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The relationship of RFI and voluntary forage intake and cow survival under range conditions

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The National Cattlemen's Beef Association identified cost efficiencies as a major profitability driver for beef production. Approximately 60% to 70% of overall energy costs for beef production go into the cow herd. Of that amount, approximately 70% goes for maintenance energy (Ferrell and Jenkins, 1982). This is the energy that a cow needs to just to stay alive. It does not include energy for growth, lactation, or gestation. Thus, approximately 46% of all energy required to produce a pound of beef is used to simply keep the cows alive and maintain their body weight. While little progress would be made in decreasing feed costs with regards to gestation, reproduction and lactation, data would suggest that maintenance costs can be decreased through selection. It has been shown that variation does exist in maintenance energy requirements among individual cows, but maintenance requirements of cattle overall appear to have been largely unchanged during the past 100 years (Johnson et al. 2003). Identifying and understanding the nutritional, metabolic, genetic, and endocrinological differences among animals will aid in the determination of why certain animals are more feed efficient than others. This knowledge will allow producers to manage beef cattle production systems in a manner that minimizes feed consumption relative to output. While much has been learned in the past 100 years, the beef industry has yet to develop a consensus as to how beef cow efficiency may be improved. Most of the genetic improvement for a beef herd comes through bull selection.

New tools in the fields of genomics, bioinformatics, and nutrition provide opportunities to advance our understanding of the regulation of nutrient utilization. A major limiting factor in improving the efficiency of nutrient utilization in beef cows are reliable, quantitative methods of measuring daily nutrient intake of grazing animals. Feed intake equipment does not measure individual feed intake for animals that are grazing, thus making cow intake more difficult to measure (Arthur and Herd, 2008).

Measuring Feed Efficiency

Residual Average Daily Gain (RADG)

Many ways of measuring feed efficiency for growing cattle are utilized. The most common method is using gross efficiency or a feed conversion ratio (FCR). This is defined as the ratio between gain and feed inputs and is commonly expressed as Gain to Feed (G:F), (Archer et al., 1999). Brelin and Brannang (1982) showed strong correlations (-0.61 to -0.95) between an animal's growth rate and the feed conversion ratio. A newer form of expressing feed efficiency is residual average daily gain (RADG). The American Angus Association (AAA) developed this tool and created an expected progeny difference (EPD). The AAA states that the quickest way, other than doing a feed test, to find out the RADG is to use a comprehensive genetic evaluation including a vast array of genetic evaluations for several trait markers. Some of these traits include weaning weight, post weaning gain, subcutaneous fat thickness, calf Dry Matter Intake DMI, and DMI genomic values (www.angus.org). These genetic values are coupled with animal ADG and fat which are the predictors of an animal's RADG potential. A regression equation is used to determine the animals predicted ADG which is subtracted from the actual ADG resulting in RADG (www.angus.org). When analyzing the RADG data, it is important to realize that, a positive or high value is desired because greater gain is achieved (www.iowabeefcenter.com). RADG is moderately heritable (0.31 to 0.41) so it can be effective in improving efficiency of feedlot cattle. RADG and FCR both work well for feedlot animals, but they are problematic for cow-calf producers because selection for these measures yield bigger, heavier cows with higher nutrient requirements. In fact, the AAA indicates that "RADG is not a cow efficiency tool" (www.angus.org).

Residual Feed Intake (RFI)

Another way of measuring feed efficiency is residual feed intake (RFI). RFI is measured by subtracting an animal's actual intake from a predicted intake. The predicted intake is determined by using a regression equation that accounts for animal weight and body composition (Archer et al., 1999). Therefore, RFI allows selection for efficiency independent of animal size. Koch et al. (1963) first proposed the idea of RFI in beef cattle by suggesting that feed intake could be adjusted for weight gain and body weight. It can then separate feed intake into two parts: a) the feed intake expected for the given level of production and b) a residual portion. The animal's expected or predicted intake is found by using feeding standards (NRC, 1996) or formulating a regression equation using the animal's actual data from a feeding period (Arthur et al., 2001). The residual portion measures how much animals differ from their expected intake. Therefore, the more efficient animals in terms of RFI have negative values; they eat less than expected. Unlike other forms of measuring feed efficiency, RFI allows for measurement without being correlated to any phenotypic trait that is used in its estimations (Basarab et al., 2003).

