The Relationship of Genetics and Nutrition and Their Influence on Animal Performance

Amy L. Kelley
Animal and Range Sciences Department
Montana State University
Bozeman, MT 59717

Introduction

The beef cattle industry relies heavily on both genetics and nutrition to achieve its production goals and to contend with other industries. However, it is important to understand how these two aspects correspond with one another and the effect they have on each other. Nutrition can be considered not only the most expensive input of animal rearing, but also the most critical. If animals do not receive proper levels of nutrition, no matter how genetically superior they are, they will not perform to their optimum level. To truly understand the impact genetics and nutrition have on one another it is important to look at how they both play roles in body condition score and body weight; energy requirements; maintenance energy requirements; feed efficiency, feed conversion and feed intake; residual feed intake; and the development of EPDs.

Review of Literature

Introduction of the Continental Breeds.

Historically, it is important to consider the introduction of the Continental breeds of cattle and their tremendous impact on both nutrition and genetics. Beginning in the 1960's, the genetic growth rate potential of beef cattle in the United States was increased by the introduction of Continental breeds of cattle (Johnson et al., 2003). Plus, the introduction of Continental breeds changed how nutrition for beef cattle was viewed. The prior method of determining energy requirements of cattle, commonly referred to as the California system, was done strictly on British breeds (Lofgreen and Garrett, 1968). The differences between British and Continental breeds, such as mature size, milking ability, etc., caused researchers to identify more current energy requirements. The intention of utilizing Continental breeds was to increase growth potential leading to increased weaning weights and heavier post-weaning gains. Also, Continental breeds provided an answer for a consumer driven market that desired a leaner product. However, the incorporation of Continental breeds also led to an increase in body size. This led to correlated increases in mature cow size, and increased feed intake, increased maintenance requirements, and decreased fat.

Body Condition Scores and Body Weight.

Nutrition has a tremendous impact on body condition score and body weight. Nutrition and related body condition, specifically the effect they have on reproductive performance, are considered the most studied-environmental factors (West et al., 1991). They both, in turn, have a large impact on not only reproductive performance, but animal performance in general. Numerous studies have shown that the performance of beef cows varies according to their total body energy reserves, or what is better known as body condition, during specific stages of the production cycle (Spitzer et al., 1995). It is important for producers to realize the need for adequate nutrition in order for animals to be at their peak performance. If a cow does not receive her nutritional requirements during gestation and lactation, no matter how genetically superior her and her calf are, chances are that the calf will not perform as expected. Additionally, when cows calved in body condition scores of 4, 5, or 6, respectively, the birth weight of the calves was progressively higher ($P < 0.05$) (Spitzer et al., 1995).

Energy Requirements. A very important aspect of livestock production involves energy requirements and the ability of producers to meet these requirements. In terms of beef cows, the NRC has produced energy requirements that are based on body weight, days after calving to peak milk yield, and maximum daily milk produced (NRC, 1996). While EPDs have been developed for traits relating to the energy requirements of beef cows, they are inconsistent with the unit of measure used by the NRC (MacNeil and Mott, 2000). Certainly the opportunity for research to genetically predict energy requirements would be beneficial to the beef industry. MacNeil and Mott (2000) found that for every 1-kg increase in predicted maternal breeding value for calf gain (from birth to weaning) there was an increase of 10.3 ± 4.6% in a lactation curve associated with unit increases in maternal breeding value for gain from birth to weaning and age of cow. Also, there was a decrease of 1.0 ± 0.6% in a lactation curve associated with a unit increase in maternal breeding value for calf gain from birth to weaning. Furthermore, a strong genetic correlation between maternal gain from birth to weaning and total milk yield exists, with it being approximately 0.8 (Miller and Wilton, 1999). Thus, it is important to meet the energy requirements of lactating females in order to provide an adequate level of milk production for the calf to achieve its genetic potential for gain.

