EVALUATION OF INTAKE AND FEED EFFICIENCY MEASURES IN BEEF CATTLE

BY

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DISSERTATION

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ABSTRACT

Four experiments were conducted to evaluate intake and measures of feed efficiency in beef cattle. In Exp. 1 and 2, measures of feed efficiency were calculated on Angus and SimAngus heifers (Exp.1; n = 623, and Exp. 2; 404); and heifers were classified as either high, medium, or low residual feed intake (**RFI**), residual BW gain (**RG**), residual intake and BW gain (**RIG**), and DMI. The objective of these experiments was to determine the relationship between post-weaning feed efficiency and intake in heifers, and subsequent cow performance, reproduction, and longevity as 2-and 5-yr-old cows. As heifer RFI improved, cow forage DMI was reduced in both 2-and 5-yr old cows ($P < 0.01$) and resulted in more desirable 2-yr old cow efficiency ($P < 0.01$). Heifer RFI classification did not affect ($P \geq 0.07$) reproductive traits, cow production traits, or herd longevity up to 5 yr of age. Heifer RG classification did not affect ($P \geq 0.08$) reproductive traits; cow production traits, cow efficiency, or DMI in 2-yr-old cows. As heifer RIG improved, 2-yr-old cow forage DMI was reduced ($P < 0.01$) during lactation, resulting in more desirable cow efficiency ($P = 0.02$). Heifer RIG classification did not affect ($P \geq 0.12$) reproductive traits; calf birth or weaning BW; cow BW, milk production, 12^{th} rib fat thickness, or BCS in 2-yr old cows. Heifer DMI was highly correlated ($P < 0.05$) to cow forage intake as both 2- and 5-yr-old cows. Heifers classified as low DMI were least frequently ($P < 0.01$) kept as replacements and were youngest ($P = 0.04$) at first calving. Calves from 2-yr-old cows, classified as high DMI heifers, had the greatest ($P < 0.01$) birth BW; yet, there were no differences ($P = 0.60$) in weaning BW. Intake classification had no effect ($P \geq 0.07$) on cow BCS, 12^{th} rib fat thickness, or milk production in either 2- or 5-yr-old cows. Cows, classified as low DMI heifers, weighed the least ($P = 0.02$) and had reduced ($P < 0.01$) hip heights as both 2- and 5-yr old cows. Cows, classified as low DMI heifers, had reduced ($P \leq 0.01$) DMI, improved

(P = 0.01) cow efficiency, and a greater percentage of females remaining in the herd at 5 yr of age. These data indicate that females classified as more efficient have reduced cow DMI without compromising production traits and longevity. Heifer DMI is an accurate predictor of cow forage intake at different biological time points in life. In Exp. 3, measures of feed efficiency were determined in Angus and Simmental X Angus heifers (n = 263), and heifers were classified within feed intake and efficiency groups as described in Exp. 1 and 2. The objective of this experiment was to determine the relationship between measures of heifer feed efficiency and mature cow intake of forage of divergent quality. At 5 or 6-yr of age, cows were evaluated for voluntary forage intake of high-quality forage (**HQDMI**) and poor-quality forage (**PQDMI**). Heifer RFI classification had no effect on cow production traits; yet, cows classified with the least desirable heifer RFI had the greatest ($P \leq 0.05$) HQDMI and PQDMI. Heifer RG classification had no effect on cow production traits or DMI. Heifer RIG classification had no effect on cow traits. Cows classified as low RIG heifers had the greatest ($P = 0.02$) HQDMI; yet, only tended to have the greatest PQDMI ($P = 0.09$). Cows classified as high DMI heifers were heavier ($P = 0.05$) and had greater ($P < 0.01$) DMI than cows classified as low or medium DMI heifers. This study suggests that feed costs can be reduced by selection for heifer RFI, RIG, and DMI. In Exp. 4, Charolais crossbred heifers and steers (n = 628) endured two performance and intake tests during the growing and finishing phases of the feedlot phase. Objectives were to determine the effects of test period duration, timing, and diet type on measures of feed efficiency in feedlot calves. Dry matter intake and RFI were repeatable (r = 0.56; $P < 0.01$, and 0.63; $P < 0.01$, respectively) for both periods of grain-fed steers. Average daily gain was not repeatable (r = 0.11; $P = 0.06$) across both test periods for steers. However, growing and finishing ADG were correlated (r = 0.58; $P < 0.01$, and r = 0.69; $P < 0.01$, respectively) to total feeding period ADG.

Regardless of test length, from 7 to 70d, DMI was correlated (r ≥ 0.87; *P* < 0.01) to total DMI during the growing period. Heifer forage DMI was correlated (r = 0.58; *P* < 0.01) to grain DMI. Forage and grain RFI were moderately correlated (r = 0.40; *P* < 0.01) for heifers. These data indicate that DMI is repeatable across varying stages of maturity in cattle, and accurate feed efficiency measures can be obtained in either the growing or finishing period. The relationship of forage and grain DMI and efficiency in heifers suggests that measures of DMI and feed efficiency are relevant, regardless of diet fed. Intake evaluation periods can be shortened without losing accuracy in predicting individual animal DMI; and measures of feed efficiency can be calculated by decoupling performance and intake information. Collectively, these experiments provide insight into the effects of DMI and feed efficiency on many production traits; and the potential methods in which both feedlot and cow-calf producers can improve profitability within their operations.

Keywords: feed efficiency, intake, residual feed intake

DEDICATION

For my parents, Kevin and Debbie Cassady. Without your love and unconditional support, I would have never been able to complete my academic journey. You have instilled in me the strength, courage, and integrity I need to raise a family of my own.

For my wife Katie, may this work be the key to unlock the doors of opportunity in our life journey together. For my son and future children, I hope this serves as an inspiration. You can achieve your goals and dreams if you work hard and never give up.

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CHAPTER 1

LITERATURE REVIEW

INTRODUCTION

The beef industry has strived to increase profitability for its producers, regardless of their goals or direction. Cattle prices have increased compared to past decades (Feuz et al., 2001; Schulz, 2015); thus, the increased value of beef provides incentive to maximize production outputs such as, but not limited to: growth, carcass value, and pounds of marketable product. Majority of terminal systems measure their economic status based upon these outputs because they are easy to measure and record. However, an increase in outputs can result in a subsequent increase in input costs for producers. Input costs are generally not the primary focus on improving profitability in a majority of cow-calf enterprises, even though costs of feed inputs have increased over the past decades (Hughes, 2013). It is important to recognize that profitability is a function of outputs and inputs. Miller et al. (2001) highlighted that feed costs is the greatest operational cost for beef producers and is the greatest critical control point for profitability in the beef industry; especially considering 50% of total energy expenditure for beef production is used just to maintain the cow herd (Johnson, 1984; Ferrell and Jenkins, 1985b). If feed intake can be reduced without an impact on cowherd and feedlot productivity, operational cost can be easily reduced. This concept is extremely important, as the price of common feedstuffs have simultaneously increased as compared to past decades, as demand for cereal grains has increased for human food and ethanol production (Wisner, 2008). Thereby, improvements in feed efficiency can have a major impact in the economic sustainability of the beef industry.

Energy utilized for beef production is inefficient, especially compared to pork and poultry production (Luiting, 1991). A large proportion of energy used to produce U.S. beef is in the form of high-fiber forages that cannot be used by monogastrics. Ruminants play an important role in utilizing these forages, especially in non-arable regions. Feed consumption of grazing animals or in a typical pen/bunk feeding situation is difficult to measure. Consequently, minimal progress has been made within the past decade in regard to measuring input costs of beef production. In 2011, it was reported that as little as a 10% improvement in feed efficiency across the entire feedlot sector would reduce feed costs by approximately $1.2 billion (Weaber, 2011). Recognizing the need for improvement and potential economic gain, industry professionals need to focus more on the relationship of inputs to outputs to improve beef production efficiency and increase profitability to producers. Improvements in efficiency within terminal systems can help producers maximize carcass value while minimizing days on feed; yet, cowherd efficiency is more complicated. An efficient cow-calf enterprise is defined as one that provides adequate nutrition for not only maintenance and reproductive success of the cowherd, yet maximizes calf performance with minimal increases in feed and other input costs. For beef production as a whole to become more profitable, all sectors of feed efficiency must be explored.

FACTORS AFFECTING FEED INTAKE

One of the most vital components of beef cattle feed efficiency is feed intake, commonly known as dry matter intake (DMI). Numerous factors affect individual animal DMI. Individual animal intake is highly dependent upon many variables and their interaction with another. Intake can be affected by physical limitations, metabolic feedback, environmental stress, feed preference, as well as management and dietary strategies. Regulation of feed intake is a complex paradigm, with many explanatory theories.

Historically, the National Research Council (1987) suggested that DMI is related to energy content of feed delivered. Specifically, as energy density of the diet decreases, mostly roughages and fibrous feeds, animal intake increases in order to meet respective energy requirements. Alternatively, feed intake decreased as energy level of the diet increased, as less intake was required to meet animal's energy demands. Collectively, intake of less digestible, high-fiber diets was primarily limited by physical factors such as rumen distention and passage rate of digesta. Consumption of concentrates or other highly-digestible, low fiber diets was controlled by the animal's energy demands or other chemostatic responses (NRC, 1996). Ketelaars and Tolkamp (1992) challenged this intake regulation theory by examining voluntary intake and digestibility of 831 roughages to study the relationship between organic matter digestibility (OMD) and organic matter intake (OMI). As forage OMD increased from 30 to 84 percent, OMI increased linearly (Ketelaars and Tolkamp, 1992). According to earlier studies, voluntary intake is controlled by animal energy demand, thereby; intake should increase quadratically or plateau as forage quality increases (NRC, 1996). This conflict led to the theory that cattle do not eat as much as they can, but consume levels of forage relative to optimal oxygen intake (Ketelaars and Tolkamp, 1992). This hypothesis was successfully applied as a prediction equation for intake in sheep (Ketelaars and Tolkamp, 1992). A thorough review of research in intake regulation suggested similar intake regulation theories. When poor quality, roughage-based diets are fed, Perfogastro intestinal capacity is the first limiting intake regulator, but can be adapted to accommodate for nutrient demands, at the expense of animal performance. Intake of concentrates or any other grain-based, high energy feeds was controlled by energy demand and genetic potential of the animal unless the diet was rapidly fermentable and digestive disorders occur (Mertens, 1994). One can hypothesize that since genetic potential for intake plays an important role in regulating feed intake, forage and grain feed efficiency values are correlated, but due to mechanisms of intake of these diets may not be utilized interchangeably. This is important to recognize considering that diet types among beef enterprises can be substantially different, depending on their focus (feedlot vs. cow-calf) and environment.

Regulation by physical constraints has been well documented, yet perhaps the greatest unknown limiting factor of voluntary intake is metabolic feedback. Illius and Jessop (1996) provided a theoretical framework for these metabolic constraints on animal intake. They assume that each animal has a maximum productive capacity, dependent upon genetic potential, stage of growth, health, age, and so on. Variation exists among each animal's ability to store and dispose of nutrients fed (Illius and Jessop, 1996). The ratio of nutrients required is dependent upon production traits desired, such as, maintenance, lactation, growth, locomotion, etc. An optimal diet is required to cater to these varying nutritional demands, and imbalances could potentially result in metabolic feedback on intake. When given a choice of diets varying in protein content, pigs chose diets that were non-limiting in instances where a low ratio of amino acids to energy was fed, individual animals consumed more to meet their protein demands (Kyriazakis et al., 1990). This generally holds true for simple-stomach animals. A study conducted by Kyriazakis (1993) showed that intake of diets with levels of CP meeting growing sheep requirements were greater than diets excessive or limiting in CP. Arnold and Hill (1972) found similar results, where intake increases quadratically in diets that range from inadequate from excessive nutrients, where intakes were maximized when adequate levels of nutrients were fed. Nutrient imbalances can limit feed intake by buildup of metabolites. Illius and Jessop (1996) explained that acetate clearance in adipose tissue was dependent upon blood glucose supply. Glucose is needed to balance the NADPH and ATP requirements for effective trigyceride synthesis. High levels of blood acetate unable to be generated into adipose, causes a buildup of blood acetate, limiting intake, especially when a lack of gluconeogenic precursors (i.e. lactate, glycerol, glucogenic amino acids, etc.) are available. Considering these findings, a review by Provenza (1995) suggested that ruminants develop nutritional wisdom, in the sense that ruminants select foods that meet nutritional demands and avoid excess nutrients and toxins.

Environmental elements, specifically ambient temperature is known to influence feed intake. It is important to recognize that a product of rumen fermentation and metabolism is heat. Theoretically, daily feed consumption should fluctuate around the thermoneutral zone of each animal (NRC, 1996). Kadzere et al. (2002) summarized this theory, stating that animals must retain or dissipate certain amounts of heat to retain thermal neutrality, which was critical for appropriate physiological function. Animal responses to extreme cold ambient temperatures initiate an elevated maintenance requirement, stimulating appetite and feed intake (Young, 1981). This is consistent with the findings of Delfino and Mathison (1991), who studied the effects of cold environment and intake level on energetic efficiency of feedlot steers. Steers fed outdoors during winter months with a mean temperature of -7.6°C had increased DMI (62.2 g/ kg BW) as compared to steers fed indoors with a mean temperature of 16.9°C (60.9 g/ kg BW), yet ADG was not improved. Inversely, cattle subjected to heat stress may exhibit lower feed intakes to balance thermal homeostasis; and has been reviewed extensively (Kadzere et al., 2002; West, 2003). These findings may not hold true when cattle are acclimated to chronic cold conditions. Beverlin et al. (1989) studied voluntary forage intake of cold-acclimated, 5-year-old cows grazing in Montana during the winter months. When ambient temperatures fluctuated from previous days, intake was significantly greater. However, differences were so small they may not be biologically relevant, as forage intake was less than 0.0005% $BW \cdot d^{-1} \cdot {}^{\circ}C^{-1}$. Conclusively, environmental temperature and animal thermal regulation are known as either positive or negative influences on level of intake.

Animal feed intake can easily be influenced by psychogenic factors involving stimuli of the feed or feeding environment, independent of the feed's energy level or filling potential (Mertens, 1994). Palatability is the most commonly known feed characteristic influencing psychogenic regulation of intake. Typically, physical characteristics such as moisture content, acidity, particle size, plant maturity, etc. contribute to differences in feed preference and palatability (Baumont, 1996). When fed simultaneously, sheep had a strong preference for hay treated with butyric acid or monosodium glutamate compared to hay treated with MgO (Gherardi and Black, 1991). Evidence suggests that feed preference represents the relationship between feed characteristics and animal satiety or behavior. Ruminants generally develop preference for feeds that allow them to reach a level of satiety as rapidly as possible (Baumont, 1996), thus causing a potential change in animal intake pattern as compared to non-preferred feeds. This may not be beneficial in all cases. Rapid intake of highly-fermentable feeds may cause acute acidotic conditions, limiting long-term intake and performance. Grazing animals are also exposed to many different species of forage, typically a blend of grasses and legumes. Preferred selection for only one species while grazing may not provide adequate nutrition to the grazing animal. It is important to consider that palatability may not directly be related to overall effective forage utilization, yet does play a major role influencing intake.

Different management strategies can result in various levels of intake, and can be controlled or influenced by the producer. Ionophores have been used for many years to improve cattle feed efficiency by altering the rumen microbiome by lowering the ratio of acetate to propionate in the rumen (Russell and Strobel, 1989). This process results in less methane production, allowing for more effective energy utilization and limiting intake without negative effects on performance. A study involving the addition of monensin to corn silage in beef steers showed that feed intake can be limited by more efficient nutrient utilization. Cattle fed ad libitum with 200 mg monensin daily consumed 7.8% less feed daily than cattle fed the control diet (Byers, 1980). Other growth promotants, primarily hormonal implants, are often used by feedlot producers. Implants increase the amount of growth hormone and insulin via the pituitary gland, resulting in increased muscle tissue synthesis and reduction in lipogenesis (Stewart, 2013). Increased blood hormone levels and muscle growth can influence intake to match these new metabolic demands. This theory is confirmed by Rumsey et al. (1992); when steers fed a 60 percent concentrate diet were administered an estradiol benzoate/progesterone implant, DMI increased from 4 to 6 percent.

TECHNIQUES USED TO ESTIMATE FEED INTAKE

Feed efficiency is a relationship of outputs relative to nutrient utilization. It is important to realize that level of feed intake is the one of the most important components of measuring animal feed efficiency. Measuring voluntary intake of animals, especially grazing animals, has been a challenge over the years. There are many ways to measure feed intake, and techniques continue to evolve. Most techniques focus on fecal output and digestibility and almost all use some form of external or internal markers (Lippke, 2002). Recently, automated feeding systems have been used to quantify individual animal intake. These systems for evaluating individual feed intake are accurate. Estimation of intake is difficult, yet reliable methods to quantify individual intake have been established.

The simplest method to determine individual feed intake is by housing animals individually, offering feed ad libitum, and weighing feed refusals at 24-h intervals. While this technique is the most elementary method of determining daily individual feed intakes, the application of this procedure does not represent a typical production setting. Individually feeding animals can limit social interaction that would likely occur in a typical feedlot/grazing situation, and the effect of behavior on DMI is not accounted for (Forbes, 2007). The flaws associated with this technique may limit the efficacy of daily feed refusal measurements on true daily feed intake.

Most historical methods of estimating intake focus on digestibility of feed and total fecal output. There is a relationship that exists between the intake of feed, its indigestibility, and the resulting fecal output (Mayes and Dove, 2000). This association allows for estimation of individual feed intake by total fecal collection and digestibility analysis of the diet. Total fecal collection requires extensive labor, and daily collection of fecal output can add stress to the animal (Hatfield et al., 1993), consequently altering grazing behavior, and ultimately animal DMI.

Total fecal output and digestibility of feeds can be estimated by the administration and recovery of an external marker. Substances such as chromic oxide (the most commonly used external marker) can be given either with one large dose at the initiation of a study, frequent daily pulses, or a controlled release device (Lippke, 2002). The kinetics behind markers may result in variation in marker recovery. Owens and Hanson (1992) claimed as these foreign substances are introduced into the GI tract, many digestive processes can be affected (i.e. marker migration, inhibition of digestion, etc.), causing diurnal variability in marker recovery in the feces. However, with consistent dosing of marker, recovery variation can be limited, and fecal samples can be collected multiple times daily. Unlike confinement feeding situations, it is challenging to administer an external marker in grazing animals, since these markers are primarily mixed into the diet. Therefore, the use of chromic oxide in grazing intake evaluations may require bolus feeding, which may add some stress to the animal. If the external marker is given and recovered properly, one can estimate the total fecal output of an animal as well as the digestibility of certain nutrients. The association between fecal output and digestibility of the diet allows for the prediction of individual animal feed intake.

Internal markers have the advantage of already being mixed into or naturally occurring in the feed. Therefore the use of internal markers may be better suited for grazing animals. There are many substances such as lignin, indigestible organic matter, and acid insoluble ash (**AIA**) that have been used as internal markers. Specifically, AIA represents the acid insoluble residue of feed and feces as a natural marker for ruminant feeds (Van Keulen and Young, 1977). Marker recovery of AIA residue has been reported to be as high as 99.8% in sheep (Shrivastava and Talapatra, 1962) and 98% in cattle (Van Keulen and Young, 1977). Collectively, using AIA as an internal marker is proven to be a dependable method to estimate pasture consumption in grazing animals.

The use of plant-wax hydrocarbons (alkanes) has increased due to the tremendous potential they have as nutritional markers in grazing ruminant animals (Mayes and Dove, 2000). These alkanes can be naturally occurring or artificial long-chain fatty acid compounds that are indigestible and bypass through the GI tract. Mayes et al. (1986) reported that as hydrocarbon chain length increased from C_{27} to C_{35}, recovery of the marker increased linearly; and the estimation of forage intake using C_{33} and C_{32} n-alkanes did not differ from actual observed forage intake in sheep. Dove and Mayes (1996) pointed out that plant components and species have their own distinguishing pattern of naturally-occurring alkanes. The combination of high marker recovery rates, as well as the potential to distinguish which plant components are being consumed provides tremendous potential to intake evaluation of forages (Lippke, 2002).

Feed intake can be estimated using techniques outside of makers and total fecal collection. More recently, the use of automated feeding systems has gained popularity. Two of the most commonly used feeding systems are the GrowSafe® System (GrowSafe Systems Ltd., Airdire, Alberta) and the Insentec System (Onsentec, B.V., Marknesse, the Netherlands). The GrowSafe® System has the capability of monitoring daily feed intakes and feeding behavior (Sowell et al., 1998). This automated feeding system is able to read an electronic ear tag attached to the animal's ear up to eight times per second, and wirelessly transmit the disappearance of feed to a computer within 50 mi. GrowSafe Data Acquisition (**DAQ**) software has the capability of bundling these feeding actions and audit unaccounted feed disappearance. Collectively, DAQ is able to calculate daily feed intakes for groups of cattle. The GrowSafe System is accurate ($R^2 = 0.994$, $P < 0.001$) and a viable method for calculating individual animal feed intake (Basarab et al., 2002; Basarab et al., 2003). The Insentec system is a reliable tool to evaluate individual animal feeding behavior data (Huzzey et al., 2014). Similar to GrowSafe, the use of electronic identification allows for the recording of individual feed intake. However, the Insentec system can identify an animal and either allow or deny its access to a feed bunk and record the visiting time. This provides an advantage to the GrowSafe system, because as many as four different diet types can be fed simultaneously, and intake of each can be recorded per animal. Both feeding systems can provide reliable intake information for producers.

MEASURES OF FEED EFFICIENCY

Feed efficiency can be defined as the relationship of an animal's DMI relative to their level of desired output. Choosing only one measure of feed efficiency to be used in the beef industry as a universal production selection criterion is inadequate. This is mainly due to the fact that feed intake and utilization of an individual animal are dependent upon a complex of traits (i.e. growth rate, lactation status, basal metabolic rate, reproduction, body composition, health, activity, and climate) (Arthur et al., 2004). Feed intake is highly correlated to level of production and many output traits (Mertens, 1994); thereby, it is important to quantify measures of feed efficiency relative to biological status of the animal. Measures of feed efficiency in the feedlot are simpler since producers purchase feed and sell on a pay weight basis. This is because most feedlots are business oriented, and pay weight brings forth the most economic benefit to producers. Mature, non-growing animal feed efficiency can be dependent on a producer's cowherd genetic base, resource availability, and output marketing scheme (Roberts et al., 2011). Collectively, there isn't any common measure of feed efficiency that is applicable to all sectors of the industry. Feed efficiency values for cattle are normally categorized as either ratio or regression/residual traits (Berry and Crowley, 2013), and are typically defined in either growing or lactating animals.

Growing Animals

Gross efficiency, commonly known as gain to feed (G: F), is an accepted measure of feed efficiency characterized as a ratio of outputs to inputs, specifically individual animal BW gain relative to feed consumption over a specific time point. Feed conversion ratio (**FCR**) is the inverse of gross efficiency, and is the most traditional measure of feed efficiency in beef cattle. It is expressed as feed to gain (F: G) and is calculated by dividing feed intake by BW gain over a specific time. Feed conversion ratio can be used as a simple breeding selection criterion as it is a moderately heritable trait (h^2: 0.36 to 0.37) (Koch et al., 1963; Schenkel et al., 2004). Arthur et al. (2001) demonstrated that FCR was highly correlated to phenotypic relative growth rate (*r* = -

0.64) in young Charolais bulls. This implies that selection for improvements in FCR may potentially result in greater mature BW and allow feedlot producers to have less days on feed, or increase their pay weights. Feed conversion ratio may be a beneficial tool for growing animals and improve relative growth rates in young cattle. Feed conversion ratio can be an effective terminal sire selection tool; as evidence suggests that the reduction in days on feed for growing market cattle can improve terminal beef production efficiency. Selection for FCR should be used with caution since retention of heifers with superior FCR could yield increased average cow BW and greater maintenance requirements. Mertens (1994) explained that intake typically increases with increasing BW of the animal. Depending on a cow-calf producer's environment and available feed resources, selection for FCR may not profitably align with specific regions or environments to maximize overall production efficiency.

Partial efficiency of growth (**PEG**) is the relationship of growth per feed intake, after accounting for energy used for maintenance (Berry and Crowley, 2013). Partial efficiency of growth can be calculated by dividing ADG by feed intake after maintenance intake is subtracted. Maintenance requirements are estimated using NRC prediction equations for groups of cattle. This poses a challenge, as this prediction equation is based from a group of animals, and variation exists for maintenance requirements among individual animals within a specific feeding group. This issue can be eliminated by determining individual animal maintenance requirements; yet this may not be economically feasible (Retallick, 2012). Partial efficiency of growth is a moderately heritable trait (Nkrumah et al., 2007), and in a study of growing cattle, Nkumrah (2004) found that PEG is correlated to relative growth rate (r = 0.36). However, a stronger correlation between FCR and relative growth rate exists (r = -0.75). This evidence suggests that improvements in PEG can be achieved relatively quickly due to its moderate heritability, yet as compared to FCR, PEG may result in less noticeable changes in animal growth patterns. This may yield in lesser magnitude of increased mature cow size for producers. If one has the capability to predict individual maintenance requirements and can effectively utilize PEG as a selection criterion, it may provide a greater impact in overall beef production efficiency as compared to FCR.

Residual average daily gain (**RG**), the first residual trait measurement of feed efficiency to be discussed, represents the difference between actual and predicted BW gain. Animals are considered more efficient when they gain more than predicted (Crowley et al., 2010), thus a greater RG value is considered more efficient. Residual BW gain was introduced as an EPD by the American Angus Association (**AAA**). A feed test can be utilized to determine individual RG values, as RG can represent the residuals of a multiple regression model regressing ADG on DMI and metabolic BW. However, another method to determine individual RG values is to use a comprehensive genetic evaluation of several phenotypic traits, including: calf weaning weight, post-weaning gain, subcutaneous fat thickness, individual DMI, and DMI genomic values (American Angus Association, 2010). These genomic traits are then combined with individual animal weight, ADG, and fat thickness generating an adjusted or predicted ADG for each animal. This predicted gain is subtracted from actual animal gain, resulting in a residual portion or RG (American Angus Association, 2010). An average animal has an RG of 0 and those individuals that have increased daily gains per unit of feed consumption are considered more efficient (Iowa Beef Center, 2010). Considering RG is moderately heritable, RG can be an effective selection tool for feedlot producers, especially considering its strong correlations with accelerated growth rates and FCR (Berry and Crowley, 2012; Retallick, 2012). This can allow terminal beef producers to select for more efficient animals based on gain and minimize days on feed. However, since the calculation for RG is based off an animal's post-weaning or growing period, RG may not be an effective cow efficiency tool (American Angus Association, 2010). Its relationship with growth rates, suggests that selection for RG in the cow-calf sector may yield in larger cow sizes and increased energy sinks for maintenance.