The testing phase for RFI requires measuring DMI and growth over a period of time. It is important t to control as many factors as possible such as; age, sex, diet composition, and testing procedures during the testing phase (Arthur and Herd, 2008). The fact that individual intake and performance must be measured to calculate RFI makes it a very expensive test. This is one of the major limitations in successful implementation of RFI into all facets of beef cattle industry.

Byerly (1941) was one of the first to acknowledge that individuals of the same body weight have vastly different feed requirements for the same amount of production. Many biological factors are shown to have an effect on the variation that exists in beef cattle feed efficiency. In figure 1, Richardson and Herd (2004) listed and gave the amount of variation explained by the different factors.

Research shows that RFI as well as FCR are moderately heritable across a multitude of beef cattle breeds (Herd and Bishop, 2000; Arthur et al., 2001; Robinson and Oddy, 2004; Nkrumah et al., 2007). They showed that RFI is correlated to the animals FCR (0.45 – 0.85). As a result, selection for RFI will also result in an improvement in FCR. However, unlike the FCR, RFI can be selected for without having an effect on animal growth. Correlations to animal growth traits have been shown close to zero in these studies comparing RFI to Average Daily Gain (ADG) and also metabolic weight. It is correlated with DMI (0.43 – 0.73) with low RFI cattle consuming less feed.

Measuring feed efficiency in terms of RFI has the potential to play a major role in the cattle feeding industry. RFI is a heritable trait and selecting for ithas been shown to be effective in the feedyard. Both heifers and steers sired by either a "good" RFI sires that possess a low RFI value or "bad" RFI sires that possess a high RFI value have been evaluated at the University of Illinois. The preliminary data (Table 1) show that progeny sired by the "good" RFI sires have a more desirable RFI value and are 5% more efficient independent of size or growth rate (Retallick et. al, unpublished). This further illustrates the heritability of RFI and its ability to improve efficiency in the feedyard.

Table 1. Simple linear correlations among variables (Retallick et al, unpublished).

	ADG	DMI	REA	HCW	Marb	Yield Grade	F:G	RFI	RG	RIG
ADG, kg/d	1	0.54*	0.23*	0.54*	0.15*	0.35*	-0.64*	0.00	0.67*	0.40*
DMI, kg/d		1	0.15*	0.57*	0.27*	0.43*	0.26*	0.45*	0.00	-0.27*
REA, cm2			1	0.48*	0.00	-0.34*	-0.7*	-0.12*	0.21*	0.20*
HCW, kg				1	0.32*	0.51*	-0.06	0.00	0.16*	0.09*
MS					1	0.41*	0.06	0.03	-0.03*	-0.09*
Yield Grade						1	-0.02	0.14*	-0.08*	-0.13*
F:G							1	0.37*	-0.71*	-0.64*
RFI								1	-0.42*	-0.84*
RG									1	0.84*
RIG										1

** $P < 0.05$

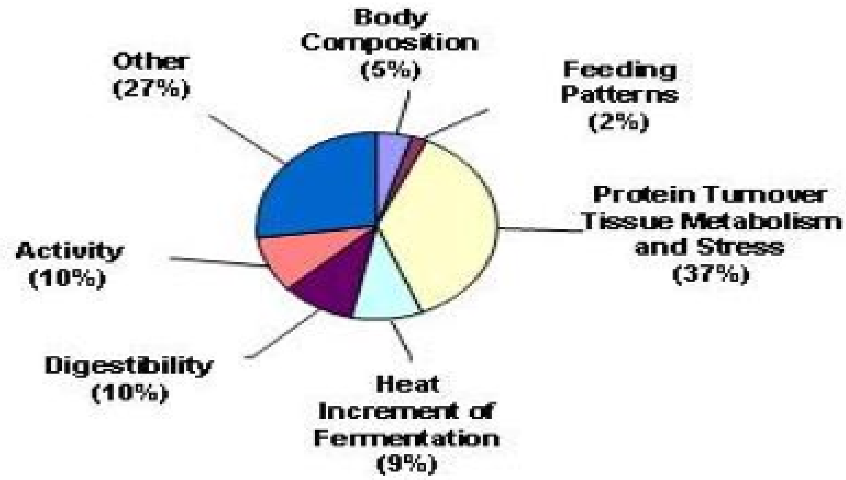

Figure 1. Contributions of biological mechanisms in residual feed intake as determined from the experiments on divergently selected cattle (from Richardson and Herd, 2004).