Maintenance Energy Requirements. Improving production efficiency will allow the United States beef cattle industry to remain competitive with alternative products (Shuey et al., 1993). However, to improve production efficiency it is critical to consider factors affecting it. One major factor is maintenance energy requirements. Maintenance energy requirements can be thought of as the amount of energy intake required for zero body energy change, or in other words, the amount of energy the animal requires to maintain homeostasis. The primary way of determining maintenance energy requirements is through the monitoring of fasting heat production. Genetic potentials for milk production and growth rate are positively correlated with maintenance energy requirements (Shuey et al., 1993). A change in the intake of dairy cows can affect maternal energy retention and milk production at the same time, but milk production will have a small response if it is expressed near its genetic potential (Broster and Broster, 1984).

Shuey et al. (1993) found that by selecting for a lower maintenance energy requirement, it is unlikely that the production efficiency of heifers will be improved unless the heifers are fed above their requirements. Plus, maintenance energy requirements are important in determining production efficiency only when nutrition is restricted. As well, it was determined that maintenance energy requirements are closely related to fasting heat production ($r^2 = 0.73$) (Shuey et al., 1993). Therefore, it would be possible to use fasting heat production to determine maintenance energy requirements.

Feed Efficiency, Feed Conversion and Feed Intake. Perhaps the most important aspect of nutrition is feed efficiency and feed intake. The single largest expense in most commercial beef production operations is feed costs, and therefore it is important to improve feed efficiency to lower the cost of feeding (Arthur et al., 2001). It may also be possible to select animals that are more efficient, which will also help lower production costs (Fan et al., 1995). However, this may be difficult as wide variation in heritability and genetic correlation exists when looking at feed efficiency (Bishop et al., 1991). This makes the calculations of genetic predictions more difficult. Fan et al. (1995) estimated various heritabilities for both Hereford and Angus bulls, and found them to be, respectively, 0.08 and 0.35 for gross feed efficiency and 0.14 and 0.28 for net feed efficiency (Table 1). Moreover, gross and net feed efficiency were moderate to high and positive in terms of genetic correlation. It was also found that as average daily gain increased, not only did gross feed efficiency increase, but so did metabolizable energy intake and yearling weight. This indicates that more efficient animals will have greater average daily gain leading to greater body weight, weigh more at yearling age, and unfortunately, require more feed intake.

Gregory et al. (1994) reported that gain efficiency differed significantly among all cattle breeds, which were Red Poll, Hereford, Angus, Limousin, Braunvieh, Pinzgauer, Gelbvieh, Simmental, and Charolais. Breeds with the smallest weight to maintain were more efficient over a constant period of time, while breeds with the highest rate of gain were more efficient when a constant level of gain was reached. When cattle were fed to a specific marbling score, breeds with lower amounts of marbling, specifically the Continental breeds, were less efficient, while the breeds with the most marbling were the most efficient. Breeds with the most retail product were more efficient when retail product weight was the endpoint. Feeding a higher energy density diet resulted in steers that were more efficient when live weight gain to time was constant, live weight gain was constant, marbling score was constant, and to a certain retail product end point. Plus, composites of the nine breeds previously mentioned were found to have retained heterosis that wasn't consistent for measures of gain efficiency. Finally, the study found that a higher initial body weight increased the feed requirement for maintenance, which resulted in a negative effect on the measures of gain efficiency.

Feed conversion has widely been used to genetically improve feed utilization. Feed conversion is determined by the ratio of feed consumed to live weight gain. Feed conversion has a direct heritability estimate of 0.29 ± 0.04 based on records of 1,180 Angus bulls and heifers from a performance test were looked at (Arthur et al., 2001). Feed conversion was negatively correlated ($r = -0.62$ and -0.74, respectively), both genotypically and phenotypically, with average daily gain. Also, feed intake and feed conversion were positively correlated ($r = 0.31$and $r = 0.23$, respectively) genotypically and phenotypically. As well, feed intake was positively correlated, both genetically and phenotypically, with scrotal circumference, $12^{th}/13^{th}$ rib fat depth, rump fat depth, and both 200 and 400 d weights. It is suggested that selection will allow for genetic improvements in feed efficiency (Arthur et al., 2001).