A measure of feed efficiency that has garnered more interest in recent years is residual feed intake (**RFI**). The idea of RFI was first proposed decades ago by Koch et al. (1963), suggesting that feed requirements were affected by body weight maintained and body weight gain. Thereby, Koch et al. (1963) explains that feed intake can be classified into portions: 1) an expected intake given a specific requirement relative to an animal's metabolic capacity (maintenance) and gain over a specific time and 2) a residual portion. Collectively, RFI can be defined as the difference between actual feed intake and predicted feed intake over a specific amount of time; and cattle with numerically lower or negative RFI are considered more efficient. Using the actual data from a given performance test period, individual intakes can be estimated by regressing feed intake on ADG and mid-test metabolic weight (Arthur and Herd, 2008) and the error term represents the residual portion of intake (RFI). Selection against RFI has been studied in both growing and mature animals. In a study of growing crossbred steers, Basarab et al. (2003) found that cattle classified as efficient (low-RFI) had a 6.4 and 10.4% reduction in feed intake when compared to medium- and high-RFI cattle, respectively. The reduction in intake of steers classified as low-RFI had similar ADG (P = 0.99) than steers of both RFI classification groups. These results were consistent with a strong, positive phenotypic correlation (r = 0.61) of RFI and FCR in British Hereford cattle (Herd and Bishop, 2000). Considering the method in which RFI values are calculated, these results are consistent with the theory that RFI is independent of production traits such as: growth/size, productivity, and reproduction (Koch et al., 1963).

To investigate the effects of selection for RFI on cow production traits, Arthur et al. (2005) evaluated 185 Angus cows divergently selected for post-weaning RFI. Each year, heifers with lower RFI values were bred to low-RFI bulls to create generations (mean of 1.5) of more efficient lines of cattle. Inversely, inefficient lines of cattle based off RFI were created by mating high-RFI heifers to high-RFI bulls during the same generational time period. Reproductively speaking, generational selection for improved RFI did not have negative impacts on reproductive traits: percent cows pregnant, calving percentage, and percent calves weaned. Selection for RFI resulted in no differences in maternal production traits such as calving date, milk production, and weights of calf born/weaned per cow exposed. No differences were detected in subsequent calf postweaning growth from cows selected for RFI. These findings were consistent with Adcock et al. (2011), and a positive correlation existed between postweaning heifer RFI values and DMI of lactating and midgestating 2-yr-old cows (r = 0.21 and 0.29, respectively). These findings suggest that selection for RFI as heifers does not negatively influence cow production traits, decreases voluntary intake, and can be selected for over many generations to improve cow efficiency.

Half of the genetics expressed within a calf crop are represented by the herd sire. Therefore, the improvements in feed efficiency due to selecting for reduced RFI in herd bulls is encouraging. Evidence exists that RFI and bull fertility are related. Wang (2012) reported that breeding soundness exam (**BSE**) traits were not different in bulls classified as low-or high-RFI. However, of the percentage of bulls failing the BSE, low-RFI bulls tend to have a greater percentage of inadequate sperm motility as compared to high RFI bulls (Wang et al., 2012;

Awda et al., 2013) The effect of RFI on percentage of abnormal sperm was also concerning, however, Wang (2012) also reported that of the herd sires that passed a breeding soundness exam, low RFI bulls sired a greater number of progeny per year.

There is evidence that selection for improvements in RG and RFI can be beneficial to producers, yet their efficacy may depend on the type of enterprise. Residual feed intake can be scrutinized by terminal systems, as selection for RFI does not yield increased growth rates (Basarab et al., 2003). The savings derived by lower feed intake in feedlot cattle may not offset the increased number of days on feed required to reach a finishing weight relative to other measures of feed efficiency (i.e. FCR and RG). Alternatively, selection for RG can provide incentive for feedlot producers, as selection for this measure of feed efficiency can result in faster growth rates and fewer days on feed to target finishing weights, or simply increased pay weights. For cow-calf producers, the increase in growth rates due to selection for RG may lead to increases in cow size and subsequent maintenance cost.

Residual intake and gain (**RIG)** has recently been proposed as a dual-purpose measure of feed efficiency that combines the desired characteristics associated with selection for RG and RFI. Considering RIG values are calculated by the sum of negative RFI and RG, both standardized to a variance of 1, the theory behind RIG is that it allows producers to identify animals with superior growth rates, yet consume less feed than expected to support this added growth, while remaining independent of BW (Berry and Crowley, 2012). Like all residual trait measurements of efficiency, RIG is moderately heritable ($h^2 \geq 0.22$) (Retallick, 2012; Berry and Crowley, 2012). Berry and Crowley (2012) investigated RIG by evaluating 2,605 performance-tested bulls and showed phenotypic correlations between RIG and DMI as well as RIG and ADG (r = -0.34 and 0.41, respectively). Although this may be an effective feed efficiency selection tool for most cow-calf producers, Retallick et al. (2012) showed that selection for RIG may result in approximately a 5% reduction in marbling scores for feedlot cattle characterized as having a desirable RIG as compared to cattle characterized as poor RIG. Cattle characterized as having desirable RIG had significantly greater ADG (1.92 kg) and subsequent HCW (355 kg) compared to cattle with poor RIG (1.50 kg and 341 kg, respectively). They also had significantly lower DMI than cattle of average or poor RIG. These findings suggest that the profit captured by selection for RIG in the feedlot is due to substantial increases in pay weight and a simultaneous reduction in feed costs. Depending upon market conditions, the profit loss for terminal beef systems associated with a reduction in marbling scores can be alleviated by increased carcass weights and reduced days on feed. Alternatively, if these findings hold true in cow-calf enterprises, cow-calf producers can effectively select for increases in production outputs and reductions in intake, improving overall beef production efficiency.

Mature Cow Efficiency

Unlike growing animals, defining feed efficiency in the cowherd is more challenging. Different environments and production systems make it difficult to generate a universal form of feed efficiency within the cow-calf sector. At the British Society of Animal Production symposium, Robertson (1973) concluded that cowherd efficiency is characterized by the function of producing units. Since cow efficiency can affect long-term profitability, an efficient cow can be defined as an animal that weans off a heavy calf annually, returns to estrus appropriately prior to the subsequent breeding season, and has moderate intake. Unfortunately, there is no universally accepted measurement of cow efficiency. This is concerning, since nearly half of all feed resources are needed to maintain the cowherd (Ferrell and Jenkins, 1985b) and majority of beef feed consumption occurs between conception and weaning. Collectively, even a small improvement in cowherd feed efficiency could positively impact overall beef production profitability.

There have been many methods of evaluating mature cow efficiency. Calf weaning BW has been used historically to quantify output potential of each cow. However, input costs and long-term production traits within the herd are not accounted for using this method. It is important to recognize this as cow maintenance requirements are historically dependent on cow size (Klosterman et al., 1968). Considering the relationship of outputs to inputs, Dinkel and Brown (1978) defined cow efficiency as a ratio of calf weaning BW relative to both calf and cow total TDN intake. Surprisingly, calf weaning BW was not strongly related to either cow weight or milk production ($r = 0.06$ and 0.15, respectively), which suggests calf growth potential plays a larger role in determining calf weaning BW. The authors also reported that cow weight alone was not strongly correlated ($r = 0.13$) to this measure of cow efficiency, yet the ratio of cow weight to calf weaning weight was correlated to cow efficiency ($r = -0.85$). An equation predicting cow efficiency was generated regressing cow efficiency on calf weaning BW and cow weight and 84% of the variation of cow efficiency was explained with their model. These findings suggest that sole selection for cow size does not necessarily lead to improvements in cow efficiency. In fact, a regression analysis by Vasco et al., (1992) found that increased cow mature BW actually led to a decrease in number of calves weaned per cow over 5 calving seasons. Literature suggests cow mature size alone does not explain the variation in cow efficiency.

Calf weaning BW plays a critical role in determining cow efficiency. Maternal effects of the dam, such as: calf age/birth BW, milk production, cow biological type are important factors affecting calf weaning BW. Cows that calve earlier in the calving season have been reported to not only calve earlier the following year, but also have increased lifetime calf production compared to cows that calve later in the calving season (Burris and Priode, 1958; Lesmeister et al., 1973). Considering most producers wean their calf crop all at once, calves born earlier in the calving season are able to nurse their dams for a longer period of time pre-weaning. This allows the cow's lactation period to be extended, potentially limiting calf intake of creep feed. This theory was tested by Marshall et al. (1976), and they reported that age of calf when combined with calf weaning BW explained 68% of the variation in cow weaning efficiency in both Continental and British breeds. Collectively, reproductively sound cows that calve earlier in the calving season tend to have a more productive life and are more efficient.

Calf weaning BW is the most common output variable for defining the output portion of cow efficiency. Theoretically, selecting for genetics of increased calf weaning BW may improve cowherd efficiency. However, evidence supports that calf weaning BW is correlated to calf birth BW (Bourdon and Brinks, 1982). This can pose a problem for mature cow efficiency, as calving difficulty has been reported to increase 2.30 ± 0.21% for each kg increase in birth BW (Laster et al., 1973). Dystocia can negatively impact the production of a mature cow. Young, primiparous Holstein cows experienced drastic linear losses in milk yield as more assistance was needed at calving (Dematawena and Berger, 1997). Although milk yield losses in these cows were not as drastic due to calving difficulty when they were beyond their first parity, dystocia has other detrimental effects to mature cow efficiency. This includes reduced reproductive success, as more trauma experienced by the uterine environment requires a longer period of involution to return to cyclicity (Colburn et al., 1997). Laster et al. (1973) reported dystocia resulted in a 15.6% and 15.9% reduction in conception to AI rates and overall conception rates, respectively. Collectively, increased calf weaning BW is important to improve cow efficiency, but producers must take caution when genetic selection for increasing this output trait leads to increases in calf birth BW and dystocia. A cow experiencing a reduction in milk yield and compromised reproductive soundness may wean off a heavy calf once due to the genetic potential of the calf, but her long-term efficiency can be negatively affected with reproductive failure.

Lactation potential of the mature cow plays an important role in cowherd efficiency. The positive relationship between cow milk yield and calf weaning BW is well documented (Neville, 1962; Meyer et al., 1994). Marston et al., (1992) reported a moderate correlation between total milk yield and adjusted 205-d calf weaning BW for Angus (r = 0.30) and Simmental (r = 0.47) dams; considering a 1-kg change in total milk yield would result in an increase in calf weaning BW by 0.014 ± 0.006 kg and 0.032 ± 0.009 kg for Angus and Simmental cows, respectively. Increases in milk production by the cow however, may elevate energy maintenance requirements. The added feed costs associated with this maintenance expense for lactation can be offset by the added pay weight of their respective calf's performance. As a result, the increase in pounds of calf weaned due to milk production can improve efficiency, only if adequate nutrition is provided.

Calf weaning BW, cow milk production, and the ability to rebreed post-calving play critical roles in determining efficiency in mature cows. Focusing solely on outputs neglect the input function of efficiency. Maintenance may be the largest input determining efficiency in mature animals; however, cows of different biological types may have drastically different maintenance energy costs. This poses the largest problem regarding the use a universal cow efficiency value, because certain biological types thrive in certain environments or availability of feed resources. Genetic potential for production traits (e.g., growth rate, milk production, etc.) are positively associated with maintenance requirements (Ferrell and Jenkins, 1985b). This suggests that animals with the genetic capability of achieving these increased production traits may be at a disadvantage when feed resources are limiting, and vice versa. Jenkins and Ferrell (1994) investigated the efficiency of varying breed types with different genetic potential for production traits under varying feed availabilities. Cow biological efficiency (g of calf weaned · kg DMI^{-1} · cow $exposed^{-1}$) was greater for Red Poll cattle when feed availability was minimal. Low input breeds such as Red Poll and Angus were more biologically efficient at scarce feed availability mainly due to their significant advantage in reproductive success. Specifically, the calving rates of Red Poll and Angus were at least 40% greater as compared to all other breeds evaluated. The authors speculate that energetic requirements for both maintenance and lactation are much lower for these low-output breeds. In environments of restricted feed resources, this lower maintenance cost allows cattle to maintain proper breeding condition, which has been proven to be correlated to reproductive success (Whittier et al., 1993), and be more efficient. Alternatively, as feed availability increased, biological efficiency of continental breeds (Gelbvieh, Charolias, Braunvieh, Simmental, Pinzgauer, and Limousin) increased linearly. Calving rates were similar across breeds when adequate nutrition was available. Predicted calf weaning BW increased linearly, and was greater for continental breeds as DM availability increased. Consequently, since reproductive success was equal across breeds in this environment, continental breeds were more biologically efficient since the added weight due to genetic potential for growth and milk production allowed for increases in calf weaning BW. These data suggested that depending on the availability of feed, the efficiency of differing cow biological types may re-rank. Thereby, the concept of matching the proper biological cow type to an appropriate environment will always maximize production efficiency for beef producers. However, it is important to note that variation in production traits and intake exist within breeds or biological types (Adcock, 2011); and certain breeds (i.e. Angus) that have been traditionally characterized as low input may have greater milk production compared to decades past. In fact, Cundiff et al. (2004) explained that calves from Angus dams had similar weaning BW as compared to calves from Charolais and Limousin dams. This suggests that genetic progress has been made for increasing outputs of certain breeds, making the traditional characterization of low-input breeds obsolete. It is important for producers to have a firm understanding of their herd's genetic potential and its interaction with the environment in order to maximize production efficiency.

It is important to recognize that defining cow efficiency in the cowherd is not as simple as defining feed efficiency in the feedlot. Cowherd efficiency is perhaps most important to improving overall beef production efficiency; as approximately 72% of all ME consumed from the period from conception to slaughter occurs during the cow calf component of the production cycle (Ferrell and Jenkins, 1982). There are many traits (e.g., calf weaning BW, milk production, growth rates, reproductive success, etc.) to evaluate when considering cow efficiency, yet perhaps the most effective way to maximize efficiency within operations is to effectively match certain genetics to the appropriate environment.

FACTORS AFFECTING MAINTENANCE ENERGY REQUIREMENTS

Maintenance energy requirements can be defined as the amount of feed energy intake that will result in no net loss or gain of body tissues (NRC, 1996). Efficiency of production in all sectors of the beef industry is heavily influenced by the energy cost of maintenance. This is an important concept, because nearly half of available energy resources are needed solely for the maintenance of the cowherd (Ferrell and Jenkins, 1985b). The beef industry is composed of many different breed types, each providing a different contribution relative to desired outputs.

Hence, variation in production potential across breeds exists, and can explain many of the differences associated with maintenance requirements. The majority of the variation in individual maintenance costs can be associated with, but not limited to, production potential (breed type) or biological status.

Ferrell and Jenkins (1984) tested the effects of cow size and milk production potential on maintenance requirements. Angus x Hereford (**AHX**), Charolais x Hereford or Angus (**CHX**), Jersey x Hereford or Angus (**JX**), and Simmental x Hereford or Angus (**SX**) non-pregnant, non-lactating cows represented cows of moderate size and milk production potential, large size and moderate milk production potential, small size and high milk production potential, and large size and high milk production potential, respectively. Cows were fed either a low, medium, or high plane of nutrition ad libitum to achieve varying energy balances. When individual maintenance requirements ($kcal \cdot kg^{.75} \cdot d^{-1}$) were calculated by regressing heat production ($\log_{10}$ heat production) on metabolizable energy intake ($kcal \cdot kg^{.75} \cdot d^{-1}$), ME requirements were higher for JX and SX cows as compared to AHX and CHX cows (145 and 160 vs. 130 and 129, respectively). This evidence suggested that non-lactating cows consisted of breeds with greater genetic potential for milk had elevated energy requirements for maintenance. Minimal effects on maintenance energy requirements due to mature size were observed by Ferrell and Jenkins (1984), which may be due to increased metabolic activity via greater visceral organ size (Burrin et al., 1990). Similar results are evident in cows of genetically similar size and differing milk production potential during gestation and lactation. Montaño-Bermudez et al. (1990) explained that lactation increased daily maintenance requirements approximately 18% when compared to gestating cows, and daily requirements of cows with low milk production potential (Hereford x Angus) were 12% lower than cows of moderate (Red Poll x Angus) and high milk (Milking

Shorthorn x Angus) production potential. Collectively, these studies explain that lactating cows typically require more energy for maintenance than gestating cows; yet, regardless of size, cows with the genetic potential for greater milk production potential required more energy for maintenance.

Animal sex has been proven to influence maintenance requirements. Garrett (1970) did not observe biological differences in maintenance energy requirements as evidence of fasting heat production between females and castrates. However, there have been reported differences in maintenance requirements between females and intact males. When comparing ME requirements amongst sexes of Hereford and Simmental breeds, Ferrell and Jenkins (1985a) discovered that Hereford bulls had a 2% greater ME requirement than Hereford heifers, and Simmental bulls had a 16.5% greater ME requirement than Simmental heifers. Animals of greater body size and visceral organ capacity have proven to have greater intake to meet their energy needs and metabolic activity appears to be related to organ size (Burrin et al., 1990). Considering mature weights and body mass of intact males are substantially greater than that of mature females of the same genotype, it comes to no surprise that ME requirements for bulls were 15% greater on average than their heifer and steer counterparts (Australian Agricultural Council. Ruminants Subcommittee et al., 1990).

Beef cattle production encompasses a variety of ages of cattle ranging from the mature cow to a young, growing feedlot steer. It is important to recognize that age of the animal has effects on their ME requirements. Basal metabolic rate is highest at times where growth and production are highest (i.e. growing calves), but typically, maintenance per unit of size decreases with age in cattle and sheep (Graham et al., 1974). Maintenance requirements change very little between the ages of 5 and 34-wk of age (Vermorel et al., 1979); however, Carstens et al. (1989)

reported that from the period of growth postweaning to a yr of age, a 6 and 8% decrease in fasting heat production and ME requirements, respectively. Investigating later stages of maturity, maintenance at 6 yr of age is approximately 84% of maximal growing maintenance (Australian Agricultural Council. Ruminants Subcommittee et al., 1990), suggested a 3% decrease in maintenance requirements annually. Maintenance energy requirements per unit of BW were greatest when growth rates were maximized.

Fermentation and metabolism occurring during digestion and absorption in ruminant animals produces heat. Considering this rise in body temperature associated with heat production from metabolic functions, the animal must maintain a zone of thermoneutrality. Heat can be released from the animal by means of evaporation, convection, and conduction allowing the animal to maintain a consistent body temperature and preserve normal metabolic function (NRC, 1996). When ambient temperatures rise above the animal's zone of neutrality, basal metabolic rate increases, creating a greater challenge for the animal to release heat produced from fermentation and maintain metabolic homeostasis. Inversely, when environmental temperatures fall below the thermoneutral zone, metabolic processes must occur more rapidly to produce enough heat to maintain body temperature. The effects of both cold and heat stress increase the maintenance energy requirements of cattle, regardless of their physiological status. This is important to recognize as the seasonal climate changes annually can affect maintenance requirements for cattle. Birkelo et al. (1991) reported that fasting heat production and maintenance metabolized energy were lower during the fall as compared to the summer. Collectively, it is important for producers to recognize that throughout the fluctuations in ambient temperature associated with the changes of the season, maintenance requirements for energy are changing, and adequate nutrition must be provided to offset these deviations from basal metabolic rate. Therefore, the increase in energy provided to the animal is for maintenance rather than output/production traits (i.e. milk production). An increase in input costs without an increase in outputs proves that fluctuations in temperature can not only change maintenance requirements, but negatively affect cow efficiency.

It is generally accepted that a pregnant female's maintenance requirements will increase to support the developing fetus (NRC, 1996). Moe and Tyrrell (1972) investigated this by comparing ME requirements of non-pregnant and gestating dairy cows. The amount of ME required for gestating cows at term is 75% greater as compared to nonpregnant cows of similar BW. Moe and Tyrrell (1972) also observed that ME requirements actually increased exponentially, particularly in the third trimester. This is mainly due to the fact that majority of fetal growth in beef cows occurs during this time period (Robbins and Robbins, 1979). This increase in metabolic energy demand is important because reproductive functions are typically the first biological system to fail when adequate levels of energy are not provided (Short and Adams, 1988). Since successful reproductive function is a major contributor to longevity and profitability in cowherds, the additional nutritional needs for cows during gestation must be acknowledged.

DETERMINING FEED EFFICIENCY IN BEEF CATTLE

Growth and intake measurements to calculate individual feed efficiency values in growing beef animals are primarily taken via a centralized performance test, where environmental impact on phenotype is standardized across all cattle on observation. Standard procedures of centralized test stations require cattle to be grouped within contemporaries based upon, but not limited to: age, sex, breed, and prior management. These contemporaries are weighed periodically and fed ad-libitum; thereby, individual gain and DMI is monitored over a specific duration of time. Intake and growth information can then be used to calculate feed efficiency of each animal and make comparisons of traits within a contemporary (i.e. ratios).

Historically, a 112-d test was considered an industry standard for accurate measurements of growth rate (Brown et al., 1991). However, the necessary equipment and time allotment for accurate measurements of intake and growth in cattle over time is extremely costly. Due to this undesirable expense, it’s important to minimize the duration of the performance test without sacrificing high accuracy measurements of growth and intake. A multiple-year evaluation of British breed bulls and heifers (n = 760) by Archer et al. (1997) investigated the efficacy of shortening the test period to achieve accurate individual growth and intake information. Phenotypic correlations of individual ADG with the 119-d test were strong at 70 d (r = 0.85), and selection efficiency of 1.00 was achieved and remained steady beyond this time point. Compared to the 119-d total test period, phenotypic correlations for DMI reached 0.87 at 35-d. Although efficiency of selection for DMI reached 1.00 at 70-d, the small (0.04) increase in selection efficiency from 35-d to 70-d test suggests that little improvements in accuracy of DMI measurement would be achieved in a period longer than 35-d. Likewise, Wang et al. (2006) discovered stronger phenotypic relationships of individual ADG and DMI over a 91-d test period at 70-d and 35-d (r = 0.95 and 0.93, respectively) when repeated measures were used in the analysis. The Beef Improvement Federation (**BIF**) has developed a set of standards for performance test stations to use in order to establish consistency in testing stations across varying regions. The BIF guidelines recommend a 70-d duration for growth tests, but suggest a 45-d intake evaluation period for accurate measurement of individual animal daily DMI (Beef Improvement Federation and Guidelines, 2010).

Previous literature would suggest the challenge of shortening the performance and intake test period was due to the number of days on test needed to accurately measure an animal's gain. Other estimates of gain may need to be considered to minimize test durations, yet maintain accurate feed efficiency measurements. Retallick (2015) compared individual on-test, regressed ADG with postweaning gain (**PWG**) records on 5,606 growing steers and heifers from the U.S. Meat Animal Research Center in Clay Center, NE. Postweaning gain was calculated as the difference in adjusted 205-d weights from 365-d weights divided by 160. Genetic correlations were strong ($r \geq 0.65$) between ADG on-test and PWG for both sexes. Retallick (2015) concluded that according to this genetic relationship, PWG can serve as an adequate proxy for on-test ADG, suggesting that longer test periods may not be necessary to obtain accurate gain information. There is promise of using performance records, rather than a 70-d test for gain to assess individual animal gain, allowing performance test stations to shorten time on feed to 35-d needed to meet the accuracy requirements of animal intake. This technique of obtaining gain information to calculate feed efficiency values can increase the rate of genetic change due to increased capacity of cattle to be tested (Retallick, 2015) and can provide economic incentive to test stations due to a shorter time on feed (Archer et al., 1999).

SUMMARY

Beef producers strive to be profitable and historically have primarily focused their economic success on outputs. Average cattle prices have doubled since the 1990s (Schulz, 2015). When prices are inflated and outputs are easy to measure, it makes sense that producers would focus their operational success based off maximizing outputs. However, increasing outputs leads to an increase in maintenance energy costs, which is the biggest detriment to profitability in the long-term. Land area for agricultural use is declining, and considering the increasing global population and competition of resources for fuels, it is imperative that cattle enterprises strive to become more efficient. Feedlot and cow-calf production systems define feed efficiency differently, but the idea of profitability being a function of inputs and outputs remains constant for both sectors of the industry. However, minimal comparisons of feedlot vs. cowherd efficiency have been made up to this point. Unlike previous generations, there is reliable technology available to determine animal feed intake. These available technologies should allow for advancements in performance and intake testing; and a reduction of days on test can allow the industry to expand their genetic evaluations of cattle nationwide. If researchers and producers alike can work together to identify more efficient lines of cattle, beef production can be a sustainable industry continuously.

FUTURE INVESTIGATIONS

There is a tremendous opportunity to improve feed efficiency of all types of enterprises. The basis of the research conducted at the University of Illinois is to investigate feed efficiency of the cowherd and feedlot sectors, and their relationship with each other and at different periods of life. In subsequent chapters, multiple research studies will be provided to investigate ways to improve beef production efficiency.

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CHAPTER 2

HEIFER INTAKE AND EFFICIENCY AS INDICATORS OF 2-YR OLD COW INTAKE AND EFFICIENCY

ABSTRACT

Objectives were to determine the relationship between post-weaning feed efficiency and intake in heifers, and subsequent cow performance and reproduction as 2-yr-old cows. Postweaning DMI, ADG, and backfat were evaluated on Angus and SimAngus heifers (n=623) over a 6-yr period. Heifers received similar forage-based diets, and individual DMI were recorded using the GrowSafe (Airdrie, AB) system. Residual feed intake (**RFI**), residual BW gain (**RG**), and residual intake and BW gain (**RIG**) were calculated. Heifers were classified into high, medium, or low RFI, RG, RIG, and DMI groups. Cow forage DMI, hip height, BW, BCS, and 12th rib fat thickness were recorded at 60 d (lactating) and 240 d (dry) postpartum; 24-h milk production was estimated at 60 d. Cow predicted DMI was estimated by regressing DMI on metabolic BW, backfat, and 24-h milk production. Cow efficiency (**cow_RFI**) is the difference between actual and predicted DMI. As heifer RFI improved, cow forage DMI was reduced (P<0.01) resulting in more desirable cow_RFI (P<0.01). The RFI classification did not affect (P≥0.07) reproductive traits; calf birth or weaning BW; cow BW, milk production, backfat, or BCS. Heifer RG classification did not affect (P≥0.08) reproductive traits; calf birth or weaning BW; cow BW, hip height, BCS, milk production, backfat, cow_RFI, or DMI. As heifer RIG improved, cow forage DMI was reduced (P<0.01) during lactation, resulting in more desirable cow_RFI (P=0.02). The RIG classification did not affect (P≥0.12) reproductive traits; calf birth or weaning BW; cow BW, milk production, backfat, or BCS. Heifer DMI was highly correlated (P<0.05) to cow forage intake. Heifers classified as low DMI were least frequently (P<0.01) kept as replacements and were youngest ($P=0.04$) at first calving. Calves from cows, classified as high DMI heifers, had the greatest ($P<0.01$) birth BW; yet, there were no differences ($P=0.60$) in weaning BW. Intake classification had no effect ($P\geq0.07$) on cow BCS, backfat, or milk production. Cows, classified as low DMI heifers, weighed the least ($P=0.02$) and had reduced ($P<0.01$) hip heights at 60- and 240-d postpartum. Cows, classified as low DMI heifers, had reduced ($P\leq0.01$) DMI and improved ($P=0.01$) cow_RFI compared to cows within the high heifer DMI group. This study suggests that females classified as more efficient have reduced cow DMI without compromising production traits.

