findings of Chapter 2, cows with a larger body weight consumed more feed (kg) in a day but engaged in less meals. Additionally, cows that spent more time of their day eating tended to wean a lower percent of their body weight as calf.

Various measures of efficiency, feed intake of the cow, calf weaning weight, and calf average daily gain, were related with cow body size. Larger cows (ABW, VOL, and FS) consumed a greater amount of feed (kg) and had calves with greater weaning weights (kg) compared to smaller cows. However, when measured as a percent of cow body weight, larger cows weaned a smaller percent compared to that of smaller cows. Many individual body measurements were related with DMI, CWW, and CWWP. The findings from Chapter 2 indicate that body measurements may add to prediction models for efficiency traits. Further, the findings from Chapter 3 demonstrated that linear body measurements could serve as an alternative for predicting DMI. Various models with linear body measurements captured a moderate to high amount of variation in DMI ranging from 0.63 to 0.72. These measurements represent a non-invasive and inexpensive measure of intake that could be easily implemented into production systems. Additionally, body measurements may account for additional variation in animal size that might not be reflected in other models with measures such as body weight.

In summary, linear body measurements seemed to be representative of certain efficiency measures as well as a valuable addition to prediction models of intake. A model with body measurements may serve as a reliable and accurate representative of dry matter intake and provide a more readily method for on farm use. The findings suggest that animal size is related to efficiency and further research is warranted to better understand the relationship between body size and efficiency. Future studies involving larger populations are warranted to further validate the results.

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