The genetic parameters for feed intake, feeding behavior, and average daily gain were estimated in composite ram lambs that were ½ Columbia, ¼ Hampshire, and ¼ Suffolk. The intent was to investigate the possibility of genetically improving feed conversion by selection, utilizing estimates of heritability of feed intake and the genetic correlations between feed intake measurements. Daily feed intake had an estimated heritability of 0.25 and event feed intake had a heritability of 0.33. Those two measures of feed intake had a positive genetic correlation. It was concluded that including feed intake into selection criteria would result in a more overall desirable terminal sire breed (Cammack et al., 2005). If this study were extrapolated to cattle, a producer utilizing terminal should consider their EPDs for feed intake to reduce feed costs.

Jensen et al. (1991) investigated the genetic parameters of feed intake and feed conversion. They reported no significant interaction between genotype and amount of roughage in the diet. Also, they reported daily gain to be negatively correlated with feed conversion, but positively correlated with daily energy intake. Calf weight at 28 d of age was positively correlated to daily gain but negatively correlated to both total energy intake and total dry matter intake. It was suggested that the negative reaction was a result of heavier weights at 28 d of age, which d1ecreased weight gain and thus decreased the amount of energy required to reach a set live weight of 200 kg.

Residual Feed Intake. Residual Feed Intake **(RFI)** is an indirect measurement of metabolism, which combines both maintenance and gain. It can also be considered the difference in feed intake, based on size and growth rate (Herd et al., 2003). Koch et al. (1963) defines RFI as the difference between an animal's actual feed intake and its expected feed requirements for maintenance and growth. A positive RFI is not desirable, as it indicates that an animal has greater intake than what was predicted. An RFI of zero means that the animal is consuming exactly to meet its requirements. A negative RFI is very desirable, and means that an animal is eating less energy than predicted, suggesting that either their requirements are less than what was predicted or they require less feed to meet their requirements. Genetic variation in RFI exists during growth and for adult cattle (Herd et al., 2003) (Table 2). The heritability of RFI ranged from 0.16 to 0.39 (Johnson et al., 2003). Utilizing the records of 1,180 Angus bulls and heifers found a direct heritability estimate of 0.39 ± 0.03. Moreover, it was discovered that RFI and average daily gain were independent of one another ($r = -0.04$ and -0.06), respectively for genotype and phenotype. RFI and feed conversion ratio were correlated ($r = 0.31$ and 0.23, respectively), for genotype and phenotype, as was RFI and feed intake ($r = 0.69$ and 0.72) (Arthur et al., 2001). Another study looked at variations in RFI and other production traits of Hereford cattle and found that RFI was not correlated to average daily gain. Additionally, this same study found that RFI and feed conversion were highly correlated both genotypically and phenotypically ($r = 0.61$ and $r = 0.70$, respectively) (Herd and Bishop, 2000). Lastly, Nkrumah et al. (2004) found that animals having a more positive RFI (being less desirable) would be less efficient than animals with a lower RFI. More research is needed into the use of RFI in selection and the effect it will have genetically before it becomes a more practical production tool.

Expected Progeny Differences Concerning Nutrition. The idea of producers being able to genetically select for animals that will nutritionally perform to the standards of each individual operation is desired. The development of EPDs to predict differences in nutritional requirements between animals will result in selection to lower feed requirements (or improve feed efficiency). The American Red Angus Association, in conjunction with Colorado State University, has done so by creating the Mature Cow Maintenance Energy Requirement EPD **(ME)**. The intent of this EPD is to allow cattle producers to select animals for increased feed efficiency, more correctly pair cattle to their forage and production environment, and provide additional insurance against harsh weather conditions. The ME EPD is based upon the energy required to maintain body tissues with no net change in body tissue. The two factors that contribute to the ME EPD are mature cow weight and milk. Cattle having a lower ME EPD should have lower energy requirements (Evans et al., 2001). Research used to create the ME EPD found that there is a moderate to strong additive genetic relationship between weaning weight and mature weight. There was also an additive genetic relationship between post-weaning weight and mature weight in cows between 2 and 9 years of age. Additionally, heritability estimates for weaning weight ranged from 0.35 to 0.36 (Evans et al., 2000).