Key words: beef cow, efficiency, intake, residual feed intake

INTRODUCTION

Profitability in beef production is dependent on outputs and inputs. Feed costs represent a majority of total operational inputs, and is the biggest detriment to profitability for beef producers (Miller et al., 2001). More efficient nutrient utilization can reduce feed costs, and the impact of improved feed efficiency in the feedlot has been well documented (Arthur et al., 2001; Herd et al., 2003; Retallick et al., 2013). Approximately 72% of all ME consumed from the period from conception to slaughter occurs during the cow-calf component of the production cycle (Ferrell and Jenkins, 1982); therefore, cowherd feed efficiency is imperative to improving overall beef production efficiency. Defining an efficient cow is challenging, as there are many factors that influence the productivity of cows in their respective environments; and it is difficult to measure grazing forage intake (Archer et al., 1999). Reducing feed costs via more efficient nutrient utilization in the cowherd has led to growing interest in other feed efficiency traits, such as: residual feed intake (**RFI**), residual body weight gain (**RG**), and residual intake and body weight gain (**RIG**).

Evidence has suggested that improvements in heifer RFI result in reduced forage DMI as cows without adverse effects on cow performance (Meyer et al., 2008; Black et al., 2013). Limited work has been done evaluating the relationship between heifer RG, RIG, DMI, and performance during the postweaning growing period and cow performance, efficiency, and reproductive traits. The hypothesis of this work is that heifer feed intake and efficiency will be related to intake and efficiency as 2-yr old cows. The objective of this study was to determine the relationship between RFI, RG, RIG and DMI in heifers during the postweaning period and subsequent cow performance, intake, efficiency and reproduction as 2-year-old lactating and dry cows.

MATERIALS AND METHODS

Experimental Animals

A 7-yr study with 6-yr class cohorts of females was conducted using 626 Angus and Simmental × Angus heifers. Heifers were born and weaned at three locations: the University of Illinois ORR Agricultural Research Center in Baylis, IL, the University of Illinois Beef Field Research Laboratory in Urbana, IL, and a single outside source (Yukon, OK). Following weaning (age 216 ± 20 d), heifers were managed together as a group and fed a common growing diet at the University of Illinois Beef Field Research Laboratory in Urbana, IL each year. All cattle were managed according to the guidelines endorsed in Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010). All experimental protocols were approved by the Institutional Animal Care and Use Committee.

Postweaning Heifer Evaluation

A postweaning intake and performance evaluation was conducted on Angus and Simmental × Angus heifers (*n* = 626; age 294 ± 37 d) over a 6-yr period. Heifers were developed each year at the University of Illinois Beef Field Research Laboratory in Urbana, IL. They were developed on a diet consisting of roughage, corn co-products, and supplement (Table 2.1). Each year, heifers were randomly allotted to pens equipped with a GrowSafe automated feeding system (Model 4000E, GrowSafe Systems Ltd., Airdrie, Alberta, Canada), and individual intakes were recorded. Individual feed intakes were audited daily by trained personnel. Daily individual feed intake data were considered acceptable if both 85% of the feed supplied to the bunk and 90% of the corresponding feed disappearance assigned to each individual electronic ID was accounted for. Data was discarded for the affected pens not meeting these criteria. A minimum of 42-d of acceptable intake data was required to measure accurate daily feed intake and a minimum of 70-d were required each year to calculate individual animal ADG. This complied with Beef Improvement Federation (**BIF**) recommendations for performance data and intake collection (BIF, 2010). The postweaning intake and performance test was extended for an additional 2-wk if both criteria were not met. Recording individual DMI and ADG allowed the calculation of multiple feed efficiency traits: RFI, RG, RIG, and feed conversion ratio (**FCR**).

For all years, initial and final BW was the average of 2 consecutive day full BW measurements. For years 1, 2, and 3, individual ADG was calculated by dividing total BW gain by the number of days on test. Individual heifer mid-test metabolic BW (**MMW**) was determined by the average of the initial and final BW of the test period. For years 4, 5, and 6, heifers were weighed every two weeks. Heifer ADG was calculated by regressing each individual weight of all time points of the test. Individual MMW was determined by the linear regression coefficients for each animal.

In years 4, 5, and 6, individual animal 12^{th} rib fat thickness was recorded via ultrasound, to account for the variation in feed intake due to body composition. Ultrasound measurements were taken by trained personnel using an Aloka 500SV (Wallingford, CT) B-110 mode instrument equipped with a 3.5-Mhz general purpose transducer array. Twelfth rib fat thickness was taken in transverse orientation between the 12^{th} and 13^{th} ribs approximately 10 cm distal from the midline. Images were analyzed using CPEC imaging software (Cattle Performance Enhancement Company LLC., Oakley, KS). Twelfth rib fat thickness measurements were taken on the final d of the evaluation period.

Heifers with structural soundness problems, poor docility, or extremely poor performance were culled annually prior to the breeding season. Heifers (*n* = 463) kept as replacements were synchronized using a 7 d CO-Synch + CIDR (Controlled Internal Drug Release; Pfizer Animal Health, New York, NY) and timed AI. Heifers were exposed to clean-up bulls for 60 d following AI. Following the breeding season, pregnant heifers were managed as part of the herd at either the University of Illinois Beef Field Research Laboratory or the ORR Agricultural Research Center rotated through mixed pastures of endophyte infected fescue (*Festuca arundinacea*), red clover (*Trifolium pretense*), and orchard grass (*Dactylis glomerata*) from April to December annually. Each year, during the winter months prior to cow evaluation, cows managed at the ORR Agricultural Research Center were managed on corn stalk residue and supplemented with distillers grains, and cows managed at the University of Illinois Beef Field Research Laboratory were fed silage-base diets. Individual calving data was used to determine first service AI conception rates, overall pregnancy rates, age of cow (d) at first calving, and calf birth BW.

Two-Year-Old Cow Evaluation

In yr 2-7, 2-yr-old cows that produced a live calf were observed at 60- and 240-d postpartum; representing the cows' lactating and dry phases, respectively. For each evaluation period, cows were allowed a 1-wk adaptation, then were offered ad libitum access to a common forage based diet (Table 2.2). Individual DMI was measured using the GrowSafe automated feeding system. Individual feed intakes were audited daily by trained personnel. Daily individual feed intake data was considered acceptable if both 85% of the feed supplied to the bunk and 90% of the corresponding feed disappearance assigned to each individual electronic ID was accounted for. Data was discarded for the affected pens not meeting these criteria. Cow forage intake was monitored for a minimum of 21 d; which allowed for acclimation to the GrowSafe system as well as sufficient time for cow forage DMI evaluation. Within this 21 d evaluation period, a minimum of 10 acceptable d of recorded DMI was required to accurately predict individual forage DMI. If 10 acceptable d of recorded DMI were not achieved within the 21 d evaluation, the DMI evaluation was extended until this criteria was met.

During both evaluation periods, measurements were taken to characterize individual cow production traits. At the beginning of the evaluation at 60-d postpartum (lactating), 24-h milk production estimates were determined using a 12-h weigh-suckle-weigh technique (Beal et al., 1990). At the conclusion of each evaluation period, cow BW was determined by the average of 2 consecutive day full BW. Individual hip heights were recorded. Body condition scores (1-9 scale) were assigned by a trained technician. Cow ultrasonic 12th rib fat thickness measurements were taken via trained personnel using an Aloka500SV (Wallingford, CT) B-110 mode instrument equipped with a 3.5-Mhz general purpose transducer array. Twelfth rib fat thickness measurements were taken in transverse orientation between the 12th and 13th ribs approximately 10 cm distal from the midline. Images were analyzed using CPEC imaging software (Cattle Performance Enhancement Company LLC., Oakley, KS).

Calves were weaned annually at 216 ± 19 d of age. Calves' weaning BW (**WW**) were recorded and submitted to the American Angus Association (St. Joseph, MO) and American Simmental Association (Bozeman, MT). A 205-d adjusted WW was calculated by the associations and was included in the analysis of cow productivity.

In the final 2 years of cow evaluation, dry matter digestibility was determined in cows during both evaluation periods using the acid insoluble ash (**AIA**) procedure (Van Keulen and Young, 1977). Prior to individual fecal sampling, cow feed samples were taken for three consecutive days. Fecal samples were taken via rectal palpation. Individual fecal and feed samples were then dried at 55° C for 3 d, and ground using a Wiley mill (1-mm screen, Arthur H. Thomas, Philadelphia, PA). Feed samples were composited. Five mg of feed and fecal samples were dried at 105° C overnight. Samples were removed, cooled in a dessicator, and weighed. Samples were then ashed (minimum 450° C for 9-12 hr; Thermolyte muffle oven Model F30420C, Thermo Scientific, Waltham, MA). Samples were removed and cooled in a dessicator. Ashed samples were placed in 500 ml Berzelius beakers, Pyrex #1040 (Corning Inc., Corning, NY) containing 100 ml of 2N HCl, and boiled for 5 min. All contents in the beakers were then filtered through Watman #54 filter paper (hardened, ashless; Sigma-Aldrich Co. LLC; St. Louis, MO) and the beakers were rinsed with distilled water. The filter paper was then placed into an empty, pre-ashed crucible and ashed (minimum 450° C for 9-12 h; Thermo Scientific). Ashed samples were then weighed. Percent AIA in the feed and feces represented the proportion of sample that was not hydrolyzed by 2N HCl and not subsequently volatilized upon incineration of the acid insoluble residue. Percent dry matter digestibility was determined by dividing the percent AIA in the feed by the percent AIA in the feces, and multiplying this result by 100.

Feed Sampling and Analysis

In year 1, NRC (1996) values were used to determine composition of individual growing heifer diet feed ingredients. For years 2 and 3, growing heifer diet individual feed ingredients were sampled and analyzed at Rock River Laboratory (Watertown, WI). During years 4, 5, and 6, growing heifer diet individual feed ingredients were sampled every 2 wk during the postweaning performance and intake evaluation period. Single cow forage feed ingredient samples were taken for all years and for both evaluation periods. Growing heifer diet feed ingredient samples were dried at 55° C for 3 d, ground using a Wiley mill (1-mm screen, Arthur H. Thomas, Philadelphia, PA), and composited at the end of each postweaning test. All diet ingredients for cows and heifers were individually analyzed for NDF and ADF (using Ankom Technology method 5 and 6, respectively; Ankom^{200} Fiber Analyzer, Ankom Technology), CP

(Leco TruMac, LECO Corporation, St. Joseph, MI), fat (ether extract method; Ankom Technology), and ash (600° C for 2 h; Thermolyte muffle oven Model F30420C, Thermo Scientific, Waltham, MA). For all years, feed ingredient compositions were used to construct overall diet composition.

Statistical Analysis

The descriptive statistics for all variables were calculated using the PROC UNIVARIATE procedure in SAS (SAS Institute Inc., Cary, NC). Heifer RFI and RG were calculated using the PROC MIXED procedure of SAS. Heifers were separated into 22 contemporary groups, based on year born, breed type, and source of origin since all factors attributed to variation within DMI ($P < 0.05$). For years 1, 2, and 3, RFI was assumed to represent the residuals from a multiple regression model regressing DMI on ADG and MMW, using pen as a random effect; and, RG was assumed to represent the residuals from a multiple regression model, regressing DMI on ADG, MMW, and 12th rib fat thickness using pen as a random effect. For years 4, 5, and 6, RFI was assumed to represent the residuals from a multiple regression model regressing DMI on ADG, MMW, and 12th rib fat thickness using pen as a random effect, and RG was assumed to represent the residuals from a multiple regression model regressing ADG on DMI, MMW, and 12th rib fat thickness using pen as a random effect. For all years, RIG for each heifer was calculated by the sum of negative RFI and RG, both standardized to a variance of 1 (Berry and Crowley, 2012).

Heifers were classified as low, medium, or high RFI, RG, RIG, or DMI. Classification groups were established by calculation of the mean and SD of the heifers for RFI, RG, RIG, and DMI within their respective contemporary groups. Contemporary grouping for DMI classification were also based on year born, breed type, and source of origin to remain consistent with feed efficiency classification. Heifers that had RFI, RG, RIG, and DMI values that were less than 0.5 SD below the mean within contemporary group were classified as “Low.” Heifers that had RFI, RG, RIG, and DMI values that were ± 0.5 SD of the mean within contemporary group were classified as “Med.” Heifers that had RFI, RG, RIG, and DMI values that were greater than 0.5 SD above the mean within contemporary group were classified as “High.” Two heifers that were identified as replacements were not able to be classified into their respective groups due to an insufficient number of recorded d of intake.

Cow RFI was defined as a measure of cow efficiency for all cows that were nursing a calf at 60 d postpartum. Cow RFI was calculated using the PROC MIXED procedure of SAS. For all years, cows were analyzed within their respective heifer contemporary groups, based on breed type and source of origin. For all years, cow RFI was assumed to represent the residuals from a multiple regression model regressing DMI on cow metabolic BW (**MW**), 12^{th} rib fat thickness, and 24-h milk production.

Since individual DMI was recorded using GrowSafe units, individual animal served as the experimental unit. Simple pearson correlations were calculated among heifer performance, DMI and efficiency; as well as cow performance traits, DMI, and efficiency using the PROC CORR procedure of SAS. Rho values were considered significant when $P \leq 0.05$. Correlations were considered strong when rho values were greater than or equal to 0.70; moderate when rho values were between 0.30 and 0.69; and weak when less than or equal to 0.29. The PROC MIXED procedure of SAS was used to test the effect of heifer DMI and efficiency classification on cow production traits, calf performance, and cow efficiency. The model used included the fixed effect of RFI, RG, RIG, or DMI classification group (high, medium, and low). The PROC GLIMMIX procedure of SAS was used to test the effect of heifer DMI and efficiency classification on reproductive traits (binomial data). The model used included the fixed effect of RFI, RG, RIG, or intake classification (high, medium, and low). Mean values were considered to be significantly different when $P \leq 0.05$, and considered a tendency when $P > 0.05$ and ≤ 0.10.

RESULTS

The descriptive statistics of heifer postweaning performance, intake, and efficiency are presented in Table 2.3. A positive linear relationship existed ($P < 0.05$) during the heifer postweaning evaluation between DMI and ADG, FCR, RFI, and RIG at 0.36, 0.59, 0.50, and -0.31, respectively (Table 2.4). Likewise, heifer ADG was moderately correlated ($P < 0.05$) to heifer FCR, heifer RG, and heifer RIG at -0.52, 0.37, and 0.34, respectively. Heifer FCR was positively correlated to heifer RFI (r = 0.44; $P < 0.05$); however, heifer FCR was negatively correlated ($P < 0.05$) to heifer RG and RIG at -0.33 and -0.58, respectively. A weak relationship existed between heifer RFI and heifer RG (r = -0.10; $P < 0.05$); and, improvements in heifer RFI resulted in improved heifer RIG (r = -0.72; $P < 0.05$). Heifer RG was moderately correlated to heifer RIG (r = 0.59; $P < 0.05$).

The descriptive statistics of cow performance and efficiency are presented in Table 2.5. Heifer initial and final BW during postweaning evaluation were correlated ($P < 0.05$) to cow BW at 0.40 and 0.58, respectively at 60 d postpartum (Table 2.6). Heifer initial and final BW during postweaning evaluation were correlated ($P < 0.05$) to cow BW at 0.29 and 0.47, respectively at 240-d postpartum. Heifer initial and final BW during postweaning evaluation were correlated ($P < 0.05$) to cow HH at 0.18 and 0.36, respectively at 60-d postpartum. Heifer initial and final BW were correlated ($P < 0.05$) to cow BCS at 60-d postpartum at 0.26 and 0.28, respectively. No relationship exists ($P > 0.05$) between heifer initial and final BW and cow RFI.

Linear correlations suggest that increases in postweaning heifer ADG resulted in increases in cow BW (r = 0.34; $P < 0.05$), hip height (r = 0.36; $P < 0.05$), and voluntary forage intake (r = 0.37; $P < 0.05$) at 60 d postpartum. Likewise, at 240-d postpartum, heifer postweaning ADG was related ($P < 0.05$) to cow BW, hip height, and DMI at 0.27, 0.32, and 0.29, respectively. No relationships exist ($P > 0.05$) between heifer postweaning ADG and cow RFI.

Positive correlations suggest as heifer feed intake increased during postweaning evaluation, cow hip height increased (r = 0.35; $P < 0.05$), cow forage DMI increased (r = 0.57; $P < 0.05$), and cow RFI was slightly less favorable (r = 0.11; $P < 0.05$) at 60 d postpartum. At 240 d postpartum, heifer postweaning feed intake was correlated ($P < 0.05$) to cow BW, hip height, and forage DMI at 0.11, 0.18, and 0.52, respectively.

Heifer RFI during postweaning evaluation was not correlated ($P < 0.05$) to cow BW, hip height, BCS, and 12th rib fat thickness at 60- and 240-d postpartum. However, linear correlations suggest that less desirable heifer RFI resulted in slight increases in cow forage DMI (r = 0.13; $P < 0.05$) and less favorable cow RFI (r = 0.21; $P < 0.05$) at 60 d postpartum. Similarly, heifer RFI was slightly correlated ($P < 0.05$) to cow forage intake at 240-d postpartum at 0.15. Heifer RG was not correlated ($P > 0.05$) with any traits at 60- and 240-d postpartum. Heifer RIG was not correlated ($P > 0.05$) cow BW, hip height, BCS, 12th rib fat thickness, or cow forage DMI at either 60- and 240-d postpartum. However, the negative correlation implies that improvements in heifer RIG resulted in slight improvements in cow RFI (r = -0.23; $P < 0.05$) at 60 d postpartum. Heifer FCR was slightly correlated ($P < 0.05$) to cow BW, 12th rib fat thickness, cow forage DMI, and cow RFI at -0.24, -0.16, 0.12, and 0.13, respectively, at 60-d postpartum. Weak correlations were observed ($P < 0.05$) between cow BW, hip height, 12th rib fat thickness, and forage DMI to heifer FCR at -0.12, -0.11, 0.12, and 0.18, respectively.

Heifer initial BW, final BW, ADG, and DMI were all negatively correlated ($P < 0.05$) to Dam birth date at -0.24, -0.34, -0.14, and -0.34, respectively (Table 2.7). A slight relationship existed between heifer initial BW during postweaning evaluation and heifer age at breeding (r = 0.23; $P < 0.05$) and subsequent age at calving (r = 0.16; $P < 0.05$). Calf birth BW and subsequent weaning BW were correlated ($P < 0.05$) to heifer final BW during the postweaning evaluation period at 0.15 and 0.29, respectively. A positive correlation suggested that improvements in heifer ADG during postweaning evaluation resulted in slightly increased calf birth BW (r = 0.28; $P < 0.05$) and subsequent calf weaning BW (r = 0.15; $P < 0.05$). A positive relationship existed between heifer postweaning DMI and heifer age at breeding (r = 0.21; $P < 0.05$), calf birth BW (r = 0.20; $P < 0.05$), and calf weaning BW (r = 0.20; $P < 0.05$). Linear relationships suggest that greater heifer 12th rib fat thickness resulted in slight increases in calf weaning BW (r = 0.21; $P < 0.05$). Heifer RFI was not correlated ($P > 0.05$) to any maternal or reproductive traits. A slight negative relationship existed (r = -0.11; $P < 0.05$) between heifer RG and heifer age at breeding. There was no significant correlation ($P > 0.05$) between heifer RIG and maternal or reproductive traits. Heifer FCR was weakly correlated ($P < 0.05$) to heifer age at breeding and subsequent average calving date at -0.18 and 0.17, respectively.

The linear associations between forage dry matter digestibility (**DMD**) is presented in Table 2.8. At 60 d postpartum, cow DMD was not correlated ($P > 0.05$) to cow BW, BCS, 24-h milk production or DMI. A moderate, negative association existed (r = -0.35; $P < 0.05$) between DMD and cow hip height at 60 d postpartum. At 60 d postpartum, cow DMD was positively correlated ($P < 0.05$) to cow 12th rib fat thickness at 0.37. Likewise, a positive association between cow DMD and cow RFI existed (r = 0.27; $P < 0.05$) at 60 d postpartum. Similar relationships were observed between cow production traits and forage DMD at 240-d postpartum. Cow forage DMD was not correlated ($P > 0.05$) to cow BW and BCS at 240 d postpartum. There was a moderate, negative correlation between cow forage DMD and cow hip height at 240 d postpartum (r = -0.40; $P < 0.05$). A moderate linear association would imply that increases in forage DMD resulted in increased 12th rib fat thickness (r = 0.42; $P < 0.05$) at 240 d postpartum. Unlike the 60 d postpartum cow evaluation period, forage DMD and DMI were positively correlated ($P < 0.05$) at 0.21 at 240 d postpartum.

The effects of heifer RFI classification on female reproductive and performance traits are presented in Table 2.9. Heifer RFI classification was independent of cow birth date (P = 0.15). Heifer RFI classification had no effect ($P \geq 0.38$) on percentage of females kept as replacements, first AI conception rate, or overall pregnancy rate. There was a trend ($P = 0.09$) for cows classified as High RFI heifers to calve 7 d younger than cows classified as Med RFI heifers. Heifer RFI classification had no effect ($P = 0.54$) on calf birth BW; yet cows classified as High RFI heifers tended ($P = 0.07$) to wean heavier calves than cows classified as Med RFI heifers. Cows classified as Low RFI heifers tended (P = 0.06) to have greater BW at 60-d postpartum than cows classified as Med RFI heifers. There were no differences ($P \geq 0.13$) in cow hip height, BCS, or 12th rib fat thickness across heifer RFI classification groups at 60-d postpartum. Cows classified as High RFI heifers had greatest ($P < 0.01$) DMI compared to cows classified as either Low or Med RFI heifers. Cows classified as Med and High RFI heifers had greater ($P < 0.01$) Cow RFI than cows that were classified as Low RFI heifers; heifers that ate less than predicted during the postweaning evaluation also ate less than predicted as 2-yr-old lactating cows. Heifer RFI classification had no effect ($P > 0.10$) on cow BW, hip height, BCS, and 12th rib fat thickness at 240-d postpartum; however, cows classified as High RFI heifers had the greatest (P = 0.01) DMI compared to cows classified as either Low or Med RFI heifers.

The effects of heifer RG classification on female reproductive and performance traits are presented in table 2.10. Cows classified as high RG heifers tended to be younger than cows classified as low RG heifers (P = 0.09). Heifer RG classification had no effect ($P \geq 0.54$) on percentage of females kept as replacements, first AI conception rate, overall pregnancy rate, or age at calving. There were no differences ($P \geq 0.45$) in calf birth BW or WW between the RG classifications. Heifer RG classification did not affect ($P \geq 0.27$) cow BW, BCS, 12^{th} rib fat thickness, 24-hr milk production, DMI, or Cow RFI at 60-d postpartum; however cows classified as High RG heifers tended (P = 0.08) to have greater hip heights compared to cows classified as Med RG heifers. There were no differences ($P \geq 0.22$) in cow BW, hip height, BCS, 12^{th} rib fat thickness, or DMI between heifer RG classification groups at 240-d postpartum.

The effects of heifer RIG classification on female reproductive and performance traits are presented in table 2.11. There were not differences (P = 0.29) between age of dam within heifer RIG group. Heifer RIG classification had no effect ($P \geq 0.17$) on percentage of females kept as replacements, first AI conception rate, overall pregnancy rate, or age at calving. There were no differences ($P \geq 0.12$) in calf birth BW and WW between heifer RIG classification groups. Heifer RIG classification did not affect ($P \geq 0.39$) cow BW, hip height, BCS, 12^{th} rib fat thickness, and 24-hr milk production at 60-d postpartum. However, cows classified as Low RIG heifers had greater (P = 0.02) DMI compared to cows classified as Med or High RIG heifers. Cows classified as Low RIG heifers had the greatest ($P < 0.01$) Cow RFI compared to cows classified as Med or High RIG heifers. There were no differences ($P \geq 0.33$) in cow BW, hip height, BCS, 12th rib fat thickness, and DMI between heifer RIG classification groups at 240-d postpartum.

The effects of heifer DMI classification on female reproductive and performance traits are presented in table 2.12. Cows classified as low DMI heifers were younger ($P < 0.01$) than cows classified as high DMI heifers; the medium DMI heifer group was intermediate. There were a greater ($P < 0.01$) percentage of heifers retained as replacements from the groups classified as either Med of High DMI heifers compared to the heifers classified as Low DMI. Heifer DMI classification had no effect ($P \geq 0.51$) on first AI conception rates and overall pregnancy rates; however, heifers classified as Low DMI were younger ($P = 0.01$) at calving than the heifers classified as either Med or High DMI. Cows classified as Low DMI heifers had calves with lighter ($P < 0.01$) birth BW as compared to cows classified as Med or High DMI heifers; yet, heifer DMI classification had no effect ($P = 0.60$) on calf WW. Cows classified as Med and High DMI heifers had greater ($P < 0.01$) BW and hip height at 60-d postpartum as compared to cows classified as Low DMI heifers. Heifer DMI classification had no effect ($P \geq 0.50$) on cow BCS, 12th rib fat thickness, and 24-h milk production at 60-d postpartum. Cows classified as High DMI heifers had increased ($P < 0.01$) DMI compared to cows classified as Low DMI heifers; the Med DMI heifer group was intermediate. Cows classified as High DMI heifers had less desirable ($P = 0.01$) Cow RFI than cows classified as Low DMI heifers. Results from 240-d postpartum were similar to results at 60-d postpartum. Cows classified as High DMI heifers had both greater ($P < 0.01$) BW and increased hip height compared to cows classified as Low DMI heifers, with the Med DMI heifer group being intermediate for both parameters. Cows classified as High DMI heifers tended to have greater ($P = 0.07$) BCS compared to cows classified as Med DMI heifers, yet heifer DMI classification had no effect ($P = 0.62$) on cow 12th rib fat thickness at 240-d postpartum. Dry matter intake classification had no effect on cow 12^{th} rib fat thickness at 240-d postpartum. Cows classified as High DMI heifers had greater (P = 0.01) DMI than cows classified as Low DMI heifers, the Med DMI heifer group was intermediate.