Cow Efficiency

When considering the beef cow, optimum forage utilization is especially important because of the positive relationship between meeting energy requirements for maintenance and the genetic potential for growth or milk production (Webster et al., 1977, Ferrel and Jenkens, 1987). This challenges animals with a high genetic potential for productivity by putting them at a disadvantage when the environment they occupy becomes nutritionally or environmentally restrictive (NRC, 1996). The environment including the forage quality and/or quantity can become unfavorable due to several conditions including: weather, overstocking, or inadequate forage management. Range beef cows may not consume the amount of energy that matches their requirements for maintenance, gestation or milk production, so in an unfavorable environment, energy reserves within the cow are depleted (NRC, 1996). This condition continues until the forage source is replenished, causing energy status to improve and allow production to resume (NRC, 1996).

The energy status of the cow is often measured by body condition or amount of fat cover on the animal. Cows are often evaluated for this visually and assigned a body condition score (BCS) to represent the cow's current energy status. Cows that are too fat or too thin are at risk for metabolic problems and diseases, decreased milk yield, low conception rates, and difficult calving (Ferguson and Otto, 1989). This makes management of energy reserves a critical component to the economic success with beef cows; however this is challenging because forage quality varies dramatically across the United States. The cow/calf producer is encouraged to match the breed(s), growth and milk production of their cows to the forage quality in order to optimize production and profitability.

When considering the measure of efficiency, animal metabolism is the most significant factor contributing to variation in feed efficiency. In fact, thirty-seven percent of feed efficiency differences have been equated to animal metabolism and protein turnover alone (Richardson and Herd, 2004). Cow or cattle feed intake is also an important component of feed efficiency. Energy concentration of the diet is highly related to feed intake because as the diet becomes lower in energy, generally more fibrous, intake increases to meet energy demands. As the diet increases in concentration or energy density, intake decreases because the diet is more energy dense and can meet the animal's requirements with less intake. This is based on the fact that consumption of less digestible, low energy (often high fiber) diets is regulated by physical factors such as rumen fill and digesta passage; whereas, consumption of highly digestible, high-energy, (low-fiber, high concentrate diets) is controlled by the animal's energy demands and by metabolic factors (NRC, 1996). Preliminary data (Table 1) at the University of Illinois by Retallick et al. (2013) shows that replacement heifers fed a forage diet for 70 d and then a grain diet for 70 d had RFIs which correlated at an r-square of 0.35. Cattle receiving a grain diet through the duration of the trial correlated at 0.57. While the forage and grain RFIs are significantly correlated, diet type clearly has an effect on the correlation strength. This is expected because some factors influencing efficiency are common for both high grain and high forge diets (i.e. metabolic factors), but as discussed earlier the mechanisms of intake are quite different for these two types of diets. It might expected that the genetic control of intact for the two types of diets might also be different. Two separate studies ranked correlations between steer sire groups on a high concentrate diet and their heifer contemporary sire groups on a high forage diet low (.28) (Cassidy et al., 2013). This further illustrates that the two types of diets share some common efficiency factors, but they are not highly related, probably due to differences in intake regulation. Recent unpublished data (Cassidy et al, 2013) show that RFI measured on forage or grain based diets is the same.