Conclusion and Implications to Genetic Improvement of Beef Cattle

The beef cattle industry is constantly undergoing changes that will benefit its producers. However, with all the improvements that have occurred over time there is still no doubt that nutrition and genetics still play critical roles in the industry. Many of the industry changes have impacted or been impacted by these two items. Thus, it is important to understand the relationship the two share.

To best analyze nutrition and genetics it is important to first look back at the introduction of Continental breeds into the US cow herd. They had a tremendous impact on not only genetics, but also nutrition. After they were introduced and research was conducted, many changes were made not only to the nutritional requirements used by numerous producers, but how the Continental breeds were used, such as using them for terminal crossbreeding situations.

Body condition score and body weight of cattle are dictated by both the level of nutrition an animal is provided and the genetic make-up of that animal. Being able to predict an animal's mature body size allows for the appropriate nutritional environment to be provided, so the desired body condition score and body weight can be achieved.

Energy requirements and maintenance energy requirements are critically important, especially when considering gestation and lactation of beef cows. Therefore, research should be focused on understanding how genetics play a role in these requirements. As well, nutrition is very important, because no matter how genetically superior an animal is supposed to be, if their energy requirements are above what they are being fed, chances are they will perform below their optimum level.

Feed efficiency, feed conversion and feed intake, along with residual feed intake may be well understood from a nutrition standpoint, but it is once again important to understand how genetics impacts them. The intent of knowing the role of genetics is to allow for more intelligent selection.

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Table 1. Estimates of heritability (h^2) with standard errors (± SE) for postweaning traits for Hereford and Angus bulls, and pooled h^2 (Fan et al., 1995)

	Hereford	**Angus**	**Pooled**
Trait[a]	**h^2 ± SE**	**h^2 ± SE**	**h^2 ± SE**
WWT, kg	0.46 ± 0.25	0.16 ± 0.13	0.36 ± 0.12
ADG, kg/d	0.16 ± 0.15	0.43 ± 0.24	0.26 ± 0.20
DMI, kg/d	0.18 ± 0.10	0.27 ± 0.15	0.24 ± 0.11
MEI, Mcal ME/d	0.19 ± 0.10	0.31 ± 0.15	0.25 ± 0.13
YWT, kg	0.43 ± 0.22	0.45 ± 0.22	0.42 ± 0.22
RFC, Mcal ME/d	0.07 ± 0.13	0.23 ± 0.12	0.14 ± 0.12
FE, kg/Mcal ME	0.08 ± 0.09	0.35 ± 0.22	0.16 ± 0.14
NFE, kg/Mcal ME	0.14 ± 0.16	0.28 ± 0.17	0.21 ± 0.17

[a] WWT=weaning weight, ADG = average daily gain, DMI=dry matter intake, MEI=metabolizable energy intake, YWT=yearling weight, RFC=residual feed consumption, FE=gross feed efficiency, NFE=net feed efficiency

Table 2. Published estimates for the heritability of Residual Feed Intake **(RFI)** in growing beef cattle and genetic correlations with selected mature cow traits (Herd et al., 2003)

			Genetic Correlation Mature Cow	
Breed	**Number**	**Heritability**	**RFI**	**BW**
Hereford	540	0.16 ± 0.08	--	-0.09 ± 0.26
Limousin & Charolais[a]	1,629	0.21 ± 0.39	--	--
Beef & Dairy	282	0.29	--	--
British	1,180	0.39 ± 0.09	--	--
British	751	0.23[b]	0.98	-0.22
Charolais	792	0.39 ± 0.04 to 0.43 ± 0.06	--	--
British & Tropically Adapted	2,155	0.18	--	--

[a] Two ages/feeding regimen and two methods for estimating RFI were used
[b] Mature cow RFI