DISCUSSION

The objective of this research was to determine if heifer performance, DMI, and feed efficiency would be related to 2 yr old cow performance and efficiency. The results of this study suggest that heifers that consume more feed have subsequent increased ADG, which is consistent with the findings of Schwartzkopf-Genswein et al. (2002). As expected, heifer postweaning ADG and FCR were moderately, negatively correlated since FCR is a function of individual animal feed consumption and BW gain. Alternatively, increases in heifer DMI resulted in increased heifer 12^{th} rib fat thickness and a less efficient FCR; suggesting that the increased individual BW gain associated with increased energy intake was partitioned to fat reserves rather than toward protein accretion. Similarly, the moderate phenotypic correlation between heifer postweaning DMI and heifer RFI explains that increased heifer feed consumption leads to less desirable RFI, which agrees with the findings from Nkumrah et al., (2007). The moderate correlation between heifer postweaning ADG and RG demonstrated that when heifers are provided ad libitum access to feed, cattle with superior postweaning growth traits have improved RG. Similar to the findings of Berry and Crowley (2012), heifer RIG was correlated to heifer ADG and DMI. A comparison of feed efficiency traits in heifers within this study suggests that improvements in heifer FCR are related to improvements in heifer RFI, RG, and RIG, which is consistent with previous literature (Herd and Bishop, 2000; Berry and Crowley, 2012). The relationship between FCR and residual feed efficiency traits suggests that selection for improvements in feed efficiency values derived from traditional methods may lead to improvements in residual feed efficiency measures.

The lack of linear relationship between heifer RFI and cow production traits in this study was consistent with the physiological basis for RFI (Koch et al., 1963). This finding combined with the positive correlations between heifer RFI and cow forage consumption at 60- and 240-d postpartum suggests that improvements in RFI may not alter cow performance, but lead to a reduction in cow feed intake and improved efficiency. Heifer RFI classification did not affect heifer conception and pregnancy rates, which was consistent with the findings of Shaffer et al. (2011). In this study, cows classified as high RFI heifers tended to be 7 d older at calving. It is speculated that the trend for cows classified as Med RFI heifers having decreased BW 60-d postpartum is due to the fact that they were the youngest at calving. At 240-d postpartum, selection for postweaning heifer RFI was independent of cow size; which agrees with previous literature (Koch et al., 1963; Arthur and Herd, 2008; Black et al., 2013). This study also found that cows classified as high RFI heifers had the greatest DMI during both dry and lactating production periods. Heifer RFI does not seem to be related to heifer reproductive traits or mature cow production traits. Heifers with inefficient postweaning RFI values had increased DMI as cows. In conclusion, RFI classification in heifers does not affect cow production traits such as mature size. Additionally, heifers classified as efficient based on RFI decreases voluntary DMI, reducing a major input costs for cow-calf enterprises.

Selection for heifer RG had no effect on the percentage of females being kept as replacements, heifer reproductive traits, or age at calving. Contrary to these findings, Crowley et al. (2011) found that RG in growing males was genetically correlated to age at first calving. Residual BW gain has typically been an effective tool utilized in the feedlot due to the fact that improvements in RG can result in accelerated growth rates and FCR (Retallick, 2012). Accelerated growth is a useful tool in the feedlot, as producers can minimize days on feed or increase pay weights. Due to the fact that the calculation for RG is based on an animal's post-weaning or growing period, RG may not be an effective cow efficiency tool. Its relationship with growth rates, suggests that selection for RG in the cow-calf sector may result in larger cow sizes and increased energy sinks for maintenance. In this experiment, heifer RG classification had no effect on cow productivity, intake, or efficiency during either production stage. Improvements in RG improves efficiency in the feedlot (Berry and Crowley, 2012; Retallick et al., 2013), yet has no effect on DMI and production in the cowherd. Therefore, cow-calf producers can select for this measure of feed efficiency without any effects on profitability.

Residual intake and gain has recently been proposed as a dual-purpose measure of feed efficiency that combines the desired characteristics associated with selection for RFI and RG (Berry and Crowley, 2012). The effects of growing heifer RIG on cow performance and reproduction have not been evaluated. Heifer RIG classification did not affect heifer reproduction, calf or cow production traits during both evaluation periods. It resulted in reduction of cow forage DMI and subsequent improvements in cow efficiency during lactation. Collectively, selection for improvements in RIG may be able to alleviate energy costs during lactation when cow maintenance requirements are highest, without detrimental effects on cow performance and output traits. Although production traits were not different among heifer RIG classification groups, the reduction in forage intake was not observed during midgestation, which may be due to the range in heifer DMI and ADG.

Defining feed efficiency in the cowherd can be challenging. Robertson (1973) concluded that cowherd efficiency is characterized by the function of producing units. Therefore, an efficient cow can be defined as an animal that weans off a heavy calf annually, returns to estrus appropriately prior to the subsequent breeding season, and has moderate intake. Since feed intake is the only factor in this assumption that accounts for input costs, more efficient nutrient utilization could potentially lead to improved efficiency in the cowherd. Improving dry matter digestibility in the cowherd may lead to improvements in cowherd efficiency. In this study, the linear relationships between DMD and cow hip height and 12^{th} rib fat thickness suggests that improvements in DMD was related to cow size and subcutaneous fat reserves. Therefore the nutrients metabolized by smaller cows with greater DMD were most likely partitioned into energy storage. Additionally, this study suggests that the relationship between cow RFI and DMD is complex and not fully understood. The relationship between DMD and voluntary forage intake at 240 d postpartum is consistent with the concept that as organic matter DMD increases, voluntary forage intake increases (Ketelaars and Tolkamp, 1992; NRC, 1996). However, feed passage rate through the GI tract can affect feed DMD. As feed intake increases, increased passage rate through the rumen and gastrointestinal tract result in a subsequent reduction in DMD (Colucci et al., 1982). Since no relationship exists between DMD and forage DMI at 60 d postpartum, we hypothesize that both of these theories may contribute to the lack of linear relationship in this experiment. Since increased forage intake can lead to decreased DMD due to increased passage rate; and increases in DMD of the forage can increase DMI, these two factors combined may compromise the association between DMD, forage DMI, and subsequent cow feed efficiency.

It is well established that individual animal feed consumption is the greatest cost when considering all types of beef enterprises (Miller et al., 2001). The strong correlations between heifer DMI and forage DMI of cows during lactation and midgestation in this study showed that DMI was moderately repeatable across ages and biological stages, and heifer feed intake can be used as a predictor of cow forage intake. As expected, due to heifer DMI and ADG being correlated, a greater percentage of heifers that were classified as Low DMI were younger in age, and more often culled prior to the breeding season due to poor performance; which is reflective of industry standards. Likewise, this same relationship resulted in greater cow BW and hip height at 60- and 240-d postpartum for cows classified as Medium and High DMI as compared to cows classified as Low DMI. The positive correlation between heifer DMI and age at breeding suggests that DMI may have been influenced by heifer age. Subsequently, heifers classified as Low DMI and kept as replacements were at least 7 d younger at calving compared to heifers classified as either Medium DMI or High DMI. Even though Low DMI heifers calved earlier in the season as compared to Med and High DMI heifer groups and had reduced calf birth BW; this had no impact on calf WW. This is important, because birth BW influences calving ease, and without any negative impacts on WW, profitability is not affected. At both 60-and 240-d postpartum, cows that ate less as heifers weighed less; yet, had similar BCS, backfat, and 24-h milk production. Simultaneously, cows classified as Low DMI heifers consumed the least amount of feed as cows during lactation, which led to improvement in cow efficiency as indicated by cow RFI. Even though the greatest percentage of heifers classified as Low DMI were culled prior to the breeding season (41%), those that stay in the herd are younger when they calve, and are more efficient as cows. Additionally, the repeatability of feed intake across postweaning, lactating, and gestating cows is encouraging. The strong relationship between heifer feed consumption and cow intake shown in this experiment suggested that measuring feed intake during the heifer development phase can be an accurate predictor of cow forage intake.

In conclusion, results from this study suggest that heifers that are more efficient based on RFI will consume less DMI with no differences in cow or calf performance or reproduction, resulting in improvements in cow efficiency. No relationship between heifer RG and cow performance or reproductive traits suggests that RG can be used as a selection tool within the cowherd without adverse effects on profitability. This study suggested that heifers that have more efficient RIG consume less DMI and are more efficient as cows during lactation; yet, classification for RIG had no effect on cow performance or reproductive traits. Therefore, improvements in RIG can reduce cow feed consumption without compromising productivity. The moderate correlation between heifer DMI and cow DMI during lactation and midgestation suggests that heifer intake could be an effective predictor of cow DMI. Older, heavier heifers had increased DMI and subsequently calve at an older age. High DMI heifers also have larger BW and greater hip height as 2-year-old-cows, and have increased DMI as cows. This study suggests that relationships do exist between heifer RFI, RIG, and DMI and cow DMI and efficiency. Therefore, these measures could be used as selection criteria for cow-calf enterprises striving to become more efficient. Heifer DMI should be considered in maternal and all-purpose bioeconomic indices, since DMI accounts for the greatest input cost in cowherds, and DMI is repeatable across varying stages of maturity. However, more research is needed to determine what factors contribute to the variation in cow efficiency, especially DMD.

TABLES

Table 2.1 Composition of heifer diets, %DM

	Year					
Item	1	2	3	4	5	6
Corn husklage	-	67	65	-	-	-
Alfalfa hay	-	5	-	-	-	-
Corn silage	78.5	-	-	75	75	42.5
Alfalfa haylage	-	-	-	-	-	42.5
Corn gluten feed	-	23	25	-	-	-
Dry distillers grains with solubles	-	-	-	25	-	-
Wet distillers grains with solubles	16.5	-	-	-	20	10
Supplement[1]	5	5	10	-	5	5
Analyzed Values						
NDF, %	43.1	34.8	35.7	43.8	40.7	43.3
ADF, %	-	16.2	18.1	20.6	24.7	29.7
Fat, %	3.6	3.7	1.0	3.1	3.9	2.9
Protein, %	12.3	13.0	13.5	13.2	13.1	16.1

[1] Supplements fortified to meet or exceed NRC (1996) requirements for vitamins and minerals. Year 4 heifers were offered a free-choice mineral blend consisting of: 69.8% Salt, 4.6% Ca (Ca_2PO_4 and $CaCO_3$), 2.58% P (Ca_2HPO_4), 0.2% Mg (MgO), 0.02% K (Ca_2PO_4 and $CaCO_3$), 0.3% S (Ca_2PO_4 and $CaCO_3$), 1.34% Fe ($FeSO_4$), 1.1% Zn (ZnO), 1.3 mg/kg Co (Ca_2PO_4), 112 mg/kg I ($C_2H_{10}I_2N_2$), 3419 mg/kg Cu (Cu_2SO_4), 2190 mg/kg Mn ($MnSO_4$), 32 mg/kg Se (Na_2SeO_3), 6640 IU/kg vitamin A, 664 IU/kg vitamin D3, 89 IU/kg vitamin E.

Table 2.2 Composition of 2-yr-old cow diets, %DM[1]

	Year					
Item	2	3	4	5	6	7
Alfalfa hay	90	30	-	-	-	-
Oatlage	-	60	-	-	-	-
Corn condensed distillers solubles	10	10	-	-	-	-
Alfalfa haylage	-	-	100	100	100	100
Analyzed Values						
NDF, %	53.6	53.6	43.4	56.2	41.3	46.5
ADF, %	37.6	33.7	33.1	38.4	31.2	35.6
Fat, %	2.0	2.6	2.6	3.5	2.8	2.8
Protein, %	13.3	14.0	18.5	17.7	18.9	17.8

[1] Cows were offered a free-choice mineral blend consisting of: 69.8% Salt, 4.6% Ca (Ca_2PO_4 and $CaCO_3$), 2.58% P (Ca_2HPO_4), 0.2% Mg (MgO), 0.02% K (Ca_2PO_4 and $CaCO_3$), 0.3% S (Ca_2PO_4 and $CaCO_3$), 1.34% Fe ($FeSO_4$), 1.1% Zn (ZnO), 1.3 mg/kg Co (Ca_2PO_4), 112 mg/kg I ($C_2H_{10}I_2N_2$), 3419 mg/kg Cu (Cu_2SO_4), 2190 mg/kg Mn ($MnSO_4$), 32 mg/kg Se (Na_2SeO_3), 6640 IU/kg vitamin A, 664 IU/kg vitamin D3, 89 IU/kg vitamin E.

Table 2.3 Raw mean postweaning performance, efficiency, and SD of all heifers on study

Item	Mean	SD	Minimum	Maximum
Initial BW, kg	303	50	176	468
Final BW, kg	408	52	241	578
Mid-test BW, kg	355	48	213	512
Metabolic BW, kg	67	7	46	88
ADG, kg/d	1.28	0.24	0.55	2.00
DMI, kg/d	9.40	1.89	4.21	15.10
TRBF[1], cm	0.68	0.21	0.30	1.40
FCR[2]	7.49	1.70	3.34	15.36
Residual feed intake, kg	0.00	0.97	-3.89	3.67
Residual BW gain, kg	0.00	0.21	-1.65	0.74
Residual intake and BW gain	0.00	0.69	-3.30	2.32

[1]Twelfth rib fat thickness

[2]Feed conversion ratio expressed as feed:gain

Table 2.4 Simple linear phenotypic correlations among heifer postweaning variables[a]

	iBW[1]	MMW[2]	fBW[3]	ADG	DMI	TRBF[4]	FCR[5]	RFI[6]	RG[7]	RIG[8]
iBW[1]	1	**0.95**	**0.82**	-0.05	0.06	**0.56**	**0.11**	0.00	-0.07	-0.07
MMW[2]		1	**0.96**	**0.21**	**0.20**	**0.55**	0.02	0.00	0.00	0.00
fBW[3]			1	**0.41**	**0.31**	**0.53**	-0.05	0.00	0.06	0.06
ADG				1	**0.36**	-0.04	**-0.52**	0.01	**0.37**	**0.34**
DMI					1	**0.20**	**0.59**	**0.50**	0.00	**-0.31**
TRBF[4]						1	**0.19**	0.00	0.00	0.00
FCR[5]							1	**0.44**	**-0.33**	**-0.58**
RFI[6]								1	**-0.10**	**-0.72**
RG[7]									1	**0.59**

[a] |R| values in bold are significant (*P* < 0.05)
[1] Initial postweaning BW
[2] Mid-test metabolic BW
[3] Final BW
[4] 12[th] rib fat thickness
[5] Feed conversion ratio (feed:gain)
[6] Residual feed intake
[7] Residual BW gain
[8] Residual intake and BW gain

Table 2.5 Raw mean 2-yr-old cow performance, efficiency, and SD during both production periods

Item	Mean	SD	Minimum	Maximum
BW, [1] kg	562	64	384	774
Hip height, [1] cm	133	4	122	145
BCS[1]	5.6	0.5	3.5	7.5
TRBF, [1,3] cm	0.63	0.26	0.30	1.63
24-h milk production, kg	8	4	1	47
DMI, [1] kg/d	14.7	4.6	5.9	31.7
Residual feed intake, [1] kg	0.00	2.35	-7.75	10.00
BW, [2] kg	621	63	452	781
Hip height, [2] cm	136	4	124	149
BCS[2]	5.8	0.5	4.5	7.5
TRBF [2,3], cm	0.72	0.29	0.30	1.65
DMI,[2] kg/d	13.2	5.2	4.8	34.6

[1] 60 d postpartum (lactating)
[2] 240 d postpartum (dry)
[3] 12th rib fat thickness

Table 2.6 Simple linear phenotypic correlations between heifer postweaning variables and cow reproductive, performance, intake, and efficiency traits[a]

	Two-yr old cow traits measured at 60-d postpartum						Two-yr old cow traits measured at 240-d postpartum				
Heifer traits	BW	HH[1]	BCS	TRBF[2]	DMI	Cow RFI[3]	BW	HH[1]	BCS	TRBF[2]	DMI
iWt[4]	**0.40**	**0.18**	**0.26**	**0.15**	**-0.18**	0.03	**0.29**	**0.24**	0.14	0.00	**-0.36**
fWt[5]	**0.58**	**0.36**	**0.28**	**0.14**	**0.15**	0.00	**0.47**	**0.41**	0.20	0.03	0.06
ADG	**0.34**	**0.36**	-0.02	-0.06	**0.37**	-0.06	**0.27**	**0.32**	0.01	-0.09	**0.29**
DMI	0.06	**0.35**	-0.08	**-0.25**	**0.57**	**0.11**	**0.11**	**0.18**	0.08	0.04	**0.52**
TRBF[2]	0.25	**-0.11**	**0.48**	**0.53**	**0.08**	0.01	**0.17**	-0.06	0.35	0.45	**0.21**
RFI[6]	-0.02	0.02	0.01	-0.01	**0.13**	**0.21**	0.02	0.02	0.02	0.03	**0.15**
RG[7]	0.02	0.08	-0.04	-0.07	-0.01	-0.06	0.01	0.05	-0.08	-0.04	0.04
RIG[8]	0.04	0.04	-0.02	-0.04	-0.09	**-0.23**	0.02	0.03	-0.05	-0.05	-0.05
FCR[9]	**-0.24**	-0.01	-0.05	**-0.16**	**0.12**	**0.13**	**-0.12**	**-0.11**	0.06	**0.12**	**0.18**

[a] |R| values in bold are significant ($P < 0.05$)
[1] Hip height
[2] 12th rib fat thickness
[3] Cow residual feed intake
[4] Initial BW
[5] Final BW
[6] Residual feed intake
[7] Residual BW gain
[8] Residual intake and BW gain
[9] Feed conversion ratio (feed:gain)

Table 2.7 Simple linear phenotypic correlations between heifer postweaning variables and cow maternal and reproductive traits[a]

	Dam Birth Date[1]	Age at Breeding	Age at calving	Calf birth BW	Calf WW[2]	Milk[3]
Heifer traits						
iWt[4]	**-0.24**	**0.23**	**0.16**	0.01	0.12	0.00
fWt[5]	**-0.34**	**0.15**	**0.17**	**0.15**	**0.29**	0.07
ADG	**-0.14**	0.00	0.04	**0.28**	**0.15**	0.04
DMI	**-0.34**	**0.21**	0.09	**0.20**	**0.20**	-0.05
TRBF[6]	-0.02	-0.09	0.01	0.09	**0.21**	0.03
RFI[7]	-0.02	0.02	-0.06	0.01	0.06	-0.01
RG[8]	0.08	**-0.11**	-0.03	-0.06	-0.01	-0.05
RIG[9]	0.08	-0.08	-0.03	-0.03	-0.02	-0.03
FCR[10]	**-0.18**	**0.17**	0.06	0.06	0.09	-0.05

[a] |R| values in bold are significant ($P < 0.05$)
[1] Julian date is unique mo and d combination
[2] Calf weaning BW
[3] Twenty-four h milk production
[4] Initial BW
[5] Final BW
[6] 12th rib fat thickness
[7] Residual feed intake
[8] Residual BW gain
[9] Residual intake and BW gain
[10] Feed conversion ratio (feed:gain)

Table 2.8 Simple linear phenotypic correlations between cow production traits and dry matter digestibility[a], %

	60 d postpartum	240 d postpartum
Cow Traits	Dry matter digestibility	Dry matter digestibility
Measured at 60 d postpartum		
BW	-0.10	-0.16
HH[1]	**-0.35**	**-0.41**
TRBF[2]	**0.37**	**0.48**
BCS	0.09	**0.23**
24-h milk production	-0.05	-0.17
DMI	0.01	-0.18
RFI[3]	**0.27**	-0.05
Measured at 240 d postpartum		
BW	0.03	-0.08
HH[1]	**-0.36**	**-0.40**
TRBF[2]	**0.36**	**0.42**
BCS	-0.08	-0.02
DMI	0.00	**0.21**

[a] |R| values in bold are significant ($P < 0.05$)
[1] Hip height
[2] 12th rib fat thickness
[3] Residual feed intake

Table 2.9 Effects of RFI classification on female reproductive and performance traits

	Heifer RFI Category				
Item	Low	Med	High	SEM	*P*-value
Reproductive traits					
Cow birth date[1]	35	39	35	2	0.15
Retained as replacement[2], % (n)	72 (138)	77 (190)	72 (133)	-	0.38
First AI conception rate[2], % (n)	43 (54)	46 (80)	40 (48)	-	0.56
Overall pregnancy rate[2], % (n)	85 (117)	84 (159)	86 (113)	-	0.94
Cow age at first calf, d	737[xy]	733[y]	740[x]	3	0.09
Calf performance[3]					
Calf birth BW, kg	33	33	33	1	0.54
Calf weaning BW, kg	266[xy]	258[y]	272[x]	10	0.07
2-yr-old cows (lactating)[4]					
Cow BW, kg	570[x]	552[y]	568[xy]	6	0.06
Cow hip height, cm	133.4	133.1	133.9	0.4	0.34
Cow BCS	5.7	5.6	5.7	0.1	0.13
Cow TRBF[5], cm	0.64	0.63	0.63	0.26	0.97
24 h milk production, kg	8	8	8	0.4	0.85
Cow DMI, kg	13.9[b]	14.7[b]	15.8[a]	0.5	<0.01
Cow RFI, kg	-0.75[b]	0.19[a]	0.54[a]	0.24	<0.01
2-yr-old cows (dry)[6]					
Cow BW, kg	627	612	626	6	0.10
Cow hip height, cm	135.8	135.3	135.9	0.4	0.50
Cow BCS	5.8	5.8	5.9	0.04	0.63
Cow TRBF[5], cm	0.71	0.70	0.74	0.29	0.45
Cow DMI, kg	12.3[b]	13.0[b]	14.5[a]	0.5	0.01

[a,b] Row means that do not have a common superscript differ, $P \leq 0.05$

[x,y] Row means that do not have a common superscript tend to differ, $P > 0.05$ and < 0.10

[1] Julian date is unique mo and d combination

[2] LS means from Glimmix procedure of SAS

[3] Progeny of 2-yr-old cows

[4] 2-yr-old cow traits measured at 60d postpartum

[5] Twelfth rib fat thickness

[6] 2-yr-old cow traits measured at 240d postpartum

Table 2.10 Effects of RG classification on female reproductive and performance traits

	Heifer RG Category				
Item	Low	Med	High	SEM	*P*-value
Reproductive traits					
Cow birth date[1]	34^{y}	37^{xy}	39^{x}	2	0.09
Retained as replacement, % (n)	71 (135)	75 (172)	76 (154)	-	0.56
First AI conception rate, % (n)	47 (58)	41 (65)	43 (59)	-	0.54
Overall pregnancy rate, % (n)	87 (117)	84 (143)	84 (129)	-	0.75
Cow age at first calf, d	737	737	734	2	0.66
Calf performance[2]					
Calf birth BW, kg	33	33	33	0.5	0.45
Calf weaning BW, kg	267	260	266	4	0.47
2-yr-old cows (lactating)[3]					
Cow BW, kg	564	557	566	6	0.47
Cow hip height, cm	133.2^{xy}	133.0^{y}	134.1^{x}	0.4	0.08
Cow BCS	5.7	5.6	5.6	0.1	0.53
Cow TRBF[4], cm	0.65	0.64	0.60	0.25	0.27
24 h milk production, kg	8	8	8	0.3	0.63
Cow DMI, kg	14.9	14.5	14.9	0.4	0.71
Cow RFI, kg	0.31	-0.09	-0.19	0.23	0.28
2-yr-old cows (dry)[5]					
Cow BW, kg	621	614	627	6	0.22
Cow hip height, cm	135.5	135.3	136.0	0.4	0.28
Cow BCS	5.9	5.8	5.8	0.05	0.59
Cow TRBF[4], cm	0.73	0.73	0.69	0.28	0.58
Cow DMI, kg	12.8	13.2	13.6	0.5	0.50

^{x,y} Row means that do not have a common superscript tend to differ, $P > 0.05$ and < 0.10

[1] Julian date is unique mo and d combination

[2] Progeny of 2-yr-old cows

[3] 2-yr-old cow traits measured at 60d postpartum

[4] Twelfth rib fat thickness

[5] 2-yr-old cow traits measured at 240d postpartum

Table 2.11 Effects of RIG classification on female reproductive and performance traits

	Heifer RIG Category				
Item	Low	Med	High	SEM	*P*-value
Reproductive traits					
Cow birth date[1]	35	37	38	2	0.29
Retained as replacement, % (n)	70 (129)	78 (189)	74 (143)	-	0.17
First AI conception rate, % (n)	44 (51)	43 (75)	44 (56)	-	0.98
Overall pregnancy rate, % (n)	84 (107)	84 (159)	87 (123)	-	0.75
Cow age at first calf, d	736	737	734	3	0.66
Calf performance[2]					
Calf birth BW, kg	33	33	33	1	0.73
Calf weaning BW, kg	272	260	265	5	0.12
2-yr-old cows (lactating)[3]					
Cow BW, kg	563	557	568	7	0.39
Cow hip height, cm	133.3	133.5	133.5	0.4	0.89
Cow BCS	5.7	5.6	5.6	0.1	0.70
Cow TRBF[4], cm	0.64	0.63	0.63	0.27	0.99
24 h milk production, kg	8	8	8	0.4	0.56
Cow DMI, kg	15.9[a]	14.4[b]	14.3[b]	0.5	0.02
Cow RFI, kg	0.91[a]	-0.15[b]	-0.57[b]	0.25	<0.01
2-yr-old cows (dry)[5]					
Cow BW, kg	621	618	624	6	0.75
Cow hip height, cm	135.4	135.7	135.6	0.4	0.87
Cow BCS	5.9	5.8	5.8	0.1	0.33
Cow TRBF[4], cm	0.74	0.71	0.70	0.30	0.55
Cow DMI, kg	13.7	13.2	12.7	0.5	0.44

[a,b] Row means that do not have a common superscript differ, $P \leq 0.05$
[1] Julian date is unique mo and d combination
[2] Progeny of 2-yr-old cows
[3] 2-yr-old cow traits measured at 60d postpartum
[4] Twelfth rib fat thickness
[5] 2-yr-old cow traits measured at 240d postpartum

Table 2.12 Effects of DMI classification on female reproductive and performance traits

Item	Heifer DMI Category Low	Med	High	SEM	*P*-value
Reproductive traits					
Cow birth date[1]	43^{a}	36^{b}	31^{c}	2	<0.01
Retained as replacement, % (n)	59 (111)^{b}	83 (203)^{a}	78 (147)^{a}	-	<0.01
First AI conception rate, % (n)	48 (50)	41 (75)	42 (57)	-	0.51
Overall pregnancy rate, % (n)	85 (94)	84 (171)	86 (124)	-	0.95
Cow age at first calf, d	729^{b}	736^{a}	741^{a}	3	0.01
Calf performance[2]					
Calf birth BW, kg	31^{b}	33^{a}	34^{a}	1	<0.01
Calf weaning BW, kg	264	262	268	5	0.60
2-yr-old cows (lactating)[3]					
Cow BW, kg	542^{b}	567^{a}	572^{a}	7	<0.01
Cow hip height, cm	131.7^{b}	133.7^{a}	134.4^{a}	0.4	<0.01
Cow BCS	5.6	5.6	5.7	0.1	0.50
Cow TRBF[4], cm	0.63	0.65	0.61	0.28	0.51
24 h milk production, kg	8	8	8	0.4	0.51
Cow DMI, kg	12.7^{c}	15.0^{b}	16.1^{a}	0.5	<0.01
Cow RFI, kg	-0.56^{b}	-0.05^{ab}	0.51^{a}	0.26	0.01
2-yr-old cows (dry)[5]					
Cow BW, kg	595^{c}	622^{b}	637^{a}	7	<0.01
Cow hip height, cm	134.3^{c}	135.6^{b}	136.6^{a}	0.4	<0.01
Cow BCS	5.8^{xy}	5.8^{y}	5.9^{x}	0.1	0.07
Cow TRBF[4], cm	0.70	0.71	0.74	0.31	0.62
Cow DMI, kg	11.8^{b}	13.1^{ab}	14.3^{a}	0.6	0.01

^{a,b} Row means that do not have a common superscript differ, $P \leq 0.05$
^{x,y} Row means that do not have a common superscript tend to differ, $P > 0.05$ and < 0.10
[1] Julian date is unique mo and d combination
[2] Progeny of 2-yr-old cows
[3] 2-yr-old cow traits measured at 60d postpartum
[4] Twelfth rib fat thickness
[5] 2-yr-old cow traits measured at 240d postpartum

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CHAPTER 3

HEIFER INTAKE AND EFFICIENCY AS INDICATORS OF 5-YR OLD COW INTAKE, PRODUCTIVITY, AND LONGEVITY

ABSTRACT

Objectives were to determine the relationship between post-weaning feed efficiency and intake in heifers, and subsequent cow productivity and longevity as 5-yr-old cows. Post-weaning DMI, ADG, and 12^{th} rib fat thickness were evaluated on Angus and SimAngus heifers (n = 404) over a 4-yr period. Heifers received similar forage-based diets, and individual DMI were recorded using the GrowSafe (Airdrie, AB) system. Residual feed intake (**RFI**) was calculated for each individual animal, and heifers were classified into high, medium, or low RFI and DMI groups. Mature cow forage DMI, hip height, BW, BCS, and 12^{th} rib fat thickness were recorded at 60 d (lactating) and 240 d (dry) postpartum; 24-h milk production was estimated at 60 d. As heifer postweaning DMI and ADG increased, cow BW and hip height increased ($P < 0.05$). Heifer postweaning DMI was correlated (r = 0.57; $P < 0.01$, and 0.37; $P < 0.05$, respectively) to mature cow forage DMI at 60 and 240 d postpartum. Heifer RFI was correlated (r = 0.21; $P < 0.05$) to mature cow forage DMI at 60 d postpartum. Heifer RFI classification had no effect ($P \geq 0.18$) on cow reproductive or performance traits; yet, cows classified as low RFI heifers tended ($P = 0.15$) to have reduced DMI at 60 d postpartum. Heifers classified as low DMI were least frequently ($P < 0.01$) kept as replacements, yet those retained were most likely ($P = 0.05$) to remain in the herd at 5-yr of age. Heifer DMI classification had no effect ($P \geq 0.20$) on cow BCS, 12^{th} rib fat thickness, or 24-h milk production. However, mature cows classified as low DMI heifers weighed the least and had reduced ($P \leq 0.02$) hip heights at 60- and 240-d postpartum. Mature cows classified as low DMI heifers had reduced ($P < 0.01$) forage DMI during both evaluation periods. In conclusion, heifer RFI tends to result in a reduction in mature cow forage DMI at 60-d postpartum without negative impacts on cow productivity or longevity. Heifer DMI is an accurate predictor of forage DMI in 5-yr-old mature cows.