Cow intake is additionally influenced by physiological factors including body composition, age, gestation, lactation, and size (weight and/or frame size) (NRC, 1996). Environmental factors also have an effect with temperature, humidity, wind, precipitation, mud, and season causing fluctuation in feed intake (NRC, 1996). Management factors can also play a large role as they are related to forage availability, forage processing, offering additional feed additives (i.e. monensin), presence of nutrient deficiencies (particularly protein), and ensiling process of forages (NRC, 1996). These factors should be controlled in order to accurately evaluate animals for efficiency. The NRC (1996) developed intake prediction equations that account for these variables and prove to be accurate for groups of cattle at similar physiological states. These predictions, however, may not be as accurate for individual animals.

For instance, the accuracy of these predictions was shown by Adcock et al. (2011). When the NRC (1996) prediction model for individual animal intake was utilized, the prediction was poorly correlated (.14) with actual individual intake. When using the NRC (1996) model to predict the intake of the group of cattle at each time period, predictions are correlated well at .53. This clearly illustrates that the NRC (1996) model is effective in predicting intake for groups of cattle, but it is less effective for individual cattle.

Once cows mature they are no longer in a growing state, therefore production and metabolism are the main energy demanders. A cow's value is based upon her ability to maximize production with minimal feed intake explaining why cow economic efficiency is primarily related to feed intake. Shuey et al. (1993) calculated efficiency by measuring the feed intake of both the cow and her offspring over an entire production cycle, defined as the time from weaning of one calf to another. Results suggested that fasting heat production, highly related to the metabolizable energy of maintenance (r2=0.73), could be used as an indicator of feed maintenance requirements (Shuey et al., 1993). Similar results have been found by Herd and Arthur(2009), Webster et al., (1975), and Standing Committee on Agriculture, (2000) denoting variation in intake to maintenance requirements in ruminant animals. When cow intake is increased this causes an increase in visceral organ size thus increasing maintenance requirements. Since these organs serve as biologically active tissues, an increase in size up regulates energy expenditures and metabolic rates which in turn decreases efficiency (Herd and Arthur, 2009). When considering the selection of animals on RFI, animals with lower RFIs have decreased intakes, which have the potential to decrease maintenance requirements in relation to high RFI cattle.

Duration of the meal and rate of intake are components of intake which affect feed efficiency deeming them factors to consider when determining economic profitability of cattle (Adam et al., 1984). Selection of animals on RFI could have a substantial impact in improving these components. Richardson (2003) showed that high RFI cattle exhibited a trend for an increase in number of meals compared to low RFI cattle. Robinson and Oddy (2004) also showed that high RFI cattle had an increase meal numbers and meal duration and that these are shown to be moderately heritable traits in cattle.

Heifer RFI and Mature Cow Efficiency

RFI testing to date has mainly been conducted in the feedlot with growing animals which are harvested when they reach a certain desired endpoint. Data regarding replacement heifer RFI is limited, especially describing the repeatability of RFI once heifers are put into production. Adcock et al. (2011) measured forage intake (in four stages of production) for two groups of first calf heifers previously tested for RFI on forage as growing heifers. Intake as first calf heifers exhibited extreme variation between individual animals. For example, for two heifers with identical intake predictions and requirements (based on size, milk production, age, and stage of production), one ate 13.7 kg/day and the other 24.3 kg/day (2.2 or 3.9% of body weight) over four time periods.

When predicting intake as cows with RFI, the most important factor in estimating intake was RFI value measured as heifers (Adcock, 2011). It was even more important than physiological measures like weight and milk production. For every 1 kg difference in RFI as growing heifers there is a 1.2 kg/day difference in feed intake during lactation as first calf heifers and 1.4 kg/day difference as dry heifers after they had raised their first calf. There were no correlations between gain and intake indicating that RFI can be used to select cows that eat less independent of other factors like cow size and milk production. Cassidy et al (2013) found that good RFI cows ate 4 kg less than bad RFI cows on both good and poor quality forage.

Meyer et al. (2008) conducted a study using two replicated (n=7/replicate) low and high RFI classified cows in an 84 d grazing study. Intake was measured by grazing enclosures, weekly rising plate meter readings, and forage harvests every twenty-one days. There was no difference in BW change or BCS change between the two groups, however the low RFI cows had a twenty-one percent decrease in DMI compared to high RFI cows (Meyer et al., 2008).