Key words: beef cow, efficiency, intake, residual feed intake, longevity

INTRODUCTION

The goal of any cow-calf producer is to be profitable, and their financial success can be measured by a function of inputs and outputs. Feed costs represent the most significant portion of operational costs (Miller et al., 2001), so more efficient nutrient utilization is critical to minimize input costs. The economic impact of improved feed efficiency in the feedlot is well documented (Arthur et al., 2001a; Herd et al., 2003; Retallick et al., 2013), and even small improvements in feed efficiency can lead to major savings in beef production (Weaber, 2011). However, nearly half of the feed resources used in beef production are used for maintenance of the cowherd (Ferrell and Jenkins, 1985). Therefore, improvements in cowherd efficiency may have the greater impact on total beef production efficiency compared to the feedlot. Robertson (1973) concluded that cowherd efficiency is characterized by the function of producing units; whereas, an efficient cow can be defined as an animal that weans a heavy calf annually, returns to estrus prior to the subsequent breeding season, and has moderate feed intake. Cows that are able to meet these criteria have greater longevity, stay in the herd for many years, and are more efficient.

There is evidence suggesting that improvements in heifer RFI can result in reduced forage DMI as cows without impacting cow performance (Meyer et al., 2008; Black et al., 2013; Cassady et al., 2015). However, limited work has been done evaluating the relationship between heifer RFI, DMI, and performance during the postweaning growing period and mature cow productivity and longevity. We hypothesize that heifer feed intake and efficiency will be related to intake and efficiency as 5-yr old cows. The objective of this study was to determine the relationship between residual feed intake (**RFI**), and DMI in heifers during the postweaning period and subsequent cow productivity and stayability as 5-year-old lactating and dry cows.

MATERIALS AND METHODS

Experimental Animals

A 9-yr study was conducted using 4 yr class cohorts of 404 Angus and Simmental × Angus heifers. Heifers were born and weaned at two locations: the University of Illinois ORR Agricultural Research Center in Baylis, IL, or the University of Illinois Beef Field Research Laboratory in Urbana, IL. Following weaning (age = 219 ± 20 d), heifers were fed a common growing diet and managed together as a group at the University of Illinois Beef Field Research Laboratory in Urbana, IL and the ORR Agricultural Research Center each year. All cattle were managed according to the guidelines endorsed in Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010). All experimental protocols were approved by the Institutional Animal Care and Use Committee.

Postweaning Heifer Evaluation

A postweaning intake and performance evaluation was conducted on Angus and Simmental × Angus heifers (*n* = 404; age = 300 ± 35 d) over a 4-yr period. Heifers were developed each year at the University of Illinois Beef Field Research Laboratory in Urbana, IL. They were developed on a diet consisting of roughage, corn co-products, and supplement (Table 3.1). Each year, heifers were randomly allotted to pens equipped with a GrowSafe® automated feeding system (Model 4000E, GrowSafe Systems Ltd., 86 Airdrie, Alberta, Canada), and individual intakes were recorded. Individual feed intakes were audited daily by trained personnel. Daily individual feed intake data was considered acceptable if both 85% of the feed supplied to the bunk and 90% of the corresponding feed disappearance assigned to each individual electronic ID was accounted for. Data was discarded for the affected pens not meeting these criteria. A minimum of 42-d of acceptable intake data was required to measure accurate daily feed intake, and a minimum of 70-d were required each year to calculate individual animal ADG. This complies with Beef Improvement Federation (**BIF**) recommendations for performance data and intake collection (BIF, 2010). The postweaning intake and performance test was extended for an additional 2-wk if both criteria were not met. Recording individual DMI and ADG allowed the calculation of multiple feed efficiency traits: RFI, RG, RIG, and feed conversion ratio (**FCR**).

For all years, initial and final BW was the average of 2 consecutive day full BW measurements. For years 1, 2, and 3, individual ADG was calculated by dividing total BW gain by the number of days on test. Individual heifer mid-test metabolic BW (**MMW**) was determined by the average of the initial and final BW of the test period. For year 4, heifers were weighed biweekly. Heifer ADG was calculated by regressing each individual weight of all time points of the test. Individual MMW was determined by the linear regression coefficients for each animal.

In year 4, individual animal 12th rib fat thickness was recorded via ultrasound, to account for the variation in feed intake due to body composition. Ultrasound measurements were taken by trained personnel using an Aloka 500SV (Wallingford, CT) B-110 mode instrument equipped with a 3.5-Mhz general purpose transducer array. Twelfth rib fat thickness was taken in transverse orientation between the 12th and 13th ribs approximately 10 cm distal from the midline. Images were analyzed using CPEC imaging software (Cattle Performance Enhancement Company LLC., Oakley, KS). Twelfth rib fat thickness measurements were taken on the final d of the evaluation period.

Heifers with structural soundness problems, poor docility, or extremely poor performance were culled annually prior to the breeding season. Heifers (*n* = 264) kept as replacements were synchronized using a 7 d CO-Synch + CIDR (Controlled Internal Drug Release; Pfizer Animal Health, New York, NY) and timed AI. Heifers were exposed to clean-up bulls for 60 d following AI. Following the breeding season, pregnant heifers were managed as part of the herd at either the University of Illinois Beef Field Research Laboratory or the ORR Agricultural Research Center rotated through mixed pastures of endophyte infected fescue (*Festuca arundinacea*), red clover (*Trifolium pretense*), and orchard grass (*Dactylis glomerata*) from April to December annually. Each year, during the winter months prior to cow evaluation, cows managed at the ORR Agricultural Research Center were managed on corn stalk residue and supplemented with distillers grains, and cows managed at the University of Illinois Beef Field Research Laboratory were managed on silage-base diets. Cows were culled each year due to reproductive failure, poor docility, feet and udder problems, or other health reasons.

Five-Year-Old Cow Evaluation

Each year, 5-yr-old cows that still remained in the herd and produced a live calf (*n* = 136) were observed at 60- and 240-d postpartum; representing the cows' lactating and dry phases, respectively. For each evaluation period, cows were allowed a 1-wk adaptation, then were offered ad libitum access to a common forage based diet (Table 3.2). Individual DMI was measured using the GrowSafe® automated feeding system. Individual feed intakes were audited daily by trained personnel. Daily individual feed intake data was considered acceptable if both 85% of the feed supplied to the bunk and 90% of the corresponding feed disappearance assigned to each individual electronic ID was accounted for. Data was discarded for the affected pens not meeting these criteria. Cow forage intake was monitored for a minimum of 21 d; which allowed for acclimation to the GrowSafe system as well as sufficient time for cow forage DMI evaluation. Within this 21 d evaluation period, a minimum of 10 acceptable d of recorded DMI was required to accurately predict individual forage DMI. If 10 acceptable d of recorded DMI were not achieved within the 21 d evaluation, the DMI evaluation was extended until this criterion was met.

During both evaluation periods, measurements were taken to characterize each individual cow production traits. On d-1 and d0 of the 60-d postpartum (lactating) evaluation, twenty-four h milk production estimates were determined using a 12-h weigh-suckle-weigh technique (Beal et al., 1990). At the conclusion of each evaluation period, cow BW was determined by the average of 2 consecutive days full BW. Individual hip heights were recorded. Body condition scores (1-9 scale) were assigned by a trained technician. Cow ultrasonic 12th rib fat thickness measurements were taken via trained personnel using an Aloka500SV B-110 mode instrument equipped with a 3.5-Mhz general purpose transducer array. Twelfth rib fat thickness measurements were taken in transverse orientation between the 12th and 13th ribs approximately 10 cm distal from the midline.

Feed Sampling and Analysis

In year 1, NRC (1996) values were used to determine composition of growing heifer diet individual feed ingredients. For years 2 and 3, growing heifer diet individual feed ingredients were sampled and analyzed at Rock River Laboratory (Watertown, WI). For year 4, growing heifer diet individual feed ingredients were sampled every 2 wk during the postweaning performance and intake evaluation period. Single cow forage feed ingredient samples were taken for all years and for both evaluation periods. Growing heifer diet feed ingredient samples were dried at 55° C for 3 d, ground using a Wiley mill (1-mm screen, Arthur H. Thomas, Philadelphia, PA), and composited at the end of each postweaning test. All diet ingredients for cows and heifers were individually analyzed for NDF and ADF (using Ankom Technology method 5 and

6, respectively; Ankom[200] Fiber Analyzer, Ankom Technology), CP (Leco TruMac, LECO Corporation, St. Joseph, MI), fat (ether extract method; Ankom Technology), and ash (600° C for 2 h; Thermolyte muffle oven Model F30420C, Thermo Scientific, Waltham, MA). For all years, feed ingredient compositions were used to construct overall diet composition.

Statistical Analysis

The descriptive statistics for all variables were calculated using the PROC UNIVARIATE procedure in SAS (SAS Institute Inc., Cary, NC). Heifer RFI was calculated using the PROC MIXED procedure of SAS. For all years, animals were separated into 16 contemporary groups, based on year born, breed type, and source of origin. For years 1, 2, and 3, RFI was assumed to represent the residuals from a multiple regression model regressing DMI on ADG and MMW, using pen as a random effect. For year 4, RFI was assumed to represent the residuals from a multiple regression model regressing DMI on ADG, MMW, and BF using pen as a random effect.

Heifers were classified as low, medium, or high RFI or DMI. Classification groups were established by calculation of the mean and SD of the heifers for RFI and DMI within their respective contemporary groups. Heifers that had RFI and DMI values that were less than 0.5 SD below the mean were classified as "Low." Heifers that had RFI and DMI values that were ± 0.5 SD of the mean were classified as "Med." Heifers that had RFI and DMI values that were greater than 0.5 SD above the mean were classified as "High."

Since individual DMI was recorded using GrowSafe units, individual animal served as the experimental unit. Simple pearson correlations were calculated among heifer performance, intake and efficiency; as well as cow performance traits, intake, and efficiency using the PROC

CORR procedure of SAS. Rho values were considered significant when $P \leq 0.05$. Correlations were considered strong when rho values were greater than or equal to 0.70; moderate when rho values were between 0.30 and 0.69; and weak when less than 0.29. The PROC MIXED procedure of SAS was used to test the effect of heifer DMI and RFI classification on cow production traits. The model used included the fixed effect of RFI or DMI classification group (high, medium, and low). The PROC GLIMMIX procedure of SAS was used to test the effect of heifer intake and efficiency classification on reproductive traits (binomial data). The model used included the fixed effect of RFI or DMI classification (high, medium, and low). When a significant ($P \leq 0.05$) effect was detected, least squares means were separated by the Pdiff option. Mean values were considered to be significantly different when $P \leq 0.05$ and considered a tendency when $P > 0.05$ and ≤ 0.15.

RESULTS

The descriptive statistics of cow production traits and voluntary forage DMI is presented in Table 3.3. A moderate, positive association existed (r= 0.46; $P < 0.05$) between heifer postweaning ADG and cow BW at 60 d postpartum (Table 3.4). Likewise, a similar relationship existed (r = 0.40; $P < 0.05$) between heifer postweaning ADG and cow BW at 240 d postpartum. A moderate correlation existed (r = 0.41; $P < 0.05$) between heifer ADG and cow hip height at 60 d postpartum; however, the linear relationship between ADG and cow hip height at 240 d postpartum was weaker (r = 0.18; $P < 0.05$). Heifer postweaning ADG was moderately correlated (r = 0.30; $P < 0.05$) to cow forage DMI at 60 d postpartum; however, was weakly correlated (r = 0.21; $P < 0.05$) to cow forage DMI at 240 d postpartum. No linear associations existed ($P \geq 0.06$) between heifer ADG and cow BCS, 12^{th} rib fat thickness, or milk production. Heifer postweaning DMI was also moderately correlated ($P < 0.05$) to 60 and 240 d postpartum cow BW at 0.36 and 0.33, respectively. A weak correlation existed (r = 0.29; $P < 0.05$) between heifer DMI and cow hip height at 60 d postpartum. However, heifer DMI was moderately correlated (r = 0.32; $P < 0.05$) to cow hip height at 240 d postpartum. Moderate linear relationships existed (P < 0.05) between heifer DMI and cow forage DMI at 0.57 and 0.37 when evaluated at 60 and 240 d postpartum, respectively. Heifer DMI was weakly correlated (r = 0.27; $P < 0.05$) to cow 24 h milk production. No relationship existed ($P \geq 0.06$) between heifer RFI and cow BW, hip height, BCS, 24 h milk production, and 12th rib fat thickness when evaluated at either 60 or 240 d postpartum. A positive correlation existed (r = 0.21; $P < 0.05$) between heifer RFI and cow forage DMI at 60 d postpartum. However, heifer RFI and cow forage DMI at 240 d postpartum only tended to be related ($P = 0.06$) at 0.17.

The effects of heifer RFI classification on cow reproductive and performance traits are presented in Table 3.5. Heifer RFI classification had no effect ($P = 0.22$) on the percentage of heifers kept as replacements. Likewise, heifer RFI classification did not affect ($P \geq 0.18$) percentage of cows that calved as 2, 3, 4, and 5-yr old cows. At 60 d postpartum, heifer RFI classification had no effect ($P \geq 0.47$) on cow BW, hip height, BCS, 12th rib fat thickness, and 24 h milk production. However, cows classified as low RFI heifers tended ($P = 0.15$) to have decreased DMI at 60 d postpartum when compared to cows classified as high RFI heifers. Heifer RFI classification had no effect ($P \geq 0.58$) on cow BW, hip height, BCS, 12th rib fat thickness, or forage DMI when traits were measured at 240 d postpartum.

The effects of heifer DMI classification are presented in Table 3.6. Cows classified as low DMI heifers were less likely to be kept as replacements ($P < 0.01$) than cows classified as medium or high DMI heifers (48% vs. 75 and 70%, respectively). Heifer DMI classification had no effect ($P \geq 0.35$) on the percentage of retained replacements that calved at 2, 3, or 4 yr of age.

However, the percentage of replacements that calved at 5 yr of age was greater (64% vs. 49 and 43%, respectively; $P = 0.05$) for cows classified as low DMI heifers when compared to the percentage of replacements that calved at 5 yr of age for cows classified as medium or high DMI heifers. At 60 d postpartum, cows classified as low DMI heifers were lighter ($P < 0.01$) and had reduced ($P < 0.05$) hip heights when compared to cows classified as either medium or high DMI. Heifer DMI classification had no effect ($P \geq 0.20$) on cow BCS, 12th rib fat thickness, and 24 h milk production when cow traits were measured at 60 d postpartum. At 60 d postpartum, cows classified as High DMI heifers had increased ($P < 0.01$) DMI compared to cows classified as Low DMI heifers; the Med DMI heifer group was intermediate. Similar results were observed when cow traits were measured at 240 d postpartum. Cows classified as low DMI heifers had reduced ($P \leq 0.02$) BW and hip heights when compared to cows classified as medium or high DMI heifers. Heifer DMI classification had no effect ($P \geq 0.39$) on 240 d postpartum cow BCS or 12th rib fat thickness. Cows classified as High DMI heifers had increased ($P < 0.01$) DMI at 240 d postpartum when compared to cows classified as Low DMI heifers; the Med DMI heifer group was intermediate.

DISCUSSION

The objectives of this study were to determine if heifer performance, DMI, and RFI were related to 5 yr old cow DMI, productivity, and longevity. Accelerated growth rates in young animals have been associated with increased mature BW (Arthur et al., 2001b; Crowley et al., 2011). The linear associations between heifer ADG and cow BW and hip height at both evaluation periods suggest that heifers who experienced more postweaning gain also developed into larger mature, 5-yr-old cows. This increase in mature cow size can lead to increases in maintenance energy costs (Ferrell and Jenkins, 1984) and subsequent feed resources to meet this energy demand. The positive association between heifer postweaning ADG and cow forage DMI at 60 and 240 d postpartum reflect the increase in DMI due to increased cow size and maintenance requirements. Collectively, selection for heifer growth rates may not be a profitable option for producers with limiting forage resources, since increases in heifer postweaning ADG increase cow size and DMI without any positive impact on cow production traits.

The fact that no linear associations existed between heifer RFI and cow reproductive or performance traits was not surprising; since the physiological basis for RFI is that it is independent of production traits (Koch et al., 1963). A positive correlation between heifer RFI and mature cow forage DMI at 60 d postpartum suggests that improvements in heifer RFI can lead to a reduction in cow forage DMI, which was also observed when heifer RFI was compared to 2-yr-old cow forage DMI (Cassady et al., 2015). This evidence is also supported by a tendency for cows classified as low RFI heifers to have at least a 1.4 kg reduction in forage DMI at 60 d postpartum. The fact that heifer RFI classification had no effect on cow production traits is consistent with heifer RFI being independent of mature cow size (Koch et al., 1963; Arthur and Herd, 2008; Black et al., 2013). Since heifer RFI was not correlated to cow production or reproductive traits; and heifer RFI classification did not affect cow production traits, we assume that selection for RFI will not result in detrimental cow productivity, but may potentially reduce forage DMI at 60 d postpartum. This finding is important to improving cowherd efficiency, since profitability is a function of outputs and inputs. However, heifer RFI was not related to cow forage DMI at 240 d postpartum, and heifer DMI or RFI classification had no effect on cow forage DMI at 240 d postpartum. Therefore, heifer RFI may be more effective in reducing cow forage DMI when energy demands are greater due to lactation.

The linear associations between heifer postweaning DMI and cow forage DMI at both evaluation periods is consistent with Cassady et al. (2015); who reported a correlation of 0.57 and 0.52 when comparing heifer DMI and cow forage DMI at 60- and 240-d postpartum, respectively. This suggests that DMI is repeatable across different stages of age and maturity, and heifer DMI information can be used as a predictor of mature cow forage DMI. Since heifer DMI and ADG are correlated (Cassady et al., 2015; Schwartzkopf-Genswein et al., 2002), it was no surprise that a greater percentage of heifers classified as low DMI were culled prior to their first breeding season due to poor performance. However, those cows classified as low DMI heifers that were retained were more likely to stay within the herd as 5-yr old cows; and had reduced BW and hip height. This reduction in mature cow size led to a reduction in cow forage DMI during both evaluation periods, which is possibly due to a reduction in maintenance energy requirements. Collectively, those cows classified as low DMI heifers that were kept as replacements had improved longevity, since DMI classification had no effect on production traits, yet led to a reduction in feed intake and positively influenced stayability. Cows classified as low DMI were more efficient as 2-yr-olds (Cassady et al., 2015), and mature, 5-yr-old cows were also more efficient due to improved longevity as defined by Robertson (1973); where cowherd efficiency is influenced by a dam's ability to produce a marketable calf each year with moderate DMI.

In conclusion, results from this study demonstrate that improvements in heifer RFI do not negatively impact cow longevity or productivity as 5-yr olds. However, improvements in heifer RFI resulted in a minor reduction in cow forage DMI at 60 d postpartum, and no reduction in forage DMI at 240 d postpartum. Collectively, RFI can be selected for when retaining replacements, but the most drastic improvements in cow efficiency may be observed when cows are in peak lactation. More importantly, this study demonstrates that heifer DMI and cow forage DMI is repeatable as 5-yr-old mature cows. Heifers with reduced postweaning DMI were less likely to be kept before the first breeding season, yet those that were retained had a greater probability of staying in the herd at 5-yr of age. Cows classified as low DMI heifers were smaller and ate less, without any negative impact on cow production traits. This study proves that relationships exist between heifer DMI and feed efficiency and the productivity and longevity of mature, 5-yr-old cows. Therefore, these measures could be used as selection criteria for cow-calf enterprises striving to become more efficient. Heifer DMI should be considered in maternal and all-purpose bioeconomic indices, since DMI accounts for the greatest input cost in cowherds, and DMI is repeatable across ages. More research is needed to evaluate the relationship between heifer RFI and mature cow forage DMI during the dry phase of production.

TABLES

Table 3.1 Composition of heifer diets, %DM

	Year			
Item	1	2	3	4
Corn husklage	-	67	65	-
Alfalfa hay	-	5	-	-
Corn silage	78.5	-	-	75
Alfalfa haylage	-	-	-	-
Corn gluten feed	-	23	25	-
Dry distillers grains with solubles	-	-	-	25
Wet distillers grains with solubles	16.5	-	-	-
Supplement[1]	5	5	10	-
Analyzed Values				
NDF, %	43.1	34.8	35.7	43.8
ADF, %	-	16.2	18.1	20.6
Fat, %	3.6	3.7	1.0	3.1
Protein, %	12.3	13.0	13.5	13.2

[1] Supplements fortified to meet or exceed NRC (1996) requirements for vitamins and minerals.

Table 3.2 Composition of 5-yr-old cow diets[1], %DM

	Year			
Item	6	7	8	9
Alfalfa hay	90	30	-	-
Oatlage	-	60	-	-
Corn condensed distillers solubles	10	10	-	-
Alfalfa haylage	-	-	100	100
Analyzed Values				
NDF, %	53.6	53.6	43.4	56.2
ADF, %	37.6	33.7	33.1	38.4
Fat, %	2.0	2.6	2.6	3.5
Protein, %	13.3	14.0	18.5	17.7

[1] Cows were offered a free-choice mineral consisting of: 69.8% Salt, 4.6% Ca (Ca_2PO_4 and $CaCO_3$), 2.58% P (Ca_2HPO_4), 0.2% Mg (MgO), 0.02% K (Ca_2PO_4 and $CaCO_3$), 0.3% S (Ca_2PO_4 and $CaCO_3$), 1.34% Fe ($FeSO_4$), 1.1% Zn (ZnO), 1.3 mg/kg Co (Ca_2PO_4), 112 mg/kg I ($C_2H_{10}I_2N_2$), 3419 mg/kg Cu (Cu_2SO_4), 2190 mg/kg Mn ($MnSO_4$), 32 mg/kg Se (Na_2SeO_3), 6640 IU/kg vitamin A, 664 IU/kg vitamin D3, 89 IU/kg vitamin E.

Table 3.3 Raw mean 5-yr-old cow performance, efficiency, and SD during both production periods

Item	Mean	SD	Minimum	Maximum
BW[1], kg	628	87	463	838
Hip height[1], cm	135	4	122	142
BCS[1]	5.7	0.7	3.5	8.0
TRBF[1,3], cm	0.63	0.30	0.30	1.63
24-h milk production, kg	9	3	1	17
DMI[1], kg/d	13.0	3.3	6.9	24.4
BW[2], kg	673	83	483	925
Hip height[2], cm	136	4	127	145
BCS[2]	6.0	0.6	4.0	8.0
TRBF[2,3], cm	0.81	0.34	0.30	1.67
DMI[2], kg/d	11.6	2.1	5.7	16.7

[1] 60 d postpartum (lactating)
[2] 240 d postpartum (dry)
[3] 12^{th} rib fat thickness

Table 3.4 Simple linear phenotypic correlations between heifer postweaning variables and cow performance and forage DMI

	Five-year old cow traits measured at 60-d postpartum						Five-year old cow traits measured at 240-d postpartum				
	BW	HH[1]	BCS	TRBF[2]	DMI	Milk[3]	BW	HH[1]	BCS	TRBF[2]	DMI
Heifer traits											
ADG	**0.46**	**0.41**	-0.06	0.07	**0.30**	0.18	**0.40**	**0.18**	0.08	0.08	**0.21**
DMI	**0.36**	**0.29**	-0.13	-0.02	**0.57**	**0.27**	**0.33**	**0.32**	0.01	0.07	**0.37**
RFI[4]	0.05	0.03	0.05	0.10	**0.21**	0.02	0.02	0.04	-0.05	0.05	0.17

[a] |R| values in bold are significant (*P* < 0.05)
[1] Hip height
[2] 12th rib fat thickness
[3] 24-h milk production
[4] Residual feed intake

Table 3.5 Effects of RFI classification on female reproductive and performance traits

Item	Heifer RFI Category			SEM	*P*-value
	Low	Med	High		
Reproductive traits					
Retained as replacement[1], % (n)	60 (75/124)	70 (109/154)	63 (80/126)	-	0.22
Calved at 2 yr of age[1], % (n)	91 (68/75)	85 (91/109)	88 (70/80)	-	0.60
Calved at 3 yr of age[1], % (n)	77 (58/75)	71 (77/109)	76 (61/80)	-	0.69
Calved at 4 yr of age[1], % (n)	73 (54/75)	61 (64/109)	71 (55/80)	-	0.18
Calved at 5 yr of age[1], % (n)	56 (43/75)	47 (52/109)	50 (41/80)	-	0.46
5-yr-old cows (lactating)[2]					
BW, kg	623	626	637	15	0.76
Hip height, cm	134.6	135.2	135.2	0.7	0.77
BCS	5.7	5.7	5.7	0.1	0.93
TRBF[3], cm	0.60	0.63	0.66	0.05	0.62
24 h milk production, kg	9	9	10	0.5	0.47
DMI, kg	12.2^{y}	13.3^{xy}	13.6^{x}	0.5	0.15
5-yr-old cows (dry)[4]					
BW, kg	665	682	668	14	0.61
Hip height, cm	136.2	136.7	136.0	0.7	0.70
BCS	6.0	6.0	5.9	0.1	0.79
TRBF[3], cm	0.77	0.84	0.82	0.06	0.58
DMI, kg	11.5	11.5	11.8	0.5	0.74

[a,b] Row means that do not have a common superscript differ, $P \leq 0.05$

[x,y] Row means that do not have a common superscript tend to differ, $P > 0.05$ and ≤ 0.15

[1] LS means from Glimmix procedure of SAS

[2] 5-yr-old cow traits measured at 60d postpartum

[3] Twelfth rib fat thickness

[4] 5-yr-old cow traits measured at 240d postpartum

Table 3.6 Effects of DMI classification on female reproductive and performance traits

Item	Heifer DMI Category			SEM	*P*-value
	Low	Med	High		
Reproductive traits					
Retained as replacement[1] % (n)	48 (59/122)[b]	75 (116/155)[a]	70 (89/127)[a]	-	<0.01
Calved at 2 yr of age[1] % (n)	88 (52/59)	87 (98/116)	89 (79/89)	-	0.92
Calved at 3 yr of age[1] % (n)	79 (47/59)	73 (83/116)	74 (66/89)	-	0.66
Calved at 4 yr of age[1] % (n)	74 (44/59)	63 (70/116)	69 (59/89)	-	0.35
Calved at 5 yr of age[1] % (n)	64 (38/59)[a]	49 (57/116)[ab]	43 (41/89)[b]	-	0.05
5-yr-old cows (lactating)[2]					
BW, kg	586[b]	640[a]	655[a]	15	<0.01
Hip height, cm	132.8[b]	135.5[a]	136.6[a]	0.7	<0.01
BCS	5.5	5.8	5.7	0.1	0.25
TRBF[3], cm	0.57	0.67	0.63	0.05	0.29
24 h milk production, kg	9	10	10	0.4	0.20
DMI, kg	11.7[c]	13.1[b]	14.4[a]	0.6	<0.01
5-yr-old cows (dry)[4]					
BW, kg	638[b]	682[a]	692[a]	13	<0.01
Hip height, cm	135.0[b]	136.5[ab]	137.5[a]	0.4	0.02
BCS	6.0	6.0	6.0	0.1	0.92
TRBF[3], cm	0.75	0.84	0.83	0.05	0.39
DMI, kg	10.6[c]	11.5[b]	12.7[a]	0.3	<0.01

[a,b] Row means that do not have a common superscript differ, $P \leq 0.05$

[1] LS means from Glimmix procedure of SAS

[2] 5-yr-old cow traits measured at 60d postpartum

[3] Twelfth rib fat thickness

[4] 5-yr-old cow traits measured at 240d postpartum

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CHAPTER 4

RELATIONSHIP BETWEEN HEIFER FEED EFFICIENCY MEASURES AND INTAKE OF HIGH- AND POOR-QUALITY FORAGE IN MATURE BEEF COWS

ABSTRACT

The objective of this study was to determine the relationship between measures of heifer feed efficiency and mature cow intake of good-quality and poor-quality forage. Measures of feed efficiency were determined in crossbred heifers (n=139). Individual intakes were recorded using the GrowSafe automated feeding system. Residual feed intake (RFI) was assumed to represent the residuals from a multiple regression model regressing DMI on ADG and mid-metabolic BW. Residual BW gain (RG) was assumed to represent the residuals from a multiple regression model regressing ADG on DMI and mid-metabolic BW. Residual intake and BW gain (RIG) was calculated as the sum of -1 x RFI and RG standardized to a variance of 1. Ranking of high, medium, and low feed efficiency and DMI groups were established by calculation of the mean and SD of the heifers grouping them within ± 0.5 SD of the mean. These heifers were kept as replacements and, as 5 or 6-yr old cows, were placed on GrowSafe during mid-gestation to record individual voluntary forage intake. Cows were randomly allotted to 1 of 2 diets: 1) high-quality forage diet (HQ; 100% alfalfa haylage), and 2) poor-quality forage diet (PQ; 80% switchgrass, 20% corn condensed distillers solubles). After 2 wk of intake were recorded for each diet, cows switched diets and another 2 wk of intake were recorded. Performance traits evaluated were DMI, hip height, BW, BCS, and backfat via ultrasound. Heifer RFI classification had no effect on cow traits; yet, cows classified with the least desirable heifer RFI had the greatest ($P \leq 0.05$) HQDMI and PQDMI. Heifer RG classification had no effect on cow production traits or DMI. Heifer RIG classification had no effect on cow traits. Cows classified as low RIG heifers had the greatest (*P* = 0.02) HQDMI; yet, only tended to have the greatest PQDMI (*P* = 0.09). Cows classified as high DMI heifers were heavier (*P* = 0.05) and had greater ($P < 0.01$) DMI than cows classified as low or medium DMI heifers. Heifer RFI and DMI can accurately predict mature cow intake of forages of divergent quality; yet, heifer RIG measures may only be accurate in predicting cow forage intake within a respective production system of interest due to different forage availability.

Key words: beef cow, efficiency, forage quality, RFI

INTRODUCTION

Cattle prices have increased compared to past decades (Feuz et al., 2001; Schulz, 2015); thus, the increased value of beef provides incentive to maximize production outputs. However, profitability in the beef industry is a function of outputs and inputs, and little emphasis has been placed on costs associated with beef production. Feed costs alone account for over 60% of total costs associated with maintaining a beef cow and are the largest detriment to profitability to beef producers (Miller et al., 2001). To alleviate these financial strains, beef producers should strive to become more efficient. Identifying cattle that have more effective nutrient utilization has led to growing interest in alternative feed efficiency traits, such as: residual feed intake (**RFI**), residual body weight gain (**RG**), and residual intake and body weight gain (**RIG**). If feed intake can be reduced without an impact on cowherd and feedlot productivity, operational cost can be easily reduced.

Studies have been conducted evaluating feed efficiency in cow-calf enterprises; and the relationships between heifer feed efficiency and cow performance and intake is well documented (Herd and Bishop, 2000; Black et al., 2013). However, re-ranking of feed efficiency can occur when feedlot cattle are fed diets varying in energy content (Durunna et al., 2011); which may be directly related to chemical or physical regulation of feed intake. Limited work has been done evaluating the relationship of heifer feed efficiency and DMI when tested on a growing diet and DMI of high- or poor-quality forages as mature cows. We hypothesized that heifer feed DMI and efficiency will have a stronger relationship to mature cow intake of high-quality forage, because most heifer development systems utilize high-quality diets. The objective of this study was to determine the relationship between RFI, RG, RIG, and DMI in heifers during the postweaning period and mature cow performance and intake of high- and poor-quality forage.

MATERIALS AND METHODS

Experimental Animals

Two hundred sixty-three fall-born crossbred heifers (yr 1, n = 144; yr 2, n = 119) from the Dixon Springs Agricultural Center in Simpson, Illinois were used to determine the relationship between measures of heifer feed efficiency and mature cow intake of good-quality and poor-quality forage. Heifers were early weaned (103 ± 11 d of age) and normal weaned (198 ± 10 d of age) in years 1 and 2, respectively. Following weaning and backgrounding (yr 1 only), heifers were managed together as a group and fed a common growing diet at the University of Illinois Beef Field Research Laboratory in Urbana, IL each year. All cattle were managed according to the guidelines endorsed in Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010). All procedures involving animals in this study were approved by the University of Illinois Animal Care and Use Committee.

Postweaning Intake and Efficiency Evaluation

For 2 consecutive years, an 84-d postweaning intake and performance evaluation was conducted on growing heifers (age = 306 ± 12 d; initial BW = 279 ± 26 kg) at the University of Illinois Beef and Sheep Field Research Laboratory in Urbana, IL. Following a 3-wk transition to the performance test diet, heifers were allowed ad-libitum access to a growing diet (Table 4.1), which was formulated to meet or exceed growing heifer nutrient requirements (NRC, 1996). Each year, heifers were randomly allotted to pens equipped with a GrowSafe automated feeding system (Model 4000E, GrowSafe Systems Ltd., Alberta, Canada). Individual DMI was recorded and audited daily by a trained personnel. Feed intake data were considered acceptable if at least 85% of feed supplied to the bunk and 90% of corresponding feed assigned to an individual ID were accounted for. A minimum of 42-d of acceptable intake data were recorded each year to determine individual DMI. Initial and final BW were determined by 2 consecutive weights at the beginning and end of the test period. Individual animal ADG was then determined by dividing the difference of the beginning and end weights by the number of days on feed. Individual animal mid-test metabolic weight (**MWW**) was determined by the average of the initial and final BW of the test period, taken to the 0.75 power. In year 2, 12th rib fat thickness (**BF**) measurements were taken via ultrasound. These ultrasound measurements were taken by a trained technician with an Aloka 500SV (Wallingford, CT) B-110 mode instrument equipped with a 3.5-MHz transducer array. Images were analyzed using CPEC imaging software (Cattle Performance Enhancement Company LLC., Oakley, KS).

Heifers with poor performance, structural soundness problems, poor disposition, or reproductive inadequacies were culled each year prior to the breeding season. During and after the breeding season, pregnant heifers were managed as a group and rotated through mixed pastures of endophyte infected fescue (*Festuca arundinacea*), red clover (*Trifolium pretense*), and orchard grass (*Dactylis glomerata*).

Calculation of Heifer Feed Efficiency

Heifer residual feed intake, RG, and RIG were calculated for each individual animal. For year 1, RFI was assumed to represent the residuals of from a multiple regression model regressing DMI on ADG and MMW, using pen as a random effect. For year 2, RFI was assumed to represent the residuals of a multiple regression equation, regressing DMI on ADG, MMW, and BF, using pen as a random effect. Likewise, heifer RG was assumed to represent a regression equation, regressing ADG on DMI, MMW, and BF, using pen as a random effect. In order to retain the favorable characteristics of moderate intake and favorable gains associated from RFI and RG respectively, RIG was calculated individually and represented the sum of negative RFI and RG, both standardized to a variance of 1 (Berry and Crowley, 2012). Heifers were classified as either low, medium, or high DMI, RFI, RG, or RIG. Classification groups were established by calculation of the mean and SD of the heifers for DMI, RFI, RG, and RIG. Heifers that were less than 0.5 SD below the mean were classified as “Low,” heifers that were ± 0.5 SD of the mean were classified as “Med,” and heifers that were more than 0.5 SD above the mean were classified as “High.”

Mature cow evaluation

Following the breeding season each year, cows were culled each due to reproductive failure, feet and udder problems, poor docility, or other health reasons. Five-and six-year old cows that still remained in the herd and produced a live calf each year were observed during midgestation (n =139; 195 ± 12 d postpartum). Cows were placed into the barns during midgestation at the Beef and Sheep Field Research Laboratory in Urbana, IL. Cows were randomly allotted and adapted (1 wk) to one of two forage-based diets: high-quality forage or poor quality forage (Table 4.2). Individual feed intakes were collected using the Growsafe automated feeding system. Intakes were audited daily by a trained professional. Feed intake data were considered acceptable if at least 85% of feed supplied to the bunk and 90% of corresponding feed assigned to an individual ID were accounted for. For the first phase of the intake evaluation, cow forage DMI was recorded for at least 14 d. Within this 14 d evaluation period, a minimum of 10 acceptable d of recorded DMI was required to accurately predict individual forage DMI. If 10 acceptable d of recorded DMI were not achieved within the 14 d evaluation, the DMI evaluation was extended until this criterion was met. After the first 14 d period of DMI evaluation, diets were switched, and another 14 d DMI evaluation was conducted following the same required audit criteria described previously.

Collectively, intake of high-quality (**HQDMI**) and poor-quality forage (**PQDMI**) was recorded for each individual cow. At the conclusion of both intake evaluation periods, cows were characterized relative to production traits. Cow BW represented the average of two consecutive d weights, individual hip heights were recorded, BCS scores (1-9 scale) were assigned by a trained technician, and cows were ultrasound for 12^{th} rib fat thickness using an Aloka 500SV (Wallingford, CT) B-110 mode instrument equipped with a 3.5-MHz transducer array. Ultrasonic images were analyzed using CPEC imaging software (Cattle Performance Enhancement Company LLC., Oakley, KS).

Feed Sampling and Analysis

For both years, NRC (1996) values were used to determine composition of individual feed ingredients for heifer diets. During the mature cow evaluation, individual feed ingredient samples were taken at the end of the observation period. Feed ingredient samples from both groups were dried at 55° C for 3 d, ground using a Wiley mill (1-mm screen, Arthur H. Thomas, Philadelphia, PA). Ingredients were individually analyzed for NDF and ADF (using Ankom Technology method 5 and 6, respectively; $Ankom^{200}$ Fiber Analyzer, Ankom Technology), CP (Leco TruMac, LECO Corporation, St. Joseph, MI), fat (ether extract method; Ankom Technology), and ash (600° C for 2 h; Thermolyte muffle oven Model F30420C, Thermo Scientific, Waltham, MA). For all years, feed ingredient compositions were used to construct overall diet composition.

Statistical Analysis

Individual animal served as the experimental unit. The descriptive statistics for all heifer and cow traits were calculated using the PROC UNIVARIATE procedure in SAS (SAS Institute Inc., Cary, NC). The PROC CORR procedure of SAS was used to test the relationships of individual heifer postweaning performance, intake, and efficiency traits. All rho values were considered significant when $P \leq 0.05$. Correlations were considered strong when rho values were greater than or equal to 0.70; moderate when rho values were between 0.30 and 0.69; and weak when less than 0.29. The MIXED procedure of SAS was used to test the effect of heifer intake or efficiency classification on heifer residual feed intake of cows still remaining in the herd at 5- or 6-yr of age, cow production traits (BW, hip height, BCS, BF) as well as individual HQDMI and PQDMI. The model included the fixed effect of RFI, RG, RIG, or DMI classification group (high, medium, and low) and initial cow forage treatment was assigned as a covariate. The PROC GLIMMIX procedure of SAS was used to test the effect of heifer DMI and efficiency classification on reproductive traits (binomial data). The model used included the fixed effect of RFI, RG, RIG, or DMI classification (high, medium, and low). When a significant ($P \leq 0.05$) effect was detected, least squares means were separated by the Pdiff option. Trends are discussed when $P > 0.05$ and ≤ 0.10.

RESULTS

The descriptive statistics of heifer postweaning performance, intake, and efficiency are presented in Table 4.3. During the postweaning period, a moderate correlation existed (r = 0.51; $P < 0.05$) between DMI and ADG (Table 4.4.). Likewise, a moderate positive association between postweaning DMI and FCR was observed (r = 0.66; $P < 0.05$). Heifer postweaning DMI was also correlated ($P < 0.05$) to heifer RFI and RIG at 0.30 and -0.18, respectively. No linear relationship existed ($P > 0.05$) between DMI and RG. Heifer postweaning ADG was correlated

(P < 0.05) to FCR, RG, and RIG at -0.26, 0.74, and 0.45, respectively. Heifer postweaning ADG and RFI were not correlated (P > 0.05). The moderate, negative association between heifer RFI and RG (r = -0.35; P < 0.05) suggests that improvements in RFI resulted in improved RG. Subsequently, heifer RIG was strongly correlated (P < 0.05) to RFI and RG at -0.81 and 0.82, respectively.

The descriptive statistics of cow performance and intake of high- and poor-quality forage are presented in Table 4.5. Heifer RFI classification had no effect (P = 0.11) on the percentage of cows that still remained in the herd at either 5- or 6-yr of age (Table 4.6). Mean heifer RFI values of cows still in the herd were greater (P < 0.01) for cows classified as high RFI as compared to cows classified as low RFI heifers, the med RFI heifer group was intermediate. RFI classification had no effect ($P \geq 0.49$) on 5- and 6-yr old mature cow BW, hip height, BCS, or 12^{th} rib fat thickness. Heifers classified as low or medium RFI had reduced (P < 0.01) HQDMI and PQDMI compared to cows classified as high RFI heifers.

The effects of heifer RG classification on performance traits are presented in table 4.7. Percentage of cows still remaining in the herd at 5- and 6-yr of age were not different (P = 0.65) among heifer RG classification groups. Mean heifer RG values of cows still in the herd were greater (P < 0.01) for cows classified as high RG as compared to cows classified as low RG heifers, the med RG heifer group was intermediate. Heifer RG classification had no effect ($P \geq$ 0.24) on mature cow performance traits including: BW, hip height, BCS, and 12^{th} rib fat thickness. Similarly, heifer RG classification had no effect ($P \geq 0.29$) on cow HQDMI or PQDMI.

The percentage of cows remaining in the herd at 5- or 6-yr of age were not affected (P = 0.85) by heifer RIG classification (Table 4.8). Mean heifer RIG values of cows still in the herd were greater ($P < 0.01$) for cows classified as high RIG as compared to cows classified as low RIG heifers, the med RIG heifer group was intermediate. Heifer RIG classification had no effect ($P \geq 0.17$) on mature cow BW, hip height, BCS, or 12th rib fat thickness. Mature cows classified as low RIG heifers had greater ($P = 0.02$) HQDMI compared to mature cows classified as high RIG heifers; mature cows classified as medium RIG heifers were intermediate. Mature cows classified as low RIG heifers tended ($P = 0.09$) to have greater PQDMI compared to mature cows classified as medium RIG; mature cows classified as high RIG were intermediate.

The effects of heifer DMI classification on mature cow performance and DMI are presented in Table 4.9. Heifer DMI classification had no effect (P = 0.15) on the percentage of cows still remaining in the herd at 5- and 6-yr of age. Mean heifer DMI values of cows still in the herd were greater ($P < 0.01$) for cows classified as high DMI as compared to cows classified as low DMI heifers, the med DMI heifer group was intermediate. Mature cows classified as low DMI heifers had reduced ($P = 0.05$) BW compared to mature cows classified as high DMI heifers; the medium heifer DMI group was intermediate. There were no differences ($P \geq 0.11$) in mature cow hip height, BCS, and 12th rib fat thickness between heifer DMI classification groups. Mature cows classified as high DMI heifers had the greatest ($P < 0.01$) HQDMI compared to mature cows classified as low or medium DMI heifers. Similarly, mature cows classified as high DMI heifers also had the greatest ($P < 0.05$) PQDMI compared to mature cows classified as low or medium DMI heifers.

DISCUSSION

Research has shown that cattle may need to be tested for feed efficiency using diet types similar to the production environment of interest (Durunna et al., 2011; Russell et al., 2016). This is primarily due to the many mechanisms of intake regulation whereas energy-dense diets are controlled metabolically or chemostatically (NRC, 1996), and “gut fill” limits intake of poor quality forages (Mertens, 1994). Many heifer development systems are based on high-quality feeds, which may mean that heifer feed DMI and efficiency measured in these systems may not be a viable predictor of cow intake of poor quality forage. Therefore, the objective of this study was to determine the relationship between RFI, RG, RIG, and DMI in heifers during the postweaning period using a traditional, high-quality feeding system, and mature cow performance and intake of high- and poor-quality forage.

The moderate linear relationship between heifer DMI and ADG suggested that heifers that have greater DMI also experienced more ADG, which mirrored the findings of Schwartzkopf-Genswein et al. (2002). This explained the positive linear relationship between heifer DMI and initial BW, MMW, and final BW. Since FCR was a function of DMI and animal BW gain, it was no surprise that heifer postweaning DMI and ADG were correlated to FCR. However, since the correlation between DMI and FCR was greater than the correlation between ADG and FCR ($r = 0.66$ vs -0.26), a greater amount of variation in heifer FCR was explained by differences in individual heifer DMI. The moderate association between heifer DMI and RFI explained that increases in feed consumption result in less desirable RFI, which is consistent with previous literature (Basarab et al., 2003; Nkumrah et al., 2007). Improvements in RG can result in accelerated growth rates in the feedlot (Retallick et al., 2013), and the strong linear relationship between heifer postweaning ADG and RG in this study confirmed that when young cattle are provided with ad libitum access to feed, those with superior growth traits have more desirable RG. Heifer postweaning ADG and DMI were correlated to RIG which was also supported by Berry and Crowley (2012). The moderate correlation between heifer FCR and residual feed efficiency traits suggested that improvements in FCR are related to more desirable

RFI, RG, and RIG. These associations between measures of feed efficiency have been well documented (Herd and Bishop, 2000; Berry and Crowley, 2012), and suggest that traditional measures of feed efficiency may lead to improved residual feed efficiency measures. The negative relationship between heifer RFI and RG explained that improvements in RFI lead to more desirable RG. Heifer RFI and RG were strongly correlated to RIG, which was not surprising since RIG is a direct function of RFI and RG.

The physiological basis for RFI is that it is independent of production traits such as cow size, milk production, etc. (Koch et al., 1963; Arthur and Herd, 2008; Black et al., 2013). Cow longevity, and measured production traits of BW, hip height, BCS, and 12th rib fat thickness were not affected by heifer RFI classification, which is consistent with the theory of RFI. However, cows classified as high or "inefficient" heifers based on RFI also had the greatest HQDMI and PQDMI. We hypothesized that RFI would be a more accurate predictor of HQDMI since heifer RFI was determined using high-quality growing diets. However, regardless of forage quality, cows classified as inefficient heifers based on RFI consumed more forage. These findings suggest that characterizing heifers via RFI in traditional heifer development systems resulted in a reduction in feed intake regardless of forage quality, without affecting cow performance traits during midgestation.

Residual BW gain is an effective tool used in the feedlot sector due to its positive association with increased growth rates and improved FCR (Retallick et al., 2013). This is important in terminal production systems, as producers can increase endpoint pay weights, and return more profit. However, RG may not be an effective tool for cow-calf producers. Since RG is strongly correlated to postweaning growth traits, selection for RG in replacement heifers may lead to increased mature cow BW. This is important, as increased cow BW may lead to greater maintenance energy costs (Ferrell and Jenkins, 1984). Surprisingly, there were no effects of heifer RG classification on cow production traits, especially cow size, since RG is related to relative growth rates (Berry and Crowley, 2012). Intake of high- and poor-quality forage was also not affected by heifer RG classification. Therefore, RG may still be a useful measure of feed efficiency due to its benefit to the feedlot and lack of impact on mature cow production traits and DMI.

To combine the desirable characteristics associated with RFI and RG, Berry and Crowley (2012) proposed a dual-purpose residual feed efficiency measure (RIG) that may be applicable to all sectors of beef production. Research has shown the benefits of RIG in the feedlot (Retallick et al., 2013), yet minimal work has been done evaluating the effect of heifer RIG on cow production traits and DMI. Heifer RIG classification had no effect on cow production traits or longevity. Cows classified as heifers who were more efficient based on RIG had reduced HQDMI compared to cows classified as heifers with inefficient RIG. However, cows that were classified as low RIG heifers only tended to have the greater PQDMI when compared to cows classified as medium RIG. Improvements in RIG resulted in a reduction in HQDMI without negatively impacting cow size or production traits. This can be beneficial for producers who have access to high-quality forages, and can reduce feed costs without impacting outputs. However, cows classified as inefficient heifer RIG only tended to have increased PQDMI compared to the medium and low RIG groups. Selecting for improvements in RIG are more effective in reducing DMI when a high-quality forage is provided. This may be attributed to the fact that the measures of heifer feed efficiency in this experiment were derived using high-quality feeds. Collectively, RIG values may only be used most effectively on diet types and production environments of interest.

Animal feed consumption represents the single greatest cost in beef production (Miller et al., 2001), and cowherd efficiency can be improved by a reduction in feed consumption. Cows that ate less as heifers had a 7% reduction in mature cow BW. Although cows classified as low DMI heifers were smaller, heifer intake classification had no significant negative effects on cow body composition. More importantly, cows that ate more as heifers had the greatest forage DMI regardless of quality. These results suggest that selection for heifers with greater DMI results in increased mature cow BW; and subsequent increases in DMI regardless of forage nutritional content.

In conclusion, heifers that are less efficient based on RFI consumed more DMI regardless of forage quality. Therefore, a variety of production systems across different grazing systems can utilize heifer RFI as a means of predicting input costs at a later stage of maturity. No relationship existed between heifer RG and intake of high-and poor-quality forage, which suggests that selection for RG in heifers will not result in any differences in intake of forages as mature cows. When heifer RIG values are calculated using high-quality growing diets, heifer RIG does not affect mature cow size, but may more accurately predict cow forage DMI when high-quality forages are offered. Lastly, cows that ate more as heifers had greater mature cow BW during midgestation, and consumed more than 17% more forage compared to cows that had low or moderate intake as heifers. Heifer RFI and DMI can accurately predict mature cow intake of forages of divergent quality; yet, heifer RIG measures may only be accurate in predicting cow forage intake within a respective production system of interest due to forage or diet differences.