In a recently study at the UA V-V Ranch, forage intake on cows that had survived under Arizona range conditions was measured. It was found that the average RFI for the cows was -1.5 lb. (good), that 74% of the surviving cows had a negative (good) RFI, and that the good RFI cows had better condition (only 18% of the cows were less than CS 5 while in the high RFI cows it was 50% less than CS 5). There was no relationship of RFI to body weight. The low RFI cows consumed the hay at 1.9% of BW while the high RFI cows consumed the hay at 2.4% of BW. This is a field observation of only 40 cows, but it suggests that RFI may be useful in selecting cows that survive under arid range conditions.

There are two important benefits to utilizing RFI in a cow herd. First, economic benefits since cattle have decreased DMI on the same overall performance making them more profitable due to lower input costs. Second an environmental impact, most obviously explained by the fact that low RFI cattle have lower DMI. In a grazing situation, animals are consuming less forage and therefore stocking rates can then be increased. Low RFI cows could providing the opportunity to utilize less forage as hay or silage for winter feeding.

Other Benefits

In addition, reduction of methane production due to less forage consumption can affect the environment. Methane is the major gas emitted by ruminants as a by-product of enteric fermentation. Livestock produce methane as well as nitrous oxide which have 21 and 310 times greater global warming potential than carbon dioxide (AGO, 2001). Methane, along with nitrous oxide, can be produced from manure given certain types of management schemes (AGO, 2001). Agriculture does in fact account for some percentage of greenhouse emissions throughout the world. Livestock production is reported to be responsible for eighteen percent of the worldwide greenhouse gas emissions (Steinfeld et al., 2006). This estimate encompasses not only the actual production of enteric fermentation by-products from the animal but also fuel emissions, plant emissions associated with livestock production.

Relating RFI to methane production, Angus steers (n=76) from lines selected for either low or high RFI have a significant relationship to methane production ($P=0.01$) with low RFI steers producing less methane (Hegarty et al., 2007). Nkrumah et al. (2006) revealed that crossbred steers (n=27) have a significant correlation of 0.44 ($P<0.05$) when considering individual RFI and methane production. These differences in methane production accounted for low RFI animals having 16,100 less L per year of methane emissions than the high RFI steers (Nkrumah et al., 2006). In conclusion, RFI could serve as not only a feed efficiency measure but as a tool to help lower the greenhouse gas emissions from ruminants.

Summary

In order for the beef cattle industry to continue to thrive in times where input costs are continuously on the rise, producers will need to focus on feed efficiency within the herd. There are many management factors involved in this which can affect feed efficiency and that can be altered to improve efficiency. When considering affective measurement of feed efficiency, RFI appears to be the most valuable tool for the cow/calf producer and feedlot operator alike. This is due to the fact that RFI is independent of production traits and size. Selection of cattle on RFI is a moderately heritable tool and has been shown to be effective in reducing feed efficiency. This has been done without having an impact on the animals' growth or carcass characteristics in feedlot and growing cattle and does not impact cow production traits. Currently, this continues to be an expensive and time consuming method of determining feed efficiency, but recent advances in the genetics field should allow for better predictions without having to do the actual RFI test by measuring individual intake and performance. Therefore, it will be easier in the future for the beef cattle industry to make larger strides in improving feed efficiency making it competitive with other livestock species.

Since current methods of measuring feed efficiency are expensive and time consuming, an alternative approach must be identified. An opportunity exists to estimate feed intake using a dense set of single nucleotide polymorphism markers distributed throughout the bovine genome. The bovine "SNP Chip" is a tool which may be used for that purpose. Once a genomic pattern differentiating feed intake has been identified then information may be obtained early in a calf's life and incorporated into the estimation of EPDs. However, the use of molecular markers in food animal selection is still a relatively new concept to many producers and consumers. Based on the substantial amount of variation present in RFI within a population, it is likely that commercial cow/calf producers will demand an EPD for efficiency from their seed stock suppliers. As a result, future cattle selection will probably include the conventional growth and carcass traits, newly-expanding reproduction traits, and efficiency traits such as RFI.

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