TABLES

Table 4.1 Composition of heifer diets

	Year[1]	
Item	1	2
Ingredient, %DM		
Ground pasture hay	40	-
Alfalfa haylage	40	-
Oatlage	-	92.5
Wet distillers grains with solubles	20	7.5
Calculated composition[2]		
Protein, %	18.4	13.7
TDN, %	67.2	61.3

[1] Heifers offered free choice mineral supplement fortified to meet or exceed NRC (1996) requirements for vitamins and minerals.
[2] NRC (1996)

Table 4.2 Composition of high- and poor-quality cow diets

Item	Poor-quality	High-quality
Ingredient, %DM		
Alfalfa haylage	-	100
Switchgrass	80	-
Corn condensed distillers solubles	20	-
Analyzed Values		
NDF, %	67.2	39.1
ADF, %	44.8	30.2
Fat, %	1.2	1.6
Protein, %	7.6	20.9

Table 4.3 Raw mean postweaning performance, efficiency, and SD for all heifers on test

Item	Mean	SD	Minimum	Maximum
Initial BW, kg	279	26	217	341
Final BW, kg	362	34	261	448
Mid-test BW, kg	320	29	247	392
Metabolic BW, kg	62	4	51	72
ADG, kg/d	0.95	0.15	0.28	1.36
DMI, kg/d	7.80	1.82	3.80	11.09
TRBF[1], cm	0.38	0.10	0.30	0.92
FCR[2]	8.30	0.83	2.28	8.50
Residual feed intake, kg	0.00	0.55	-1.76	1.53
Residual BW gain, kg	0.00	0.11	-0.40	0.34
Residual intake and BW gain	0.00	0.74	-2.48	1.89

[1]Twelfth rib fat thickness

[2]Feed conversion ratio expressed as feed:gain

Table 4.4 Simple linear phenotypic correlations among heifer postweaning variables

	iBW[1]	MMW[2]	fBW[3]	ADG	DMI	BF[4]	FCR[5]	RFI[6]	RG[7]	RIG[8]
iBW[1]	1	**0.97**	**0.92**	**0.36**	**0.35**	0.15	0.10	0.00	**-0.20**	-0.12
MMW[2]		1	**0.98**	**0.57**	**0.46**	0.16	0.05	0.00	0.00	0.00
fBW[3]			1	**0.70**	**0.53**	0.15	0.02	0.00	**0.15**	0.09
ADG				1	**0.51**	0.09	**-0.26**	0.00	**0.74**	**0.45**
DMI					1	0.13	**0.66**	**0.30**	0.00	**-0.18**
BF[4]						1	-0.01	0.00	0.00	0.00
FCR[5]							1	**0.35**	**-0.62**	**-0.59**
RFI[6]								1	**-0.35**	**-0.81**
RG[7]									1	**0.82**

|R| values in bold are significant ($P < 0.05$)

[1] Initial postweaning BW

[2] Mid-test metabolic BW

[3] Final BW

[4] Backfat

[5] Feed conversion ratio (feed:gain)

[6] Residual feed intake

[7] Residual BW gain

[8] Residual intake and BW gain

Table 4.5 Raw mean mature cow performance, intake, and SD during midgestation.

Item	Mean	SD	Minimum	Maximum
BW, kg	567	74	396	786
Hip height, cm	135	4	124	146
BCS	5.4	0.8	3.5	7.5
TRBF[1], cm	0.51	0.30	0.30	1.63
HQDMI[2], kg/d	10.1	1.3	2.9	18.6
PQDMI[3], kg	8.8	3.3	1.5	23.8

[1] 12^{th} rib fat thickness
[2] High-quality forage DMI
[3] Poor-quality forage DMI

Table 4.6 Effects of heifer RFI classification on cow longevity, performance, and intake of high- and poor-quality forage

	Heifer RFI Category				
Item	Low	Med	High	SEM	*P*-value
Cow longevity					
Remaining in the herd[1], % (n)	43 (36/83)	56 (57/101)	58 (46/79)	-	0.11
Heifer RFI[2], kg	-0.58[c]	-0.01[b]	0.60[a]		<0.01
Cow measured traits					
BW, kg	567	562	565	12	0.95
Hip height, cm	134.6	134.5	134.4	0.7	0.97
BCS	5.4	5.4	5.4	0.1	0.96
TRBF[3], cm	0.55	0.47	0.50	0.05	0.49
HQDMI[4], kg	9.2[b]	9.6[b]	11.1[a]	0.3	<0.01
PQDMI[5], kg	7.8[b]	8.4[b]	10.1[a]	0.5	<0.01

[a,b] Row means that do not have a common superscript differ, $P \leq 0.05$
[1] LS means from Glimmix procedure of SAS
[2] Mean heifer residual feed intake of cows still remaining in the herd at 5- or 6-yr of age
[3] 12[th] rib fat thickness
[4] DMI of high-quality forage
[5] DMI of poor-quality forage

Table 4.7 Effects of heifer RG classification on cow longevity, performance, and intake of high- and poor-quality forage

Item	Heifer RG Category			SEM	*P*-value
	Low	Med	High		
Cow longevity					
Remaining in the herd[1], % (n)	49 (40/82)	54 (51/95)	56 (48/86)	-	0.65
Heifer RG[2], kg	-0.12[c]	0.01[b]	0.12[a]	0.01	<0.01
Cow measured traits					
BW, kg	571	562	561	11	0.77
Hip height, cm	134.2	134.4	134.8	0.6	0.80
BCS	5.5	5.4	5.3	0.1	0.24
TRBF[3], cm	0.55	0.49	0.48	0.05	0.54
HQDMI[4], kg	10.1	10.3	9.6	0.3	0.29
PQDMI[5], kg	9.0	9.2	8.3	0.5	0.41

[a,b] Row means that do not have a common superscript differ, $P \leq 0.05$

[1] LS means from Glimmix procedure of SAS

[2] Mean heifer residual feed intake of cows still remaining in the herd at 5- or 6-yr of age

[3] 12th rib fat thickness

[4] DMI of high-quality forage

[5] DMI of poor-quality forage

Table 4.8 Effects of heifer RIG classification on cow longevity, performance, and intake of high- and poor-quality forage

Item	Heifer RIG Category				
	Low	Med	High	SEM	*P*-value
Cow longevity					
Remaining in the herd[1], % (n)	53 (40/76)	55 (57/104)	51 (42/83)	-	0.85
Heifer RIG[2], kg	-0.90[c]	0.02[b]	0.81[a]	0.05	<0.01
Cow measured traits					
BW, kg	575	558	562	11	0.48
Hip height, cm	134.4	134.3	134.8	0.6	0.80
BCS	5.6	5.3	5.3	0.1	0.17
TRBF[3], cm	0.57	0.46	0.49	0.05	0.22
HQDMI[4], kg	10.6[a]	10.1[ab]	9.3[b]	0.3	0.02
PQDMI[5], kg	9.7[x]	8.3[y]	8.7[xy]	0.5	0.09

[a,b] Row means that do not have a common superscript differ, $P \leq 0.05$

[x,y] Row means that do not have a common superscript tend to differ, $P > 0.05$ and < 0.10

[1] LS means from Glimmix procedure of SAS

[2] Mean heifer residual feed intake of cows still remaining in the herd at 5- or 6-yr of age

[3] 12th rib fat thickness

[4] DMI of high-quality forage

[5] DMI of poor-quality forage

Table 4.9 Effects of heifer DMI classification on cow longevity, performance, and intake of high- and poor-quality forage

Item	Heifer DMI Category			SEM	*P*-value
	Low	Med	High		
Cow longevity					
Remaining in the herd[1], % (n)	44 (31/70)	59 (70/119)	51 (38/74)	-	0.15
Heifer DMI[2], kg	6.89[c]	7.47[b]	8.40[a]	0.31	<0.01
Cow measured traits					
BW, kg	544[b]	562[ab]	585[a]	12	0.05
Hip height, cm	134.4	133.9	135.6	0.7	0.11
BCS	5.4	5.4	5.4	0.1	0.99
TRBF[3], cm	0.54	0.51	0.47	0.05	0.63
HQDMI[4], kg	9.0[b]	9.6[b]	11.4[a]	0.4	<0.01
PQDMI[5], kg	8.0[b]	8.4[b]	10.2[a]	0.6	<0.01

[a,b] Row means that do not have a common superscript differ, $P \leq 0.05$

[1] LS means from Glimmix procedure of SAS

[2] Mean heifer residual feed intake of cows still remaining in the herd at 5- or 6-yr of age

[3] 12th rib fat thickness

[4] DMI of high-quality forage

[5] DMI of poor-quality forage

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CHAPTER 5

EFFECTS OF TIMING AND DURATION OF TEST PERIOD AND DIET TYPE ON INTAKE AND FEED EFFICIENCY IN CHAROLAIS-SIRED CATTLE

ABSTRACT

Objectives of this experiment were to: 1) determine appropriate test length, timing, and repeatability of DMI, ADG, and efficiency over different biological time points; and 2) determine the relationship between forage-and grain-feed efficiency measures. Over 2-yr, Charolais crossbred heifers and steers (n=628) were fed for two 70d periods and DMI, ADG, and 12th rib fat thickness were recorded. Steers were fed grain-based diets during the growing and finishing periods to determine the effects of test period and timing on DMI and feed efficiency. Heifers were fed forage during the growing period and grain during the finishing period to test the effect of diet type on measures of DMI and feed efficiency. For each 70d test period, individual DMI was recorded using the GrowSafe (Airdrie, AB) system. Residual feed intake (**RFI**) was calculated for each test period and was assumed to represent a multiple regression equation, regressing DMI on mid-test metabolic BW, ADG, and 12th rib fat thickness. Total feeding period ADG (**FP_ADG**) was calculated for steers by regressing all weights taken from feedlot arrival to final BW, which was calculated by dividing HCW by a standard dressing percentage (63%). Dry matter intake and RFI were correlated (r = 0.56; $P < 0.01$, and 0.63; $P < 0.01$, respectively) for the growing and finishing periods of grain-fed steers. Average daily gain was not repeatable (r = 0.11; $P = 0.06$) across both test periods for steers. However, growing and finishing ADG were correlated (r = 0.58; $P < 0.01$, and r = 0.69; $P < 0.01$, respectively) to FP_ADG. To assess the potential of shortening the intake test, DMI was analyzed in 7d increments for grain-fed steers during the growing period. Regardless of test length, from 7 to 70d, DMI was correlated (r ≥ 0.87; *P* < 0.01) to total DMI during the growing period. Heifer forage DMI was correlated (r = 0.58; *P* < 0.01) to grain DMI; and, heifer forage ADG was negatively correlated (r = -0.30; *P* <0.01) to grain ADG. Forage and grain RFI were moderately correlated (r = 0.40; *P* <0.01) for heifers. This study suggested that DMI was repeatable across varying stages of maturity in cattle, and accurate feed efficiency measures can be obtained in either the growing or finishing period. The relationship of forage and grain DMI and efficiency in heifers suggests that measures of DMI and feed efficiency in heifers are relevant, regardless of diet fed. Intake evaluation periods can be shortened without losing accuracy in predicting individual animal DMI.

Key words: beef cattle, feed efficiency, intake, residual feed intake, diet type, test duration

INTRODUCTION

Profitability, within all sectors of beef production, is a function of inputs and outputs. In production systems, individual feed consumption represents the greatest financial burden (Miller et al., 2001). However, a majority of the intake evaluations performed in beef cattle have been conducted in cattle fed grain-based diets rather than those grazing forages. Furthermore, regulation of feed intake is driven largely by diet type; thus, there may be limitations of using feedlot intake information in heifer development systems. For example, intake of grain-based, high energy feeds is controlled metabolically or chemostatically (NRC, 1996), whereas when poor quality, roughage-based diets are fed, intestinal capacity, “gut-fill”, limits intake (Mertens, 1994). In addition, Durunna et al. (2011; 2012) discovered that feed efficiency reranking occurs in cattle fed different diet types at different biological stages. Therefore the regulation of feed intake of these different diet types may influence their efficiency of feed utilization, and some calves may be more efficient on different diet types.

Considering intake of forage and grain is regulated by different mechanisms, the hypothesis is that intake and efficiency will not be correlated across differing diet types, suggesting that feed intake and efficiency measures on differing diet types cannot be used interchangeably. We also hypothesize that intake evaluations can be shortened without losing accuracy; and feed efficiency can be measured at different stages of maturity in growing feedlot calves. This experiment has two objectives: 1) determine appropriate test length, timing, and repeatability of DMI, ADG, and efficiency over different biological time points; and 2) determine the relationship between forage-and grain-fed efficiency measures.

MATERIALS AND METHODS

Cattle were managed according to the guidelines recommended in the Guide for the Care and Use of Agriculture Animals in Agriculture Research and Teaching (FASS, 2010). All experimental procedures were approved by the University of Illinois Institutional Animal Care and Use Committee.

Management and Diets

A 2-yr study was conducted using 628 Charolais × SimAngus heifers and steers. All calves were born at the Dixon Springs Agricultural Center (Simpson, IL) and early weaned at 85 ± 18 d of age. Calves were backgrounded on mixed pastures of endophyte infected fescue (*Festuca arundinacea*), red clover (*Trifolium pretense*), and orchard grass (*Dactylis glomerata*) and a complete creep feed was offered free choice. Calves were then shipped 350 km to the University of Illinois Beef Cattle and Sheep Field Laboratory (Urbana, IL) via commercial trucking at 180 ± 29 d of age. All calves were vaccinated with Bovi-Shield Gold FP5 L5 HB (Pfizer). In yr 1, calves were vaccinated with One Shot Ultra 7 (Pfizer), and Pulmo-Guard MpB (Boehringer Ingelheim Pharmaceuticals Inc.). In year 2, calves were vaccinated with Covexin 8 (Schering-Plough Animal Health Corp., Omaha, NE), and an autogenous Moxella bovis (Schering-Plough Animal Health Corp.). Steers were implanted with a Component TE-IS with Tylan implant (120 mg trenbolone acetate, 24 mg estradiol, 29 mg tylosin; Elanco) and heifers were implanted with a Component TE-IH with Tylan implant (80 mg trenbolone acetate, 8 mg estradiol, 29 mg tylosin; Elanco) 24 weeks after weaning (age = 253 ± 18 d). Steers and heifers were re-implanted during the finishing period; approximately 11 wk after the first implant. Steers received a Component TE-S with Tylan implant (80 mg trenbolone acetate, 16 mg estradiol USP, 29 mg tylosin; Elanco) and heifers received a Component TE-H implant (140 mg trenbolone acetate, 14 mg estradiol USP, 29 mg tylosin; Elanco).

Two separate postweaning intake and performance evaluations were conducted on Charolais X SimAngus calves (*n* = 628; initial BW = 238 ± 46 kg, age = 211 ± 32 d). The 2 performance and intake tests represent the 2 major biological periods in the feedlot: growing and finishing. Upon arrival at the feedlot and prior to the growing period, steers were transitioned over 3 wk to a grain-based growing diet, and heifers were fed a forage-base diet (Table 5.1). After completion of the 70 d growing period, heifers were transitioned over 3 wk from the forage-based diet to the grain-based diet. All cattle were fed the common, grain-based diet (Table 5.2) for the 70 d finishing period.

Feed Sampling and Analysis

Individual feed ingredients were sampled every 2 wk from the initiation of the growing period until the end of the finishing period. Feed ingredient samples were dried at 55° C for 3 d, ground using a Wiley mill (1-mm screen, Arthur H. Thomas, Philadelphia, PA), and composited at the end of both evaluation periods. Ingredients were analyzed for NDF and ADF (using Ankom Technology method 5 and 6, respectively; Ankom^{200} Fiber Analyzer, Ankom Technology), CP (Leco TruMac, LECO Corporation, St. Joseph, MI), fat (ether extract, Ankom method 2; Ankom Technology), and ash (600° C for 2 h; Thermolyte muffle oven Model F30420C, Thermo Scientific, Waltham, MA). Feed ingredient analyses were used to construct diet nutrient analyses.

Growing/Finishing Intake and Performance Data Collection

Upon arrival, cattle were stratified by sire and allotted to pens equipped with a GrowSafe® automated feeding system (Model 4000E, GrowSafe Systems Ltd., 86 Airdrie, Alberta, Canada) so individual intakes could be recorded. Individual feed intakes were audited daily by trained personnel. Daily individual feed intake data were considered acceptable if both 85% of the feed supplied to the bunk and 90% of the corresponding feed disappearance assigned to each individual electronic ID was accounted for. Data were discarded for the affected pens not meeting this criteria. For each performance and intake test (growing and finishing) a minimum of 70-d were required each year to calculate individual animal ADG and DMI. This complies with Beef Improvement Federation (**BIF**) recommendations for performance data and intake collection (BIF, 2010). At the conclusion of the 70d finishing period test, individual feed intakes were no longer recorded using the GrowSafe system, as cattle were bunk fed for 60 ± 30 d until slaughter.

Performance data collection remained consistent for both years during both the growing and finishing performance tests. Initial and final BW for each test was the average of 2 consecutive d BW measurements prior to morning feeding but feed was not withheld. All cattle were weighed every 2 wk. Individual animal ADG was calculated by regressing each individual weight of all time points during both the growing and finishing evaluation period. Individual mid-test metabolic BW (**MW**) was determined by the linear regression coefficients for each animal for the growing and finishing evaluation period.

At the conclusion of each test period, 12^{th} rib fat thickness was measured via ultrasound, to account for the variation in residual feed efficiency measures due to body composition. Ultrasound measurements were taken by trained personnel using an Aloka 500SV (Wallingford, CT) B-110 mode instrument equipped with a 3.5-Mhz general purpose transducer array. Twelfth rib fat thickness measurements were taken in transverse orientation between the 12th and 13th ribs approximately 10 cm distal from the midline. Images were analyzed using CPEC imaging software (Cattle Performance Enhancement Company LLC., Oakley, KS).

Total Intake Period Performance and Intake Data Collection

Individual feed intakes were recorded during the growing, transition, and finishing periods of this experiment for steers fed grain throughout the study; therefore, the combination of recorded individual DMI during these periods was identified as the 161-d total intake period DMI (**161DMI**). Initial and final BW represented the average of 2 consecutive days BW measurements during the growing and finishing periods, respectively. Individual animal ADG was calculated by regressing all weights taken over the course of the growing, transition, and finishing periods and was identified as (**161ADG**). One hundred sixty-one d total intake period mid-test metabolic BW (**161MMW**) was calculated using the ADG regression coefficients.

Total Feeding Period Performance Data Collection

For steers fed the grain-based diet during both test periods, performance was evaluated for the duration of time on feed from feedlot arrival to slaughter. This method was used to determine total feeding period BW gain. Initial BW represented the BW of calves at arrival at the feedlot (age = 180 ± 29 d). Individual final BW was calculated by dividing HCW by a standard dressing percentage of 63%. Two total feeding period performance measures were calculated to test the relationship between traditional and regressed measurements of performance during an animal's time on feed. Total feeding period ADG (**FPADG**) was calculated by the difference between initial and final BW, divided by the number of days between feedlot arrival and harvest.

Regressed individual feeding period ADG (**R_FPADG**) was determined via regression of all weights taken from feedlot arrival to adjusted final BW.

Test Duration for DMI

To test the effects of intake evaluation period timing and duration, individual animal DMI during the growing period was divided into 10 total sections. Sections of intake during the growing period included: the final 7 d of intake (**70_63DMI**), the final 14 d of intake (**70_56DMI**), the final 21 d of intake (**70_49DMI**), the final 28 d of intake (**70_42DMI**), the final 35 d of intake (**70_35DMI**), the final 42 d of intake (**70_28DMI**), the final 49 d of intake (**70_21DMI**), the final 56 d of intake (**70_14DMI**), the final 63 d of intake (**70_7DMI**), and the final 70 d of intake (**70_0 DMI**).

Calculation of Feed Efficiency

Feed efficiency traits were determined for all cattle during the growing and finishing periods. Feed conversion ratio (**FCR**) represented the ratio of individual animal feed:gain, and was calculated by dividing individual average daily DMI by regressed ADG. Contemporary groups were assigned for each individual animal according to year born and sex. Individual animal residual feed intake (**RFI**) and residual BW gain (**RG**) were calculated for both growing and finishing periods. Residual feed intake was calculated using the PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC), and was assumed to represent the residuals of a multiple regression model regressing DMI on MW, ADG, and 12^{th} rib fat thickness using pen as a random effect. Likewise, RG was calculated using the PROC MIXED procedure of SAS, and was assumed to represent the residuals of a multiple regression model regressing ADG on DMI, MMW, and BF using pen as a random effect.

One hundred sixty-one d measures of feed efficiency were calculated for all steers fed grain during both periods. Feed conversion ratio for the 161-d total intake period (**161FCR**) represented the ratio of individual animal feed:gain, and was calculated by dividing individual average 161DMI by 161ADG. Residual feed intake for the 161-d total intake period (**161RFI**) values were determined using the PROC MIXED procedure of SAS; and was assumed to represent the residuals of a multiple regression equation regressing 161DMI on 161ADG, 161MMW, and BF from the finishing period, using pen as a fixed effect. Similarly, 161-d total intake period residual BW gain (**161RG**) were calculated using the PROC MIXED procedure of SAS; and was assumed to represent the residuals of a multiple regression equation regressing 161ADG on 161DMI, 161MMW, and BF from the finishing period, using pen as a random effect.

To test the concept of a decoupled RFI, 35 d of recorded intake were evaluated along with FPADG as the measurement of individual animal BW gain, and mid-test BW was calculated by the average of calves' initial and final BW, raised to the 0.75 power. The 35 d of recorded intake evaluated in this measure of feed efficiency represented the first and final 35 d of each feeding period. Residual feed intake represented the residuals of a multiple regression equation regressing 35 d of recorded DMI on FPADG, feeding period mid-test metabolic weight, and carcass BF using pen as a random effect.

Statistical Analysis

The descriptive statistics for all variables were calculated using the PROC UNIVARIATE procedure in SAS. Individual animal served as the experimental unit. Simple correlations were calculated for ADG, DMI, and efficiency for the growing, finishing, 160-d total intake period, and total feeding periods using the PROC CORR procedure of SAS. Pearson correlations were used to test the number of days required for accurate DMI estimates using the PROC CORR procedure of SAS. All rho values were considered significant when $P \leq 0.05$. Correlations were considered strong when rho values were greater than or equal to 0.70; moderate when rho values were between 0.30 and 0.69; and weak when less than 0.29.

RESULTS

Descriptive statistics of postweaning performance and efficiency in steer calves during the growing and finishing periods are presented in Table 5.3. A positive relationship existed ($P < 0.05$) during the growing period between DMI and ADG, RFI, and FCR at 0.64, 0.49, and 0.51, respectively (Table 5.4). Likewise, a moderate, positive relationship (r = 0.56; $P < 0.05$) existed between grain DMI during the growing and finishing period. During the growing period, steer ADG was correlated ($P < 0.05$) to RG and FCR at 0.71 and -0.31, respectively. However, growing period ADG was not correlated to ADG during the finishing period (r = 0.11; $P = 0.06$). Relationships existed between measures of feed efficiency during the growing period. Steers with more desirable RFI values also had more desirable RG (r = -0.42; $P < 0.05$) and FCR (r = 0.59; $P < 0.05$) values during the growing period. There was a strong correlation between RG and FCR during the growing period (r = -0.76; $P < 0.05$). Relationships between feed efficiency measures during the growing and finishing periods existed. Growing period RFI was moderately correlated (r = 0.63; $P < 0.05$) to finishing period RFI. Although RG during the growing period was correlated (r = 0.24; $P < 0.05$) to RG in the finishing period, the relationship was much weaker compared to RFI. Calculated FCR during the growing and finishing periods were also moderately correlated (r = 0.41; $P < 0.05$). Similar to the growing period, a positive relationship existed ($P < 0.05$) during the finishing period between DMI and ADG and RFI at 0.49 and 0.66, respectively. Even though a positive relationship existed (r = 0.22; $P < 0.05$) between finishing period DMI and FCR; the relationship between these 2 variables was weaker in the finishing period than is was in the growing period. A strong, positive correlation was observed between finishing period ADG and finishing period RG (r = 0.77; $P < 0.05$). A strong correlation existed between finishing period ADG and FCR (r = -0.72; $P < 0.05$). Similar to the growing period, relationships existed between measures of feed efficiency during the finishing period. A moderate relationship existed between finishing period RFI and RG (r = -0.51; $P < 0.05$) and FCR (r = 0.49; $P < 0.05$). Likewise, finishing period RG was also strongly correlated (r = -0.84; $P < 0.05$) to FCR.

There were moderate, positive relationships among ADG across the measured time points (Table 5.5). Growing ADG was correlated ($P < 0.05$) to 161ADG, R_FPADG, and FPADG at 0.57, 0.58, and 0.58, respectively. Stronger linear relationships existed ($P < 0.05$) among finishing period ADG and 161ADG, R_FPADG, and FPADG at 0.76, 0.69, and 0.58, respectively. Regressed ADG during the 161 d intake period was correlated to R_FPADG (r = 0.96; $P < 0.05$) and FPADG (r = 0.81; $P < 0.05$). Regressed, total feeding period ADG was strongly correlated ($P < 0.05$) to FPADG at 0.85.

The linear relationships between feed efficiency measured in steers during different evaluation periods are presented in Table 5.6. Strong linear correlations exist ($P < 0.05$) among growing period RFI and 161RFI at 0.89. Growing period RG was moderately correlated ($P < 0.05$) to 161RG at 0.59. Likewise, growing period FCR was strongly correlated to 161FCR (r = 0.77; $P < 0.05$). Similar results were observed when comparing the relationship between measures of feed efficiency during the finishing period and 161d intake period. Finishing RFI values were strongly correlated (P < 0.05) to 161RFI at 0.86. A strong linear relationship existed between growing period RG and 161RG (r =0.72 0.61; $P < 0.05$). Finishing period FCR was strongly correlated to 161FCR (r = 0.75; $P < 0.05$).

Relationships between different durations of mean DMI observations in grain-fed steers from the end of the growing period are presented in Table 5.7. Rho values between the number of recorded d of DMI and total growing period DMI increased linearly when a greater number of days were incorporated into the intake evaluation. Specifically, total growing period mean DMI was strongly correlated ($P < 0.05$) at 0.95 when 35 d of intake were recorded. However, the final 14 d of recorded intake during the growing period was moderately correlated to total DMI during the finishing period (r = 0.62; $P < 0.05$). Rho values between the number of recorded d of DMI in the growing period and total finishing period DMI decreased linearly as daily increments of recorded DMI from the final 14 d of the growing period increased. The final 7 d of recorded intake during the growing period was strongly correlated to 161DMI (r = 0.86; $P < 0.05$). Increasing daily increments of recorded DMI from the ending of the growing period resulted in a linear increase in the relationship between growing period DMI and 161DMI.

The correlations between decoupled measures of RFI and 70 d test period (growing and finishing) RFI are presented in Table 5.8. A moderate correlation existed between growing RFI values and RFI values using decoupled DMI and ADG measurements ($0.46 \leq r \leq 0.70$; $P < 0.05$). A positive, yet weak correlation existed ($P < 0.05$) between finishing period RFI and RFI when the first 35 d of DMI during the growing period were used to predict total feeding period DMI at 0.28. However, correlations were moderate to strong ($0.62 \leq r \leq 0.85$; P < 0.05) when comparing finishing period RFI to total feeding period RFI when all other 35 d sections of DMI were used to predict total feeding period DMI.

The descriptive statistics of postweaning performance and efficiency in heifer calves on different diet types are presented in Table 5.9. When heifers were fed forage during the growing period, ADG, RFI, and FCR were correlated to forage DMI ($P < 0.05$) at 0.25, 0.69, and 0.24, respectively (Table 5.10). Likewise, heifer ADG during the growing period was correlated ($P < 0.05$) to RG and FCR at 0.53 and -0.72, respectively. A moderate, linear relationship suggests that as forage RFI improved, forage RG (r = -0.29; $P < 0.05$) and forage FCR (r = 0.39; $P < 0.05$) improved. Improvements in forage RG resulted in reduced forage FCR during the growing period (r = -0.53; $P < 0.05$). A positive correlation (r = 0.58; $P < 0.05$) between heifer forage DMI and grain DMI suggests heifers with greater forage DMI also had greater grain DMI. Subsequently, forage and grain RFI values were moderately correlated (r = 0.40; $P < 0.05$). A negative, linear correlation of -0.30 ($P < 0.05$) existed between ADG on forage and ADG on grain. There was a negative correlation (r = -0.16; $P < 0.05$) between forage and grain FCR. No significant correlation ($P = 0.08$) existed between forage RG and grain RG.

DISCUSSION

The majority of performance and intake records have been obtained in growing animals when fed high-grain, energy-dense diets. However, regulation of feed intake may be influenced by diet type and stage of physiological maturity in cattle (Illius and Jessop, 1996), and feed efficiency can be influenced by diet type (Durunna et al., 2011). Therefore this study was designed to investigate the effects of test period duration and timing, as well as diet type on measures of feed efficiency. The results of this study confirm that growing and finishing steers that eat more will gain more, which is well-documented (Schwartzkopf-Genswein et al., 2002; Kelly et al., 2010; Durunna et al., 2011). The moderate, negative correlations between steer ADG and FCR during the growing and finishing period agree with previous literature (Nkrumah et al.,

2007) and suggest that accelerated growth rates play a vital role in determining feed efficiency in young, growing animals. This association is not surprising, since FCR is a function of ADG and DMI. However, increases in grain DMI resulted in less desirable RFI and FCR, which is consistent with Nkumrah et al. (2007). It was not surprising that a linear association did not exist between RFI and ADG during either feeding period because RFI is independent of growth traits (Koch et al., 1963; Arthur and Herd, 2008; Black et al., 2013). During the growing and finishing periods, as RFI improved, RG and FCR also improved, evidenced by their moderate linear correlations. These associations of feed efficiency in growing animals are well documented (Arthur et al., 2001; Arthur et al., 2001b). However, a strong linear relationship existed between RG and FCR during both feeding periods. This was expected, as evidence of the moderate to strong linear relationship of ADG to RG and FCR during the growing and finishing periods, respectively.

The moderate association between DMI in the growing and finishing periods suggests that intake evaluations can be repeatable across varying growth stages. In this study, cattle that consumed more feed earlier in life also had greater DMI at a later stage of maturity. The moderate association of DMI during the growing and finishing periods of this experiment reflects the results of Kelly et al. (2010), who reported a correlation of 0.61 between DMI when heifers were fed a 70:30 pelleted concentrate:corn silage diet during consecutive feeding periods. However, ADG was not repeatable in steers between the growing and finishing periods in our trial. Although this was a surprise, because DMI was repeatable and related to ADG in both periods, this phenomenon was also observed by Kelly et al. (2010); who also reported the same correlation of 0.11, and suggested that cattle ADG may re-rank compared to their contemporaries. The fact that ADG was not repeatable may be attributed to the possibility of compensatory gain during the growing period of some cattle. A moderate, positive association between RFI values calculated in the growing and finishing periods, suggested that RFI is repeatable when evaluated at different biological time points. Considering the fact that DMI explains a majority of the variation in RFI, the repeatability of RFI was not surprising, because DMI was moderately related in both test periods. This positive association mirrors the findings of Kelly et al., (2010) and suggests that more efficient cattle, based on RFI during the growing period, will also be more efficient in the finishing period. There has been limited work evaluating the repeatability of RG across the growing and finishing periods. This study observed a weak, positive correlation between growing RG and finishing RG. This weak association may be attributed to the fact that ADG was not repeatable across the 2 evaluation periods. The moderate linear relationship between FCR between growing and finishing periods suggest that FCR is repeatable, and cattle that have more desirable FCR during the growing period will also be more efficient in the finishing period based on FCR. This relationship is also well documented (Kelly et al., 2010; Russell et al., 2016).

The fact that ADG was not repeatable was not expected. However, there were moderate associations between growing and finishing ADG when compared to R_FPADG and FPADG. This suggests that regardless of timing of the evaluation of postweaning gain, both periods can serve as similar proxies in determining the performance of a growing animal during its entire time spent on feed. The stronger correlation between 161ADG and R_FPADG and FPADG suggests that longer periods of performance evaluation may result in more accurate determinations of ADG over an animal's entire lifespan. The strong, positive correlation between R_FPADG and FPADG suggests that cattle performance may be accurately predicted by dividing the difference of an animal's final BW and feedlot arrival weight by the number of days on feed. This is important, because FPADG is a measure of performance that is widely accepted within the industry. When FPADG is calculated by dividing the difference between adjusted HCW and feedlot arrival BW by the number of d on feed, FPADG can be an effective proxy for individual ADG over the lifespan of calves, which has been recently supported (Retallick, 2015; Retallick and Weaber, 2015).

Guidelines have been established for uniform performance testing practices (Beef Improvement Federation and Guidelines, 2010). Historically, the minimum days required was due to the number of days on test needed to accurately measure ADG. In fact, an early study claimed that 112 d were needed to accurately measure ADG (Brown et al., 1991). In later years, Archer et al. (1997) found that the accuracy of recorded DMI and ADG may not be improved with evaluation periods that were longer than 70 d. In this study, the strong, positive relationship between 161RFI and RFI during both 70 d test periods suggests that factors other than ADG contributed to the variation in RFI, because ADG was not repeatable across test periods.

Similarly, the moderate to strong correlations between 161RG and RG in both 70 d suggests that both evaluation periods are accurate measures of RG. This data set showed strong linear associations between 161FCR and FCR during both feeding periods; and since ADG was not repeatable across test periods, suggests that DMI accounts for more of the variation in FCR, and accurate FCR information can be obtained using test periods of 10 wk.

This study suggests that it is feasible to obtain accurate measures of feed efficiency for the duration of a calf's lifespan by using the difference of feedlot arrival BW and adjusted HCW divided by number of d on test, combined with a 35 d test of DMI. Therefore, the capacity of cattle to be tested annually depends on the number of days needed to obtain accurate individual DMI information, and shorter test periods equate to more cattle being tested annually. During the growing period, one wk of recorded DMI was strongly correlated to test period DMI at 0.88. As the number of recorded d of DMI increased, the association between number of d of recorded DMI and overall period DMI increased. Due to a strong correlation of 0.95, this experiment suggests that only 35 d of recorded intake are sufficient for predicting 70d test period DMI. However, *when* DMI intake is recorded for those 35 d makes a difference. Recorded DMI during the end of the growing period was a more accurate predictor of DMI during the finishing period. This study showed that in order to accurately predict DMI across different time points in life, not only is it important to record a sufficient amount of d, but the proximity of the different test periods being compared is an important factor to consider as well.

Minimal work has been done investigating the idea of decoupling performance and intake information when determining the feed efficiency of a feedlot steer during its entire time on feed. Interest in this concept is due to the fact that accurate measures of DMI and ADG require substantially different durations, and performance and intake evaluation tests are costly. Total beef production efficiency can be improved when a greater number of animals are tested annually; therefore, more cost effective ways to test growing animals are needed. In our trial, comparisons were made between RFI values using short duration intake test periods (35 d) with FPADG; and RFI measures calculated by the standards set forth by the BIF. Moderate associations between these measures of RFI using decoupled DMI and ADG and 70 d test period RFI suggests that there is a possibility that these alternative measurements of RFI may have efficacy to the industry.

Durunna et al. (2011) claimed that diet type affects measures of feed efficiency when cattle are fed a grower and finishing diet in their respective growing and finishing periods. The repeatability of DMI and feed efficiency in grain-fed steers in this study suggests that comparison of intake and efficiency can be conducted at differing biological time points. The fact that forage DMI and grain DMI were related in this study is encouraging. This suggests that intake information derived from the feedlot may be adequate in predicting forage intake in developing heifers. This is a novel, yet important finding, because the majority of intake information is derived through feedlot or bull development evaluations.

A negative, relationship between ADG when forage- and grain-based diets were fed to heifers, suggested that heifers that performed poorly when fed forage actually performed better on grain. This finding confirms the theory of compensatory gain when cattle fed forages are grain-fed during the finishing period. The compensatory gain affect likely masked the ability to detect association between RG values among heifers between periods. Similarly, a weak, negative correlation existed between FCR values on forage compared to FCR values compared to grain. Since the relationship of grain DMI and ADG for heifers were similar ($r = 0.43$ and 0.42, respectively), the compensatory gain effect influenced the negative correlation of -0.16. This relationship is weak, and may not be biologically relevant when trying to compare FCR between cattle on different diet types.

Regulation of feed intake may differ when cattle are fed differing diet types, and DMI is related to energy content of the feed delivered (NRC, 1996) or physical fill. Since DMI plays a vital role in feed efficiency, mechanisms of intake regulation for divergent diet types may confound the accuracy of comparing RFI of cattle when fed grain or forage. Russel et al. (2016) found that steers classified as highly feed efficient based on growing period G:F continued to have more desirable G:F in the finishing period, regardless of diet type fed (roughage vs. concentrate/by-product). However, minimal research has been conducted comparing RFI values when cattle are fed differing diet types. The correlation between forage and grain DMI was 0.58.

This linear relationship of DMI closely parallels the relationship of DMI during the growing and finishing period of grain fed steers (0.56), and in this study, suggests mechanisms of intake regulation on these diet types may not differ. The moderate, positive correlation between RFI values derived from forage and grain based diets suggested that growing cattle that were more efficient when fed forage were also more efficient when fed grain. This is an important discovery, as most feed intake and subsequent efficiency tests are done in feedlot-like test stations.

In conclusion, DMI is repeatable within different test periods. This suggests that accurate intake information can be obtained during either the growing or finishing periods. Additionally, the positive relationship between DMI of different diet types suggests that intake information on grain-based diets can predict forage intake. Cattle can be accurately tested for efficiency by shortening DMI evaluation tests and using simpler calculations of ADG; thus, allowing for a greater number of cattle to be tested annually, leading to more rapid improvements in feed efficiency within the beef industry.

TABLES

Table 5.1 Composition of growing diets, %DM

	Year 1		Year 2	
Item	Forage	Grain	Forage	Grain
High-moisture corn	-	20	-	30
Dry rolled corn	-	30	-	20
Distillers grains with solubles	-	15	-	15
Corn husklage	-	25	-	-
Corn silage	47.5	-	47.5	25
Alfalfa haylage	47.5	-	47.5	-
Low calcium supplement[1]	5	-	5	-
Medium calcium supplement[2]	-	-	-	10
High calcium supplement[3]	-	10	-	-
Analyzed Values				
NDF, %	44.6	25.0	48.7	24.6
ADF, %	28.4	8.6	33.4	10.9
Fat, %	3.0	4.6	3.5	3.6
Protein, %	15.0	16.3	13.2	13.5

[1] Contains 85.94% ground corn, 10% limestone, 2% dairy trace mineral salt [Trace mineral salt contains: 8.5% Ca (as $CaCO_3$), 5% Mg (as MgO and $MgSO_4$), 7.6% K (as KCl_2), 6.7% Cl (as KCl_2) 10% S (as S_8, prilled), 0.5% Cu (as $CuSO_4$ and Availa-4 (Zinpro Performance Minerals; Zinpro Corp, Eden Prairie, MN)), 2% Fe (as $FeSO_4$), 3% Mn (as $MnSO_4$ and Availa-4), 3% Zn (as $ZnSO_4$ and Availa-4), 278 mg/kg Co (as Availa-4), 250 mg/kg I (as $Ca(IO_3)_2$), 150 Se (Na_2SeO_3), 2,205 KIU/kg VitA (as retinyl acetate), 662.5 KIU/kg VitD (as cholecalciferol), 22,047.5 IU/kg VitE (as DL-α-tocopheryl acetate), and less than 1% CP, fat, crude fiber, salt.], 0.34% Rumensin (198 mg monensin/kg DM; Elanco Animal Health, Greenfield, IN), 0.22% Tylan (88 mg tylosin/kg DM; Elanco Animal Health), and 1.5% fat.

[2] Contains 73.87% ground corn, 6.6% urea, 17.5% limestone, 1% dairy trace mineral salt 0.17% Rumensin (Elanco), 0.11% Tylosin (Elanco), and 0.75% fat.

[3] Contains 57.97% ground corn, 25% limestone, 15% urea, 1% dairy trace mineral salt, 0.17% Rumensin (Elanco), 0.11% Tylosin (Elanco), and 0.75% fat.

Table 5.2 Composition of finishing diets, %DM

Item	Year 1	Year 2
High-moisture corn	20	30
Dry rolled corn	30	20
Distillers grains with solubles	15	15
Corn husklage	25	-
Corn silage	-	25
Medium calcium supplement[1]	-	10
High calcium supplement[2]	10	-
Analyzed Values		
NDF, %	23.2	22.8
ADF, %	8.5	9.2
Fat, %	4.1	3.1
Protein, %	17.0	13.0

[1] Contains 73.87% ground corn, 6.6% urea, 17.5% limestone, 1% dairy trace mineral salt [Trace mineral salt contains: 8.5% Ca (as $CaCO_3$), 5% Mg (as MgO and $MgSO_4$), 7.6% K (as KCl_2), 6.7% Cl (as KCl_2) 10% S (as S_8, prilled), 0.5% Cu (as $CuSO_4$ and Availa-4 (Zinpro), 2% Fe (as $FeSO_4$), 3% Mn (as $MnSO_4$ and Availa-4), 3% Zn (as $ZnSO_4$ and Availa-4), 278 mg/kg Co (as Availa-4), 250 mg/kg I (as $Ca(IO_3)_2$), 150 Se (Na_2SeO_3), 2,205 KIU/kg VitA (as retinyl acetate), 662.5 KIU/kg VitD (as cholecalciferol), 22,047.5 IU/kg VitE (as DL-α-tocopheryl acetate), and less than 1% CP, fat, crude fiber, salt.] 0.17% Rumensin (Elanco Animal Health, Greenfield, IN), 0.11% Tylosin (Elanco), and 0.75% fat.

[2] Contains 57.97% ground corn, 25% limestone, 15% urea, 1% dairy trace mineral salt, 0.17% Rumensin (Elanco), 0.11% Tylosin (Elanco), and 0.75% fat.

Table 5.3 Raw mean postweaning performance, efficiency, and SD of all steers fed grain during the growing and finishing periods

Item	Mean	SD	Minimum	Maximum
Growing ADG, kg	1.77	0.25	0.58	2.43
Growing DMI, kg	7.60	1.19	2.87	10.46
Growing residual feed intake, kg	0.00	0.57	-1.72	1.48
Growing residual BW gain, kg	0.00	0.17	-0.70	0.49
Growing feed conversion ratio, kg[1]	4.31	0.26	1.16	3.48
Finishing ADG, kg	1.78	0.25	0.81	2.39
Finishing DMI, kg	9.83	1.02	6.08	13.05
Finishing residual feed intake, kg	0.00	0.66	-2.08	2.66
Finishing residual BW gain, kg	0.00	0.18	-0.66	0.50
Finishing feed conversion ratio, kg[1]	5.60	0.36	1.73	4.43

[1] Expressed as feed:gain

Table 5.4 Simple phenotypic correlations between postweaning traits for steers fed grain[a]

Item	Growing DMI	Growing ADG	Growing RFI[1]	Growing RG[2]	Growing FCR[3]	Finishing DMI	Finishing ADG	Finishing RFI[1]	Finishing RG[2]	Finishing FCR[3]
Growing DMI	**1**	**0.64**	**0.49**	0.00	**0.51**	**0.56**	-0.02	**0.27**	**-0.30**	**0.44**
Growing ADG		**1**	0.00	**0.71**	**-0.31**	**0.29**	0.11	-0.04	-0.04	0.11
Growing RFI[1]			**1**	**-0.42**	**0.59**	**0.38**	-0.06	**0.63**	**-0.39**	**0.34**
Growing RG[2]				**1**	**-0.76**	-0.04	**0.19**	**-0.28**	**0.24**	**-0.22**
Growing FCR[3]					**1**	**0.38**	**-0.13**	**0.37**	**-0.30**	**0.41**
Finishing DMI						**1**	**0.49**	**0.66**	0.00	**0.22**
Finishing ADG							**1**	0.00	**0.77**	**-0.72**
Finishing RFI[1]								**1**	**-0.51**	**0.49**
Finishing RG[2]									**1**	**-0.84**
Finishing FCR[3]										**1**

[a] |R| values in bold are significant ($P < 0.05$)
[1] Residual feed intake
[2] Residual BW gain
[3] Feed conversion ratio expressed as feed:gain

Table 5.5 Simple phenotypic correlations between measurements of ADG during different feeding periods and biological timepoints[a]

Item	Growing	Finishing	161ADG[1]	R_FPADG[2]	FPADG[3]
Growing	**1**	0.11	**0.57**	**0.58**	**0.58**
Finishing		**1**	**0.76**	**0.69**	**0.58**
161ADG[1]			**1**	**0.96**	**0.81**
R_FPADG[2]				**1**	**0.85**
FPADG[3]					**1**

[a] |R| values in bold are significant ($P < 0.05$)

[1] 161 d intake period

[2] Total feeding period (regressed ADG)

[3] Total feeding period

Table 5.6 Simple phenotypic correlations between measures of feed efficiency for grain-fed steers in the growing period, finishing period, intake evaluation period, and total feeding period[a]

Item	Growing RFI[1]	Growing RG[2]	Growing FCR[3]	Finishing RFI[1]	Finishing RG[2]	Finishing FCR[3]
161RFI[4]	**0.89**	**-0.31**	**0.48**	**0.86**	**-0.47**	**0.41**
161RG[5]	**-0.34**	**0.59**	**-0.53**	**-0.20**	**0.72**	**-0.58**
161FCR[6]	**0.61**	**-0.46**	**0.77**	**0.51**	**-0.64**	**0.75**

[a] |R| values in bold are significant ($P < 0.05$)
[1] Residual feed intake
[2] Residual BW gain
[3] Feed conversion ratio expressed as feed:gain
[4] 161 d intake period residual feed intake
[5] 161 d intake period residual BW gain
[6] 161 d intake period feed conversion ratio expressed as feed:gain

Table 5.7 Simple phenotypic correlations during different durations of mean DMI observations from the end of the 70d growing period in grain fed steers[a]

Item	70-63DMI	70-56DMI	70-49DMI	70-42DMI	70-35DMI	70-28DMI	70-21DMI	70-14DMI	70-7DMI	70-0DMI	FDMI[1]	161DMI[2]
70-63DMI	**1**	**0.97**	**0.95**	**0.94**	**0.93**	**0.92**	**0.91**	**0.90**	**0.89**	**0.88**	**0.58**	**0.86**
70-56DMI		**1**	**0.99**	**0.97**	**0.95**	**0.91**	**0.91**	**0.89**	**0.88**	**0.87**	**0.62**	**0.87**
70-49DMI			**1**	**0.99**	**0.97**	**0.93**	**0.93**	**0.91**	**0.91**	**0.89**	**0.62**	**0.88**
70-42DMI				**1**	**0.98**	**0.96**	**0.95**	**0.94**	**0.93**	**0.92**	**0.61**	**0.89**
70-35DMI					**1**	**0.99**	**0.98**	**0.97**	**0.96**	**0.95**	**0.61**	**0.90**
70-28DMI						**1**	**0.99**	**0.98**	**0.97**	**0.97**	**0.58**	**0.89**
70-21DMI							**1**	**0.99**	**0.99**	**0.98**	**0.56**	**0.89**
70-14DMI								**1**	**1**	**0.99**	**0.56**	**0.90**
70-7DMI									**1**	**1**	**0.56**	**0.90**
70-0DMI										**1**	**0.56**	**0.90**
FDMI[1]											**1**	**0.85**
161DMI[2]												**1**

[a] |R| values in bold are significant ($P < 0.05$)
[1] Finishing period DMI (d91-161DMI)
[2] 161 d intake period total DMI (d0-161DMI)

Table 5.8 Simple phenotypic correlations between measures of feed efficiency for grain fed steers during the growing, finishing, and total feeding period using decoupled DMI and ADG variables in the predicted DMI model in the total feeding period[a]

Item	Growing RFI[1]	Finishing RFI[1]
0-35RFI[2]	**0.70**	**0.28**
36-70RFI[3]	**0.54**	**0.62**
90-125RFI[4]	**0.56**	**0.85**
126-161RFI[5]	**0.46**	**0.79**

[a] |R| values in bold are significant ($P < 0.05$)
[1] Residual feed intake
[2] Total feeding period residual feed intake when predicted total feeding period DMI is a linear function of the first 35d of recorded DMI during the growing period, FPADG and mid-test metabolic BW, and carcass BF.
[3] Total feeding period residual feed intake when predicted total feeding period DMI is a linear function of the final 35d of recorded DMI during the growing period, FPADG and mid-test metabolic BW, and carcass BF.
[4] Total feeding period residual feed intake when predicted total feeding period DMI is a linear function of the first 35d of recorded DMI during the finishing period, FPADG and mid-test metabolic BW, and carcass BF.
[5] Total feeding period residual feed intake when predicted total feeding period DMI is a linear function of the final 35d of recorded DMI during the finishing period, FPADG and mid-test metabolic BW, and carcass BF.

Table 5.9 Raw mean postweaning performance, efficiency, and SD of all heifers on study during the growing and finishing periods

Item	Mean	SD	Min	Max
Forage ADG, kg	0.78	0.24	0.17	1.74
Forage DMI, kg	6.09	1.14	3.33	14.73
Forage residual feed intake, kg	0.00	0.77	-2.18	6.89
Forage residual BW gain, kg	0.00	0.12	-0.36	0.38
Forage feed conversion ratio[1]	8.59	1.63	2.05	18.28
Grain ADG, kg	1.78	0.26	0.93	2.58
Grain DMI, kg	9.34	1.06	5.95	12.55
Grain residual feed intake, kg	0.00	0.68	-3.13	2.26
Grain residual BW gain, kg	0.00	0.21	-0.61	0.70
Grain feed conversion ratio[1]	5.34	0.38	1.57	4.11

[1] Expressed as feed:gain

Table 5.10 Simple linear phenotypic correlations between postweaning traits in heifers fed different diets[a]

Item	Forage DMI	Forage ADG	Forage RFI[1]	Forage RG[2]	Forage FCR[3]	Grain DMI	Grain ADG	Grain RFI[1]	Grain RG[2]	Grain FCR[3]
Forage DMI	**1**	**0.25**	**0.69**	0.00	**0.24**	**0.58**	-0.01	**0.24**	**-0.26**	**0.43**
Forage ADG		**1**	0.00	**0.53**	**-0.72**	**0.16**	**-0.30**	-0.03	**-0.17**	**0.42**
Forage RFI[1]			**1**	**-0.29**	**0.39**	**0.25**	0.00	**0.40**	**-0.17**	**0.17**
Forage RG[2]				**1**	**-0.53**	-0.08	**-0.11**	**-0.15**	-0.10	0.05
Forage FCR[3]					**1**	**0.14**	**0.27**	**0.17**	0.06	**-0.16**
Grain DMI						**1**	**0.36**	**0.65**	0.00	**0.38**
Grain ADG							**1**	0.00	**0.82**	**-0.70**
Grain RFI[1]								**1**	**-0.36**	**0.46**
Grain RG[2]									**1**	**-0.79**
Grain FCR[3]										**1**

[a] |R| values in bold are significant ($P < 0.05$)
[1] Residual feed intake
[2] Residual BW gain
[3] Feed conversion ratio expressed as feed:gain

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CHAPTER 6

CONCLUSIONS

Beef cattle producers strive to become more efficient because it directly impacts their bottom line. Maximizing outputs and minimizing inputs results in increases in profit. However, it is difficult to test large numbers of animals due to the cost of feed intake evaluation systems and time commitment. This research set out to investigate the relationships between measures of heifer postweaning feed intake and efficiency and cow intake of high and poor quality forage, cow efficiency, and longevity. Additionally, new theories as to how the industry can gain more feed intake and efficiency information was investigated by evaluating test period timing, duration, as well as diet type on measures of feed efficiency in growing feedlot cattle.

Relationships existed between measures of heifer postweaning feed intake and efficiency and cow production traits at 2- and 5-yr of age. Improvements in heifer residual feed intake (**RFI**) did not negatively impact cow production traits at either age or biological time point (lactating vs. dry). Improvements in heifer RFI reduced cow forage DMI as 2-yr-old cows in both evaluation periods; however, improvements in heifer RFI only tended to decrease cow forage DMI during lactation in 5-yr olds. Improvements in heifer RFI also resulted in decreased DMI regardless of forage quality. Other heifer feed efficiency measures had minimal to no effect on cow production traits and DMI. However, the fact that a moderate to strong relationship existed between DMI across age is encouraging. Heifer feed DMI and cow forage DMI were moderately correlated at 2- and 5-yr of age at 60- and 240-d postpartum. This means that intake information derived as heifers may be able to accurately predict mature cow voluntary forage intake. Cows classified as low DMI heifers were less likely to be kept as replacements; however, those that were kept had greater longevity, and this may be due to the fact that they were smaller cows and had reduced maintenance energy requirements.

Relationships existed between measures of feed efficiency and intake across diet type and test period. Accurate feed efficiency measures can be obtained in either the growing or finishing period of feedlot cattle. The relationship of forage and grain DMI and efficiency in heifers suggests that measures of DMI and feed efficiency in heifers are relevant, regardless of diet fed. This suggests that DMI and efficiency information derived from the feedlot may have application to the cowherd. Limitations on test period length are due to the number of d to accurately assess individual ADG. Since intake evaluation periods can be shortened without losing accuracy in predicting individual animal DMI, decoupling performance from DMI information may be the most cost effective way to test a greater number of animals annually. More research is needed to further investigate novel methods of testing for feed efficiency with the vision of improving beef production efficiency as a whole.